Appendix D.  Federal Guidelines

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1.1 **Purpose.** This Chapter establishes the basic policy, authorities, and responsibilities for the Bureau of Indian Affairs (BIA) Safety of Dams (SOD) Program.

1.2 **Policy.** It is the BIA SOD Program policy to:

   A. **Reduce the potential loss of human life and property damage** due to a catastrophic dam failure by making BIA dams as safe as practically possible; and

   B. **Encourage flood plain management** below dams and on reservoir shorelines.

1.3 **Authorities.**

   A. **Presidential Memorandum** issued April 23, 1977, to the Heads of Federal Agencies that have dam safety responsibilities, requiring each agency to conduct a thorough review of practices affecting the safety and integrity of dams;

   B. **Executive Memorandum** dated October 9, 1979, implementing Federal Guidelines for Dam Safety for each agency;

   C. **25 U.S.C. § 3801**, Public Law 103-302, Indian Dams Safety Act of 1994. This law directs the Secretary to establish a dam safety maintenance and repair program within the BIA to monitor the condition of all dams on Indian lands and maintain them in a satisfactory condition on a long-term basis;

   D. **33 U.S.C. § 467**, Public Law 92-367, National Dam Inspection Act of 1972; and


1.4 **Guidance.** Government-wide, Department of the Interior, and BIA guidance documents are available from the BIA SOD Officer, MS 4515-MIB, 1849 C Street NW, Washington, DC 20240.


   B. **Department of the Interior.**

      (1) Departmental Manual Part 753, Dam Safety Program;

      (2) Secretarial Order No. 3048, February 28, 1980;

      (3) Interagency Agreement between the BIA and the Bureau of Reclamation, dated May 16, 1996;

      (4) Value Engineering Guidance Handbook, No. VE-1; and

1.5 Responsibilities.

A. **Director, Office of Trust Responsibilities**, designates the BIA SOD Officer.

B. **BIA SOD Officer**.
   
   (1) Plans, manages, directs, and provides program oversight and guidance to Regional SOD Officers;
   
   (2) Provides staff assistance and advice to the Commissioner/Deputy Commissioner of Indian Affairs;
   
   (3) Develops and manages programs relating to the BIA responsibilities to Indian tribes as they relate to the SOD Program;
   
   (4) Monitors compliance and makes recommendations for changes to Federal, Departmental, and BIA SOD guidelines;
   
   (5) Drafts legislation and regulations as required, and reviews proposed legislation and regulations initiated elsewhere that may affect the SOD Program;
   
   (6) Formulates policy recommendations and provides direction and guidance on implementation to Regional Directors or their designated representatives;
   
   (7) Serves as liaison and promotes working agreements with tribes, states, and other Federal agencies concerning SOD Program activities;
   
   (8) Represents the BIA on the Department of the Interior Dam Safety Working Group;
   
   (9) Coordinates with other program offices of the BIA and other agencies on SOD issues, including emergency preparedness; and
   
   (10) Reviews and provides updates on BIA data for the National Inventory of Dams.
C. Regional Directors.

(1) Provide program oversight for the operation of the SOD Program within their jurisdiction in accordance with established policy, procedures, directives, and this manual part;

(2) Submit an Annual Status Report to the BIA SOD Officer by December 31 of each year for all SOD Program dams under the jurisdiction of the Regional Office; and

(3) Designate a Regional SOD Officer.

D. Regional SOD Officers.

(1) Plan, manage, and direct Regional SOD Program activities;

(2) Prepare the Regional Director's Annual Status Report on each SOD Program dam as described in the BIA SOD Program Handbook;

(3) Maintain the Regional Office record-keeping and reporting system for the SOD Program, including the National Inventory of Dams;

(4) Provide technical assistance to other Regional staff and tribes;

(5) Coordinate SOD activities with the BIA SOD Officer and provide liaison with other organizations and government agencies;

(6) Serve as the Contracting Officer's Representative (COR) or Contracting Officer's Technical Representative (COTR) on Regional SOD Program contracts when designated by the Regional Contracting Officer;

(7) Coordinate all SOD Program activities with Agency Superintendents and Agency and tribal SOD personnel, and expedite all matters relating to dam safety for any new dam project, on or off a reservation, which could affect trust lands, including those planned, designed, and/or constructed by others;

(8) Review all roadway embankments which cross waterways with the potential to affect BIA dams or trust lands to determine possible hazards from impoundment of water and to ensure adequate design of such embankments;

(9) Immediately report to the Regional Director any dam failure, incident, or any abnormal operations which adversely affect public safety or dam operations;

(10) Maintain a set of the documents referenced in the Record Keeping section of the BIA SOD Handbook;

(11) Develop and implement emergency management procedures as described in Chapter 2, Section 2.5 of this Part for each SOD Program dam;
(12) Provide oversight for, and conduct a final inspection of, all completed modifications
   to existing dams or new dam construction, prepare a Final Project Report for each project, and
determine the need for any post construction activities; and

(13) Arrange and facilitate training for Regional and tribal SOD Program personnel.

E. Agency Superintendents.

   (1) Coordinate SOD Program activities with the Regional SOD Officer, including
       training for Agency personnel involved in the SOD Program; and

   (2) Ensure that Agency responsibilities in Emergency Action Plans for dams under their
       jurisdiction are implemented.
2.1 Scope. BIA SOD Program dams include all dams that meet the criteria in the National Dam Inspection Act. This includes all dams which impound or divert water and are 25 feet or more in height from the natural bed of the watercourse, measured from the downstream toe (or lowest elevation) of the dam to the top (crest) of the dam, or which have an impounding capacity at maximum water storage elevation of 50 acre-feet or more. This does not include dams which are less than six feet in height, regardless of storage capacity, nor dams having a storage capacity at maximum water elevation of less than 15 acre-feet, unless downstream hazards to life or property exist.

2.2 Downstream Hazard Classification. A Downstream Hazard Classification (High, Significant, or Low) will be determined for each BIA SOD Program dam in accordance with the Bureau of Reclamation’s Assistant Commissioner-Engineering Research Technical Memorandum No. 11, Downstream Hazard Classification Guidelines.

2.3 Applicability.

A. SOD Program requirements in this Chapter apply to all BIA dams with a High or Significant Downstream Hazard Classification.

B. BIA SOD Program funding is available only for dams with a High or Significant Downstream Hazard Classification.

C. For BIA dams with a Low Downstream Hazard Classification, further application of any SOD Program technical requirements in this Chapter and the SOD Program Handbook to activities conducted with non-SOD Program funding is at the discretion of the Regional SOD Officer based on the specific conditions at each Low Hazard dam.

2.4 Operation and Maintenance for Existing Dams includes the operation and maintenance activities for the dams and appurtenant structures and the emergency management activities undertaken to safely operate and maintain dams.

A. Standing Operating Procedures. Standing Operating Procedures must be established for each High or Significant Hazard dam. The procedures permit responsible persons, knowledgeable in reservoir operations, but who are unfamiliar with the conditions at a particular dam, to operate the dam and reservoir during emergency situations and at times when the regular operator is not available to perform normal duties. Additional details on Standing Operating Procedures are contained in the BIA SOD Handbook. Copies of the Standing Operating Procedures are maintained at the Agency Office and the dam site, if an on-site facility exists.

B. Documentation. A documented history of the field exploration programs, design, construction, operation, maintenance, instrumentation data monitoring, periodic examinations, corrective actions, repairs, and remedial work will be established and maintained by the Regional SOD Officers so that data relating to the dam are preserved and readily available for reference. This documentation will commence with the initial site investigation for the dam and continue through the life of the structure.

C. Training. Personnel involved in the operation and maintenance of BIA dams will be
trained to detect, evaluate, and appropriately respond to emergency and non-emergency situations. Regional SOD Officers and Agency Superintendents are to identify training needs for the personnel under their supervision and request such training from appropriate sources.

2.5 Emergency Management.

A. Emergency Action Plan. This plan will be developed for all High or Significant Hazard dams as required by 753DM1.5. An Emergency Action Plan (EAP) is prepared to aid the facility manager and operations and maintenance personnel during an emergency situation or unusual occurrence. It provides information on detection of problems, immediate steps to take, whom to notify, what decisions to make, steps to take in the event of loss of communications, and other appropriate measures.

B. Inundation Maps. Inundation maps will be developed for each High or Significant Hazard dam. The inundation maps include, as a minimum, delineation of flooded areas to the point where the subject flood no longer poses a risk. The inundation maps will be included in the EAP.

C. Warning and Evacuation Plans. The Regional SOD Officer is responsible for identifying all entities, including local, state, tribal, and federal, who would be impacted during a dam failure or large operational releases. These entities should be encouraged to develop their own Warning and Evacuation Plans for each dam. The EAP must be coordinated with these Warning and Evacuation Plans.

D. Incident Response. Following an incident or emergency event, an incident report will be prepared by the Regional SOD Officer and submitted to the Regional Director and the BIA SOD Officer.

E. Early Warning Systems (EWS). EWS instrumentation will be installed, operated, and maintained at High or Significant Hazard dams and in the upstream basin when early detection of hydrologic events would provide additional time needed for emergency management activities.

2.6 Monitoring of Non-Bureau of Indian Affairs Dams. The Regional SOD Officer will be aware of the safety status of dams which are not under the jurisdiction of the BIA, but pose a potential hazard to persons or property on trust lands. The Regional SOD Officer will ensure that the EAP for these dams provides adequate notification to the BIA in the event of a dam failure or other emergency event.

2.7 Evaluation of Existing Dams.

A. Safety Evaluation of Existing Dams (SEED) Examination Program. The BIA SEED Examination Program is an onsite examination to document the structural integrity of High or Significant Hazard dams and appurtenant structures. SEED examinations will be conducted according to the BIA SOD Handbook.

B. Deficiency Verification Analysis (DVA) Report. A Deficiency Verification Analysis will
be performed on each High or Significant Hazard dam to determine if the dam has deficiencies which could lead to the failure of the dam. The results of this analysis will be included in the DVA Report and will serve as the technical documentation of any deficiencies that must be resolved or mitigated.

### 2.8 Short-term Remediation Actions.
Examination and evaluation activities could reveal deficiencies or potential deficiencies which, if uncorrected, could eventually lead to failure or misoperation of a dam. The following actions may be taken under the direction of the Regional SOD Officer when conditions warrant. Some actions may involve NEPA compliance.

**A. Emergency Corrective Action.** Emergency corrective action is required for deficiencies which could result in failure of the dam within a short period of time. The BIA SOD Officer and Regional Director will be notified immediately by the Regional SOD Officer of any dams that are in this condition, and informed as to what action is being taken to remove the threat;

**B. Interim Actions.** Measures considered necessary to protect the public during the time between a safety examination and the safety modifications will be implemented at the earliest possible time after completion of the onsite examination. Interim actions could include implementing reservoir level restrictions, temporary breach, operational changes, installation of early warning systems, or specific monitoring of instrumentation at the dam site; or

**C. Non-emergency Corrective Action.** Non-emergency corrective action is taken when there is no immediate threat to the safety or operation of the dam, or any threat to life or property downstream. The 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 arrangements for special reservoir operations when required.

### 2.9 Design Process for New Dams and for Modifications to Existing Dams.
The design of new dams and modifications to existing dams contain the same elements, which include:

**A. Conceptual Designs.** The initial phase of the design process, which leads to the selection of a preferred design alternative, must include the following:

1. National Environmental Policy Act compliance will be initiated and substantially completed during this phase of the design process in accordance with 40 CFR 1500-1508;

2. National Historic Preservation Act compliance will be conducted in accordance with 36 CFR 60 and 36 CFR 80;

3. Native American Graves Protection and Repatriation Act and Archaeological Resources Protection Act compliance will be conducted as required;

4. A Conceptual Design Report will be prepared to document all viable alternatives for a new dam or for resolving or mitigating verified deficiencies at an existing dam; and

5. A Value Engineering study, if required, will be completed during this phase of the design process in accordance with the Department of the Interior Value Engineering Guidance
B. Final Design. Final design, including assumptions, calculations, drawings and specifications will be completed for the selected alternative.

1. Appropriate and practical state-of-the-art design methods and procedures will be incorporated into the final design;

2. A Design Summary Report will be prepared which includes complete written documentation of all data, computations, and the decision making process, including the rationale supporting the design decisions;

3. Construction specifications, including all bidding, award, and contract documents, will be in accordance with current Federal Acquisition Regulations and other applicable laws and regulations; and

4. An environmental compliance review will be conducted by Regional environmental and archeological personnel.

C. Independent Technical Review. An independent technical review is required for every modification or construction project. The review will be:

1. Arranged by the Regional SOD Officer;

2. Performed early in the final design process, preferably not later than at the 30 percent completion milestone of the final design; and

3. Conducted by qualified engineers and other experts not otherwise involved in the project, including Regional environmental and archeological personnel.

2.10 Construction of New Dams and Modifications to Existing Dams. BIA personnel play a key role in several elements of the construction process, including:

A. Construction Management. During the construction phase, close coordination between the BIA, design personnel, construction personnel, and Regional safety and environmental officers is required to assure that the project design intent is carried out, that new field information is incorporated into the construction, and that the cost and time schedules are being met. This includes site inspections.

B. Documentation, Records, and Drawings. Complete written and photographic documentation of the construction will be developed and maintained by the project construction engineer and the Regional SOD Officer. This includes, but is not limited to, records of the foundation excavation and treatment, revised drawings to show "as built" conditions, and complete records of all construction inspections.

C. First and Subsequent Fillings. All aspects of the dam and reservoir performance must
be monitored and evaluated by the project construction engineer and the Regional SOD Officer from visual observation and instrumentation data during first filling. First filling must be conducted according to the first fill plan developed during the design phase.

D. Completion Report and Project Acceptance.

(1) Upon completion of construction, the project construction engineer will prepare a completion report in consultation with design and environmental personnel that documents compliance with specifications and drawings;

(2) A detailed inspection of the constructed project will be conducted or arranged by the Regional SOD Officer, and upon approval and acceptance of the project, the facility will be transferred from a construction to an operation and maintenance status; and

E. Final Project Report.

(1) After construction and the first and subsequent successful fillings and monitoring, all identified deficiencies in the DVA Report from pre-construction will be examined to determine if the deficiencies are corrected. A Final Project Report will be prepared by the Regional SOD Officer that documents the status of these deficiencies; and

(2) After the Final Project Report is submitted, the dam will transfer to an operation and maintenance status. The periodic SEED examination and analysis process will resume once the dam is in this status.

F. Post-Construction Activities. The Regional SOD Officer will critique and evaluate design, construction, and administrative activities to assist in improving future designs and construction methods for dams. The Regional SOD Officer will determine which post-construction activities are appropriate for each project and whether a written report is warranted.
D.2. Federal Emergency Management Agency
Federal Guidelines for Dam Safety

April 2004

FEMA
PREFACE

These guidelines represent the culmination of efforts, initiated by President Carter in April 1977, to review procedures and criteria used by Federal Agencies involved in the design, construction, operation, and regulation of dams and to prepare guidelines for management procedures to ensure dam safety. The guidelines are based on an intensive review of Agency practices conducted by the Departments and Agencies themselves, by an ad hoc interagency committee of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), and by an Independent Review Panel of recognized experts from the academic and private sectors. These reviews are summarized in two earlier reports: Improving Federal Dam Safety, a report of the FCCSET, November 1977, and Federal Dam Safety Report of the OSTP Independent Review Panel, December 1978.

Publication of the guidelines marks the final step in the review process. However, the Departments and Agencies recognize that there must be a continuing Federal effort to improve dam safety. Federal dam safety remains a fundamental responsibility of each Federal employee in every Department and Agency involved and it is on their technical expertise and dedication that the safety of Federal dams rests. These guidelines recognize that underlying fact and support management efforts to discharge that responsibility effectively and efficiently.

These guidelines apply to Federal practices for dams with a direct Federal interest and are not intended to supplant or otherwise conflict with State or local government responsibilities for safety of dams under their jurisdiction. Current Federal initiatives to assist States and others with non-Federal dam safety programs are being pursued under other authorities. The objective of both programs, however, is the same: to allow the people of this country to enjoy the benefits of water resource development with the best assurance of dam safety possible.

The members of the FCCSET Ad Hoc Committee are to be commended for their diligent and highly professional efforts. Gratitude and appreciation are also due the several Departments and Agencies involved for their whole-hearted interest and support.

Frank Press, Chairman
Federal Coordinating Council
for Science, Engineering and Technology
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I. INTRODUCTION

These guidelines apply to management practices for dam safety of all Federal agencies responsible for the planning, design, construction, operation, or regulation of dams. They are not intended as guidelines or standards for the technology of dams. The basic principles of the guidelines apply to all dams. However, reasonable judgments need to be made in their application commensurate with each dam’s size, complexity, and hazard.

The Federal agencies have a good record and generally sound practices on dam safety. These guidelines are intended to promote management control of dam safety and a common approach to dam safety practices by all the agencies. Although the guidelines are intended for and applicable to all agencies, it is recognized that the methods of the degree of application will vary depending on the agency mission and functions.

A. BACKGROUND

Throughout history, in all parts of the world, dams built to store water have occasionally failed and discharged the stored waters to inflict sometimes 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, at the time, accepted engineering standards of design and construction. The technology of dams has improved with the increased knowledge of design principles and of the characteristics of foundation and dam materials, and it is generally agreed that safe dams can be built and existing dams can be safely maintained with proper application of current technology. 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 and in the safety evaluation of existing dams.

As early as 1929, following the failure of the St. Francis Dam, the State of 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.

The Congress in 1972 enacted Public Law 92-367, known as the "National Dam Inspection Act." 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 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. A report on these activities and proposed legislation to implement a Federal dam safety program were transmitted to Congress in November 1976, but 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.

An April 23, 1977, Presidential memorandum (reproduced in Section I.B) directed federal agencies to review their dam safety practices, addressing many elements of dam safety. Major elements included internal and external review, qualifications of personnel, integration of new technology, emergency preparedness plans, and review of existing dams. The agencies’ reviews and the assessment of the reviews by a Federal ad hoc interagency committee and by an Independent Review Panel showed that sound practices are generally being used, but concluded that improvement is needed in some management practices for dam safety.

B. AUTHORITY AND IMPLEMENTATION
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 highest consideration, and it is the responsibility of the head of each agency concerned to ensure the adequacy of his agency's dam safety program.

I. 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.

II. 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.

III. 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 A.

Also established were subcommittees 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 B 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 C. 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.

C. DEFINITIONS
The following definitions apply in these guidelines.

**Dam or Project.** Any artificial barrier, including appurtenant works, which impounds or diverts water, and which (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 such barrier which is not in excess of six feet in height regardless of storage capacity, or which has a storage capacity at maximum water storage elevation not in excess of fifteen acre-feet regardless of height. This lower size limitation should be waived if there is a potentially significant downstream hazard.

The guidelines apply with equal force whether the dam has a permanent reservoir or is a detention dam for temporary storage of floodwaters. The impounding capacity at maximum water storage elevation includes storage of floodwaters above the normal full storage elevation.

In addition to conventional structures, this definition of "dam" specifically includes "tailings dams," embankments built by waste products disposal and retaining a disposal pond.
**Dam Failure.** Catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water. It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters which adversely affect a dam's primary function of impounding water is properly considered a failure. 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.

**Contract.** Contracts relating to project design, construction equipment, operation, or regulation, as applicable to the project and the agency function. Where work is described using the terms contract or contractor, it is meant to include also similar work by the agency's own personnel.

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

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

**Hazard.** Potential loss of life or property damage downstream of a dam from floodwaters released at the dam or waters released by partial or complete failure of the dam, and upstream of the dam from effects of rim slides. A hazard is considered significant if there is a potential to cause loss of life or major damage to permanent structures, utilities, or transportation facilities.

**Emergency Preparedness Plan.** Formal plan of procedures to alleviate hazards during construction of or after completion of a dam or to reduce damages if conditions develop in which dam failure is likely or unpreventable. These emergency plans related to dam safety do not include flood plain management for the controlled release of floodwater for which the project is designed.
II. OBJECTIVES AND SCOPE

The overall purpose of these guidelines is to enhance national dam safety. The immediate 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, and emergency preparedness. As these guidelines are directly applied to make Federal dams as safe as practical, it is hoped that they will also influence state dam safety agencies and public and private dam owners to be more safety conscious where programs are now weak.

The guidelines are intended to outline Federal agency management procedures that will continually stimulate technical methods in dam planning, design, construction, and operation for minimizing risk of failure. The objective of dam safety would be achieved as management and technical decisions during all project stages give proper recognition to safety considerations, and the strategy of these guidelines toward that end is to describe definite management practices to reinforce decision-maker awareness of safety needs. Those charged with administering these guidelines must recognize that the achievement of dam safety is through a continuous, dynamic process in which guidelines, practices, and procedures are examined periodically and updated. Technical procedures need to change with technological advancement, and management should ensure that observed deficient practices are corrected and that successful practices are duplicated.

The goal of making dams as safe as practical implies a limit to maximum reasonable effort. Those charged with implementing these guidelines need to recognize that no dam can ever be completely "fail-safe" because of incomplete understanding of or uncertainties associated with natural (earthquakes and floods) and manmade (sabotage) destructive forces; with materials behavior and response to these forces; and in control of the construction process. Management must ensure that uncertainties are properly balanced with competent technical judgment.

Although dams have been built for thousands of years, dam engineering is not an exact science and is more accurately described as an "art." It is true that this branch of engineering, like any other, 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 and/or improving existing dams. For many of these "older dams," there is little information available to document original site exploration, design, construction, and past operation. These dams must be carefully inspected and observed for indicators of distress.

To illustrate a principle from just one aspect of dam design, there are practical limitations on the amount of physical data that can be obtained during planning and design. Judgment and extrapolation are necessary to assess foundation conditions and to design an appropriate structure. Experience is essential in applying these judgments.

Construction is a critical phase in achieving a safe dam. Any project must be continuously evaluated, and "re-engineered" as required, during construction to assure 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
the construction, and constant vigilance is necessary to prevent them. Sampling and testing at a completed project cannot be relied on as an effective substitute for inspection and quality control during construction.

Monitoring existing dams and reacting quickly to inadequate performance or to danger signals is a continuing critical aspect for dam safety. Careful monitoring and quick response can prevent failures, including those caused by poor construction.

The guidelines are intended to make as small as possible the failure risk inherent in constructing new dams, and to prioritize needs to improve existing dams according to hazard potential as estimated by technical analysis and as constrained by financial and personnel resources.

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

A special situation exists regarding the application of these guidelines to dams of international nature. Several dams of concern to the United States are located partially in the United States and partially in 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 agreement with the Mexican Section of the Commission for adoption of applicable sections of these guidelines for ensuring dam safety. For dams located on the U.S.-Canadian border, the guidelines should be referred to the U.S. Section of the International Joint Commission (IJC) to seek agreement with the Canadian Section of the Commission on means by which the guidelines could be implemented through the entities that are responsible for construction, operation, and maintenance 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 E* 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. ORGANIZATION MANAGEMENT

1. General
Heads of Federal agencies are responsible for the development and implementation of policy, resources and procedures for safe design, construction, operation, and inspection of each dam under their jurisdiction, as applicable to the agency mission. The agency management structure assists the head of the agency in discharging this responsibility and shares in it. The management structure is ultimately responsible for obtaining compliance with the intent of these management and technical activities guidelines, and for assuring that procedures are evaluated and updated periodically.

a. Administration
The head of each Federal agency having responsibility for design, construction, operation, or regulation of dams should establish a dam safety office (officer) which reports directly to the head of the agency or his designated representative. The office should be responsible for ensuring that the agency, as a matter of policy and in actual practice, makes every reasonable and prudent effort to enhance the safety of the dams under its jurisdiction. Duties of the office should include surveillance and evaluation of the agency's administrative and technical or regulatory practices related to dam safety concerning design and construction of new dams, and operation, maintenance and rehabilitation of existing dams; recommending improvements in the practices when evaluation reveals safety-related deficiencies; and maintaining an inventory of agency dams.

The functions of the office should be advisory 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 mission.

If a Federal dam safety office is established within the recently proposed Federal Emergency Management Agency (FEMA), the heads of the dam safety offices in the respective agencies should be advisory in FEMA's interagency coordinating functions.

The agency organization for the design, construction, operation, or regulation of a dam project should be structured so that a single identifiable, technically qualified administrative head 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.

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 manpower and funds should give high 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. Design Responsibility
The design function can never be considered finished as long as the dam remains in place; design involvement should continue throughout construction and operation of the project. The design office should establish specific programs for onsite construction and operational inspection for review by appropriate design personnel and technical specialists. 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 inspection and approval of the dam foundation and foundation treatment before placing of dam materials. Final design inspection of the construction should include complete project surveillance and testing of operating equipment. Operational design inspections should continue throughout the life of the project, in accordance with a formal inspection program covering all project features. Management must program adequate funds to assure dam safety is not compromised by failure to conduct regular and thorough inspections and reviews.

The design function includes responsibility for planning any dam instrumentation to be installed during construction and/or operation to monitor conditions that could potentially threaten dam safety. The design should identify the purpose of the instrumentation, and include the 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 occur.

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

d. Operation Responsibility
The responsibility for project operation should be assigned to a single staff member of the operating organization. He should also handle 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.

e. Technical Coordination
All technical specialties required to plan, design, construct, and operate dams to achieve dam safety should be staffed and their efforts coordinated to ensure technical adequacy. A project design engineer should be assigned technical coordination responsibility for each dam. He should handle necessary technical coordination within the agency and with private and public organizations.
Continuing liaison 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.

**f. Emergency Planning**
An emergency plan should be formulated for each dam. The plan should be in the detail warranted by the size and location of the dam and reservoir. It should evaluate downstream inundation hazards resulting from floods or dam failure, and upstream conditions that might result from major land displacements or increased flood flows, including the effects from failure of upstream dams.

Where applicable, the plan should include inundation maps for the flows resulting from design floods and from possible failure of the dam. The complete emergency plan should be transmitted to appropriate local, state, and Federal governmental bodies. The plan should be periodically reviewed and kept up to date, and periodically 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.

**g. Risk-Based Analysis**
Risk-based analytical techniques and methodologies are a relatively recent addition to the tools available for assessing dam safety. With further refinement and improvement, risk-based analyses will probably gain wider acceptance in the engineering profession and realize potential as a major aid to decision-making in the interest of public safety. However, even when fully developed, risk analyses cannot be used as a substitute for sound professional judgment of engineers, contractors, or review boards. In view of the dual problems of uncertainty in analysis and possibility of misinterpretation by the public, but in recognition of the high potential these techniques have, agencies should be encouraged to conduct research to refine and improve the techniques and to develop the methodologies and base of expertise necessary to apply them to dam safety evaluations. Specifically, agencies should strive to perfect techniques for evaluating the probability of possible deficiencies causing dam failure and estimating the potential losses due to such a failure. Meanwhile, the agencies should evaluate the potential consequences of failure of the dams under their jurisdiction. Although the value of potential property losses can be estimated, it is recognized that potential loss of lives can only be quantified, but not evaluated. On new dams, potential losses can be used in study of project alternatives and in assessment of additional safety incorporated into the dam facilities. On existing dams, a risk-based analysis should be considered in establishing priorities for examining and rehabilitating the dams, or for improving their safety.

2. **Staffing**

**a. Technical Support**
Management should assure adequate and competent technical staffing to perform the essential functions in planning design, construction, and operation and maintenance of dams. Technical
staff should be well supported by administrative, clerical, and other elements to ensure that the technical staff is not diverted from technical work. In the planning and design function, particular emphasis should be given to adequate staffing in hydrology, hydraulics, geology, engineering seismology, field investigation, and geotechnical and structural design. Sufficient expertise should be available on the construction staff and on the operation staff to maintain an understanding of design decisions related to the various design specialties.

Construction inspection staffing should assure quality as well as quantity inspection coverage. Staffing should be reviewed by higher authority than the local construction office. Field personnel 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 must be able to recognize when the design is at odds with 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.

The operating personnel must be qualified to perform the many functions required in the operation, including the recognition of conditions possibly detrimental to dam safety. Operation and maintenance staffing requires careful attention to personnel responsible for operating inspections, and to personnel who participate in the periodic inspection program. It is essential that support personnel and equipment are provided to accomplish needed maintenance activities.

b. Competence
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, and operation of dams. All positions should be staffed by competent engineers or specialists in the related disciplines.

c. Continuity
Staffing policies should recognize that continuity of technical positions is essential to maintain consistent high standards of practice. This applies in all elements of project development from design to operation, and is especially critical in those positions having supervisory responsibility related to dam safety.

d. Professional Advancement
The agencies should maintain a positive program for advancement of technical personnel in recognition of acquired experience, training and education, and increased competence. It is essential that agencies maintain the technical as well as the managerial expertise required for safe, effective dam design, construction, and operating programs. Organizational structure, position classification, and career incentives must recognize both technical and managerial responsibility and compensate both 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 functions and the interrelationships of its organizational units. Provisions should be made for technical personnel to observe and participate in decision-making meetings and to make site visits with more experienced staff. Staff members should be allowed to attend consultant meetings in order to gain valuable experience.

Technical personnel concerned with all phases of project development should be given broad exposure to a variety of field conditions. For example, geologists and geotechnical personnel should gain experience with soil and rock drill crews and in the laboratory testing facilities; design personnel should be familiar with concrete and soil placing and testing techniques; operating personnel should be familiar with equipment installation and testing procedures.

A rotational training program should be considered that would place construction engineers in the design organization during design and design engineers in the field during construction on temporary assignments. 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.4.a). This training should make sure that all inspectors know the expected requirements in detail. Onsite instruction sessions for inspection of new features of construction should be developed and given by supervisors or lead inspectors before initiation of the work.

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

Technically qualified operating personnel should be trained in problem detection and evaluation, and application of appropriate remedial (emergency and non-emergency) measures. This is essential for proper evaluation of developing situations at all levels of responsibility which, initially, must be based on observations made by trained operating personnel at the project. The training should cover the problems that experience has shown 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. A sufficient number of personnel should be trained to ensure adequate coverage of all tasks at all times. 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 for 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.
b. Academic
Agency management should establish and maintain a program for continuing formal education and training aimed at increasing and broadening the agency's base of professional expertise in areas related to safe design and construction of dams. Such training should provide for part and/or full time attendance at universities and at special courses prepared by technical and professional organizations. Programs should be designed to further the development of younger personnel and to provide refresher training or sabbaticals for senior personnel.

Supervisory construction, inspection, and operation and maintenance staff should keep current on modern methods and techniques by attending technical courses. Pertinent courses are available from private sources and educational institutions. Also, agencies that develop internal educational programs for this purpose should make them available to other agencies, permitting the agencies to gain mutual benefit in the exchange of information on new methods and practices.

c. Professional
Professional growth of personnel should be encouraged by policies which 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 societies should be given due consideration in assessing qualifications for higher technical positions.

d. New Technology
Provision should be made for the establishment of procedures to screen and disseminate information on technical advances relating to dam design, construction, and operation. Programs for continuing professional training should be oriented toward keeping the technical staff abreast of improved technology. Interagency coordination on training in new technology should be established in areas of mutual interest.

4. Communication
Effective methods of communication, coordination, and review should be established and functioning properly at all times, and be periodically reviewed and updated. Procedures for communications among Federal, State, and local agencies on safety-related matters should be established. Specific areas of suggested communication are discussed below.

a. Interdisciplinary
Direct and easily accessible means of communication should be established between personnel in planning, design, construction, and operations. Coordination is necessary for preparation of the site investigation plan and for a common understanding of information needed for design. Prior to the site investigation the design staff should arrange for meetings between geologists, geotechnical engineers, and designers to review known site conditions, project functional requirements, and preliminary design concepts. A visit to the site should be included in the review of existing information.

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, 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 preconstruction orientation for the construction engineers by the designers, geologists, and embankment and structural engineers so that the construction engineer and his staff fully understand the design concepts and the significance of the results of the exploratory work. The construction engineers need to provide the designers, prior to advertising the construction contract, comments on the constructability and the ease of contract administration for the plans and specifications.

During construction, the construction 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 make regular visits to the construction site, and additional visits as needed when varying conditions are encountered. Changes in construction or materials should be made only after plans for changes are approved by design personnel.

The design staff should furnish to the operation staff documents, referred to by some agencies as "Operation and Maintenance Manuals," containing pertinent design and construction information on structures and equipment required for effective and safe operation of the dam. A conference of design and operating personnel should be held to ensure that the operators understand the operating and inspection procedures required for safe and reliable operation. Both the operators and the designers should have copies of equipment operating and testing manuals and procedures. The operators should notify the designers of any safety-related operating malfunctions and the actions taken to correct them. There should be continuing communication between operating and design staffs 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.

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

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

**a. Design Record**
Written documentation should be maintained in standardized format on all design-related information for the project. Planning design documentation should cover the project objectives and the studies made to locate, 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 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 operation and maintenance personnel and to 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, with any consequent 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 have a future influence on dam safety.

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 planned filling. 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 continuing remedial work, a thorough record of the work should be maintained, and a final report made after complete remedy of the problem.

e. Permanent Files
One copy of all documents concerning the project should be assembled in a single project file. The file should be kept up to date and should be 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, and inspection for the life of the project. Information such as foundation reports and as-built drawings and maps should be permanently retained at the project and also at the agency's engineering design office.

6. Reviews

a. Extent
All factors affecting the safety of a dam during design, construction, and operation should be reviewed on a systematic basis at appropriate levels of authority. 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.

b. Internal
Provision should be made for automatic internal review of all design decisions, methods, and procedures related to dam safety. Review should be at levels of authority above the design section or designer-supervisor relation. Uniformity of criteria and design technique should be maintained, as well as methods to ensure that specific experience is exchanged and used to advance the agency's ability to design, construct, and operate safe dams.

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 reviews should include mechanical and/or electrical equipment engineers. Preconstruction inspection should be made after geologic mapping is done and prior to ground surface disturbance. On large projects, construction reviews would normally be at critical construction periods such as start and completion of foundation preparation and grouting, dam
construction at several stages, and completion of the dam. Visits by appropriate personnel are recommended every six months, and to accompany the consultants during scheduled reviews. The final construction inspection should cover inspection of completed structures and equipment, the adjacent valley floor and abutments, and the reservoir rim.

On smaller projects, the frequency of 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 construction reviews are sufficient to cover the 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 preparedness plan is periodically updated.

Formal documentation should be made of all significant findings from reviews and inspections.

c. External
The need for review of a dam 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 geotechnology, complexity of the design, or a specific need perceived by the public. Consultant reviews should provide appropriate overview evaluations of site investigation, design, and construction.

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. When appropriate, meetings should include a site visit. At each meeting the agency should formally document all aspects of the continued development of the project for presentation in a meeting-opening briefing to the consultants. The consultants should formally document findings and recommendations and present them at a closing conference with the agency staff.

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 normally not more than five, permanent members. The board should always 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 necessary if a power plant is part of the project. 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, in order to keep the board completely familiar with all aspects of the project so they are in a position 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 at specific phases of construction. These phases might include, but not be 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. All board members should attend every meeting even though some meetings may not apply to all members. This would ensure that the entire board is fully aware of the complete work status before being asked for their input on specific points.

The briefing to the board by agency personnel at the start of a 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. If there is significant hazard, the agency should obtain consultant reviews adequate to assure independent assessment of the dam 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 might 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
A strong research and development effort is a necessary element in reducing the uncertainties still present in dam design, hydrology and hydraulics, materials behavior, and construction techniques, equipment and practices. As part of their dam safety programs, agency management should identify opportunities and needs for research and programs to meet those needs both internally and through other agencies such as the National Science Foundation and the U.S. Geological Survey.
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 from experience on past projects relating to constructability, observed behavior, problems encountered, and problem solutions tried and their results. Experience histories should be reviewed, summarized, and disseminated to evaluate current practice in order to advance agency practices. Research and development needed on materials and their use as revealed by dam observation and monitoring and new developments should be conducted on a continuing basis. Establishing a schedule of research priorities is necessary for overall research and development goals and for orderly and consistent progress in advancing dam technology.

b. Risk-Based Analysis
The agencies should individually and cooperatively support research and development of risk-based analysis and methodologies as related to the safety of dams. This research should be directed especially to the fields of hydrology, earthquake hazard, and potential for dam failure. Existing agency work in these fields should be continued and expanded more specifically into developing risk concepts useful in evaluating safety issues. Existing work is exemplified by (1) the interagency research conference cited in paragraph c below, (2) its adjunct meetings on hydraulics and earthquakes, and (3) the NRC methods of risk evaluation for nuclear plants as applicable to radiological safety-related dams.

c. Interagency Coordination
Existing interagency research coordination activities should be continued, with attention to minimizing unnecessary duplication. The biennial research coordination conference on water resources among the Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and Bonneville Power Administration is an example of beneficial exchange needed on issues relating to dam safety.

8. Contracts

a. Documents
Agency procedures should ensure that all contracts for dam design, construction, and operation 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 be continually aware 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 his own agency channels or through interagency or intergovernmental channels as appropriate and available to him.

a. Funding for Organizational Management
Continuity and adequacy of funding are essential to carry out the various programs which ensure safe dams. The Zero Based Budget system offers an opportunity to managers to identify for high funding priority those activities, programs, staff levels, and other operating requirements of a sound dam safety program. Managers should avail themselves of this opportunity. 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 adhered to, 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
Public individuals and groups should have the opportunity to voice their concerns in the development of public works projects and during their operation. 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. Agencies should develop and organize their procedures for early assimilation of those public views which affect possible design, construction, or operating parameters and, in turn, influence dam safety. Resolution of public issues conflicts and problems, including use of executive and legislative government decisions, should be made prior to the start of construction so that dam safety is not compromised.

B. MANAGEMENT OF TECHNICAL ACTIVITIES — SITE INVESTIGATION AND DESIGN (SID)
This section of the 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 or misoperation. 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 developed for use in design or evaluation of major dam and reservoir features, including development of appropriate floods for the construction period.

c. Flood Selection for Design (or Evaluation)
The selection of the design flood should be based on an evaluation of the relative risks and consequences of flooding, under both present and future conditions. Higher risks may have to be accepted for some existing structures because of irreconcilable conditions.

When flooding could cause significant hazards to life or major property damage, the flood selected for design should have virtually no chance of being exceeded. If lesser hazards are involved, a smaller flood may be selected for design. However, all dams should be designed to withstand a relatively large flood without failure even when there is apparently no downstream hazard involved under present conditions of development.

d. Hydrologic Design of Reservoir
In addition to 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. The evaluation of existing projects also should 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 will be 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 in an effective and efficient manner. 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 during a flood. A data information system should be designed to collect and process pertinent hydro meteorological 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 both severe flood events and normal conditions. Necessary corrections should be made as soon as practicable.

e. Downstream Effects
Safety design includes studies to ascertain areas that would be flooded during occurrence of the design flood and in the event of dam failure. The areas downstream from the project should be evaluated to determine the need for land acquisition, flood plain management, or other methods to prevent major damage. Information should be developed and documented suitable for releasing to downstream interests regarding remaining risks of flooding.
f. Warning Systems
Safety design should include an emergency flood warning system and action plan that would effectively notify all concerned in ample time for appropriate action.

2. Earthquake Investigation and Design

a. Investigation Factors
The following factors should be considered in 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 record 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, earthquakes should be selected that have sufficient potential of occurring to require consideration in the dam design. Earthquake description should include estimates to the extent practical 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, to include amplitude (displacement, velocity and acceleration), frequency content, and duration.

d. Need for Earthquake Analysis
The probable effects of earthquakes on the dam and its appurtenant structures should be evaluated to determine the need for inclusion of 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 determination is made that no earthquake forces are required in analysis, the determination should be justified.

e. Seismic and Geologic Studies
(1) Earthquake Sources. The essential first step is determination of the design seismic events (usually the maximum credible earthquakes) and an estimate of 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 are identified, and the maximum credible earthquake magnitudes postulated.

(2) Design Events. A maximum credible earthquake (MCE) is defined herein as 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 which have functions that are essential for earthquake-related safety.

(2) Analysis Method. Determination of appropriate earthquake analysis methods for evaluation of safety concerns may be, as appropriate, by qualitative evaluations, pseudostatic analysis, and dynamic analysis. The methods selected should be appropriate to the identified safety concerns, in accordance with good engineering practice and with 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 which 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 the development of the site.

(2) Documentation. Because many evaluations are possible for a given set of geotechnical conditions, it is important that full documentation be made of the reasoning process involved in geotechnical decisions. General guidelines for documentation are given in section III.A.5.
Management of Diverse Technical Expertise. Geotechnical work encompasses the expertise of geologists, geophysicists, and engineers—all with diverse experience, training, interest, 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 geotechniques is rapidly expanding, management should assure 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 so as to obtain the maximum data from each part of the program. Agency management should ensure sufficient funding for an orderly development of the exploration program in order to reduce uncertainties and to make adequate provisions for required corrective measures.

The initial onsite exploration should be preceded by 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.). This should lead to the preparation of 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, to 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 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 changes in the design.

All potential geological problems, inferred from onsite data and from experience at similar sites, should be fully explored and described. This information should cover the types of adverse features and geologic processes generally associated with a geological environment similar to that at the site. It should also cover the expected short- and long-term behavior of 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 course of 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 which might require consideration include reservoir-induced seismicity, solubility, pipability and 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) 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 one of the most important phases of construction. 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 which 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 such measures as 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.

(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 pipable material is used in the dam, the foundation surface treatment should prevent 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 that has either or both of these unfavorable conditions.

e. Instrumentation

Although a well conceived foundation instrumentation program serves to monitor the foundation and gives an indication of distress, it cannot of itself certify the safety of the foundation. The expertise of the engineer/geologist to analyze and 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 are fourfold: to (1) provide data to validate design assumptions; (2) provide information on the continuing behavior of the foundation; (3) observe the performance of critical known features; and (4) advance the state of the art of foundation engineering.

The general requirements for foundation instrumentation should be determined early in the design of the project, and the rationale for the instrumentation should be thoroughly documented. Factors that will influence the need for and the type of instrumentation include the geology of the foundation, size and type of the dam and reservoir, and the location of the project. Flexibility must be provided in the program to allow for changes from anticipated foundation conditions that are encountered during construction and/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 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 which may require redesign or changes in the type or extent of foundation treatment.

Approval should be obtained from the geotechnical and design staffs before placement of dam materials on the foundation. This approval should be documented and should indicate that all unanticipated conditions encountered were dealt with and that the foundation and its treatment meet the design requirements.
g. Reevaluation at Existing Structures
Older Federal dams may not have been designed to standards equal to current criteria. 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, systematic reevaluation of existing Federal dams should be made.

These reevaluation should go beyond analysis of problems which 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 as appropriate 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 operation of a gated passage is essential to safety, reliable manpower, 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. Outlets (sluiceways, conduits and tunnels) may be used alone or in conjunction with spillways to control flood discharges.

(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 control of the design flood if it is demonstrated that possible power load interruptions during the design flood would not preclude 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
Where 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 4.a 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 control of water during construction.

f. Design Criteria and Guidance
(1) General. If existing design criteria and guidance from past projects and experience are used for design of the hydraulic appurtenances, their sufficiency should be documented.

(2) Hydraulic Model Tests. When sufficient criteria and guidance are not available for 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 the 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 constraints, design criteria, or legal requirements may require that a reanalysis be made of the hydraulic appurtenances.

h. Hydraulic Design Involvement during Life of Structure
Hydraulic design engineers should participate in the project 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 specifically matched to site conditions and project requirements. It is essential when reviewing the safety of existing dams to consider conditions which 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, or larger design earthquakes.

b. Materials
Concrete for the structures requires competent investigation of materials sources and 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 which must be considered for safety: the foundation, the dam, and its appurtenant structures.

(1) Foundation. Proper design of a concrete dam requires information on the foundation geological conditions and materials properties to assure 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 allowable stresses of the foundation and the concrete for all loading conditions imposed on the dam. The shape and/or curvature of a dam and its contact with the foundation are 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 for 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 to be considered 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 for design of 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 assure that structures are designed to meet the requirements for safety. This includes confirmation of design input parameters, design methods, and utilization of allowable factors of safety 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 and 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, but information on structure behavior and the properties of dam and foundation materials serve to verify the design and to provide information for improvement of 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
It is necessary that the 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 particular 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 and special attention given to 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 materials characteristics is required and problem materials should be either discarded or protected by defensive design. 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 with regard to such items as 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, and 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 migration of soil materials into or out of all embankment element contacts both 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. Particular attention should be given to contacts with foundation, abutments, embedded structures, and the end slope of closure sections to ensure adequate compaction and bonding to control seepage.

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

(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 works should be located and designed so that discharges do not erode the embankment or its foundation.

e. Instrumentation
Embarkment design and prediction of embankment performance are based on an imprecise combination of theory and empirical procedure; consequently, performance during construction and operation should be monitored by a designed system of external measurements and/or installed instrumentation. A well planned system of instruments, when appropriate, should be installed to provide data on internal and external movements and on water pressures at critical locations in the embankment and foundation during both construction and operation.

f. Construction and Operational Follow-up
In addition to the need for designers to be involved in 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 and when conditions warrant. Designers should inspect and review 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 may be suspected or become obvious and should be investigated and corrected. Collected experience information should be summarized and used to further advance the state of the art.
C. MANAGEMENT OF TECHNICAL ACTIVITIES — CONSTRUCTION (CON)

1. Introduction
This section of the 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 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 of the work. Contract provisions should require the contractor to submit to the construction engineer advance notice of significant shift change, 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 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 will inspect the work and concur with the progress of construction.

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, and 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 to the close communication requirements with all concerned engineering disciplines during the construction process. For major projects, there should be periodic meetings between design and construction engineers to discuss upcoming construction activities. Also, during the initial stages of important construction activities, the construction engineers should request site inspection by the design engineers to assure 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 that are 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/or 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 assure 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; as well as subsequent exploration to assure 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 wasting, such as in berms or certain zones of the downstream shell of an earthfill dam.

(3) Embankment. Description of both acceptable and unacceptable material properties, placement, and compaction procedures for each zone. Review of required procedures for areas adjacent to abutments, around instruments, and at interfaces between zones and/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, and 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 regulations, and assure public involvement.

4. Construction Assurance

a. Construction Procedures
Agency criteria must assure 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 design, material requirements, and construction specifications as conditions dictate without altering the basic design intent.

b. Construction Materials Testing
A materials laboratory must be established at the field construction office that is adequately staffed and equipped 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 higher echelon for uniform test assurance.

c. Quality Assurance
It is mandatory that adequate construction quality assurance systems and procedures be established to assure safe dam construction. The quality assurance system must guarantee, by direct inspection and testing, 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 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 methods of documentation. 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 haulroads)
Environmental Measures
Equipment Inventory
Dewatering Foundations and Borrow Areas
D. MANAGEMENT OF TECHNICAL ACTIVITIES-OPERATION AND MAINTENANCE (O&M)

This section of the 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 which will ensure 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 proper operation and maintenance of dams that are owned by the agency or that are under its jurisdiction.

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

All operation and maintenance manuals should be kept current, and records should be maintained of instructions, inspections and equipment testing, with copies 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.

Reservoir operating rule curves should be available for each normal mode of operation and for emergency conditions.

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 be tested on a regular schedule. The tests should include 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 identification of high watermarks to indicate past or probable reservoir levels and streamflows, posting of safety instructions at highly visible and key locations, and providing audible safety warnings upstream of and below outlets as appropriate.

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

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 for 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 as well as 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 throughout the operating life of the project the structural integrity of the dam and appurtenant structures, assuring protection of human life and property. Periodic inspections disclose conditions which might disrupt 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 operation or regulation of dams.

All existing dams with a significant hazard potential 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 project history and importance of the facility. For some projects less frequent inspections may be permissible where hazard potential and structural integrity warrant such relaxation.

To maintain control of the inspection program, 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 with the level of inspection.

(1) Informal Inspections. The purpose of informal inspections is to have as far as practicable a continuous surveillance of the dam. Employees at the project are to make frequent observations of the dam and appurtenances and of 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 to 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. The schedule for inspection should be changed by the engineers as required to be responsive to observed changing conditions.

Operating personnel should make an inspection immediately after any unusual event such as large floods, earthquakes, suspected sabotage, or vandalism.

(b) Qualifications of personnel for informal inspections. Informal inspections in most instances 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, however, 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 adequate written instructions on performance of responsibilities and must be evaluated periodically to assure that they understand the requirements and are capable of performing them. 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. For other dams, intermediate inspections should be scheduled by responsible engineers on the basis of the dam's size, importance, and potential for damage to property.

(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 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 assure 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 assure 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 5 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 comprise individuals having appropriate specialized knowledge in structural, mechanical, electrical, hydraulic, and embankment design; geology; concrete materials; and construction procedures. They must be capable of interpreting structural performance and relating conditions found 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 be a means of assuring 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 extensive property 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 record purposes.

(a) Frequency of observations. The frequency of instrument readings should be established at the time the instrumentation system is designed in order 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. It is essential that instrumentation data 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. 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 already 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 which could result in failure of the dam within a short period of time. Heads of agencies should have authorities, procedures and levels of delegation for 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 and/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 and/or the Congress.

(2) Non-emergency Corrective Action. Non-emergency corrective action is action taken when there is no immediate threat to the safety or operation of the dam, nor any threat to life or property downstream. The 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 along with 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 all corrective measures are being completed. When deficiencies are not corrected in a reasonable length of time, an investigation should be made to determine the reason for 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, repair, 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 structure.

(1) Instrumentation. All instrumentation observation data and evaluations thereof 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, 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, detail, and recommendations. Formal and special inspections require complete formal technical reports of all findings, corrective actions and recommendations, for permanent record and reference purposes in order 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 as a result of 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 as a result of changes in criteria to meet current practices or changes in dam technology should be fully documented, including as-constructed drawings.

3. Emergency Action Planning

a. General
It is intended that the 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 which 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. These guidelines provide operating and mobilization procedures to be followed upon indication of an impending or possible dam failure or a major flood.

Each Federal agency which owns or is responsible for dams and each public or private owner of a Federally regulated dam (hereinafter, dam agency or owner) 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, and 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 and property. Plans should then be prepared in a degree of detail commensurate with the hazard, and instructions provided to operators and attendants regarding the actions to be taken in an emergency. Planning should be coordinated with local officials, as necessary, to enable those officials to draw up a workable plan for notifying and evacuating local communities when conditions affecting dam safety arise.

b. Evaluation of Emergency Potential
Prior to development of an emergency action plan, consideration must be given to the extent of land areas, and types of development with the areas, that would be inundated as a result of dam failure or flood, and the time available for emergency response.

(1) Determination of Mode of Dam Failure. There are many potential causes and modes of dam failure, depending upon the type of structure and its foundation characteristics. Similarly, there are degrees of "failure" and, often progressive stages of failure. Many dam failures can be prevented from reaching a final catastrophic stage by recognition of early indicators or precursor conditions, and by prompt, effective emergency actions. While emergency planning should emphasize preventive actions, recognition must be given to the catastrophic condition and hazard potential. Analysis should be made to determine the most likely mode of dam failure under the most adverse condition and the resulting peak water outflow following the failure. Where there is a series of dams on the stream, analyses should include consideration of
the potential for progressive "domino" failure of the dams.

(2) Inundation Maps. To evaluate the effects of dam failure, maps should be prepared delineating the area which would be inundated in the event of failure. Land uses and significant development or improvements within the area of inundation should be indicated. The maps should be equivalent to or more detailed than the United States Geological Survey (USGS) quadrangle maps, 7-1/2 minute series, or of sufficient scale and detail to identify clearly the area that should be evacuated if there is evident danger of failure of the dam. Copies of the maps should be distributed to local government officials for use in the development of an evacuation plan.

(3) Classification of Inundation Areas. To assist in the evaluation of hazard potential, areas delineated on inundation maps should be classified in accordance with the degree of occupancy and hazard potential. The potential for loss of life is affected by many factors, including but not limited to the capacity and number of exit roads to higher ground and available transportation. Hazard potential is greatest in urban areas. Since the extent of inundation is usually difficult to delineate precisely because of topographic map limitations, the evaluation of hazard potential should be conservative.

The hazard potential for affected recreation areas varies greatly, depending on the type of recreation offered, intensity of use, communication facilities, and available transportation. The potential for loss of life may be increased where recreationists are widely scattered over the area of potential inundation since they would be difficult to locate on short notice.

Many industries and utilities requiring substantial quantities of water for one or more stages in the manufacture of products or generation of power are located on or near rivers or streams. Flooding of these areas and industries can, in addition to causing the potential for loss of life, damage to machinery, manufactured products, raw materials and materials in process of manufacture, interrupt essential community services.

Rural areas usually have the least hazard potential. However, the potential for loss of life exists, and damage to large areas of intensely cultivated agricultural land can cause high economic loss.

(4) Time Available for Response. Analyses should be made to evaluate the structural, foundation, and other characteristics of the dam and determine those conditions which could be expected to result in slow, rapid or practically instantaneous dam failure.

c. Actions to Prevent Failure or Minimize Effects of Failure

(1) Development of Emergency Action Plan. An emergency action plan should be developed for each dam that constitutes a hazard to life and property, incorporating preplanned emergency measures to be taken prior to and following assumed dam failure. The plan should be coordinated with local governmental and other authorities involved in public safety and be approved by appropriate top level agency or owner management. To the extent possible, the emergency action plan should define emergency situations that require immediate notification of local officials. The emergency action plan should include notification plans, which are
discussed in section (2) below.

Emergency scenarios should be prepared for possible modes of failure for each dam. Periodically these scenarios should be used to test the readiness capabilities of project staff and logistics.

A procedure should be established for review and revision, as necessary, of the emergency action plan, including notification plans and evacuation plans, at least once every 2 years. Such reviews should be coordinated among all organizations responsible for preparation and execution of the plans.

(2) Notification Plans. Plans for notification of key personnel and the public are an integral part of the emergency action plan and should be prepared for slowly developing, rapidly developing, and instantaneous dam failure conditions. Notification plans should include a list of names and position titles, addresses, office and home telephone numbers, and radio communication frequencies and call signals, if available, for agency or owner personnel, public officials, and other personnel and alternates who should be notified as soon as emergency situations develop. A procedure should be developed to keep the list current.

Each type of notification plan should contain the order in which key agency or owner supervisory personnel or alternates should be notified. At least one key supervisory level or job position should be designated to be manned or the responsible person should be immediately available by telephone or radio 24 hours a day. A copy of each notification plan must be posted in a prominent place at the project site near a telephone and/or radio transmitter. All project personnel should be familiar with the plans and the procedures each is to follow in the event of an emergency. Copies of the notification plans should be readily available at the home and the office of each person involved.

Where dams located upstream from the dam for which the plan is being prepared could be operated to reduce inflow or where the operation of downstream dams would be affected by failure of the dam, operators of those dams should be kept informed of the current and expected conditions of the dam as the information becomes available.

Civil defense officials having jurisdiction over all or part of the area subject to inundation should receive early notification. Local law enforcement officials and, when possible, local government officials and public safety officials should receive early notification.

The capabilities of the Defense Civil Preparedness Agency's National Warning System (NAWAS) should be determined for the project and utilized as appropriate. Information can be obtained from State or local civil defense organizations.

Potentially affected industries downstream should be kept informed so that actions to reduce risk of life and economic loss can be taken. Coordination with local government and civil defense officials would determine responsibility for the notification. Normally, this would be a local government responsibility.
When it is determined that a dam may be in danger of failing, the public officials responsible for the decision to implement the evacuation plan should be kept informed of the developing emergency conditions.

The news media, including radio, television, and newspapers, should be utilized to the extent available and appropriate. Notification plans should define emergency situations for which each medium will be utilized and should include an example of a news release that would be the most effective for each possible emergency. Use of news media should be preplanned insofar as is possible by agency and owner personnel and the State and/or local government. Information should be written in clear, concise language. Releases to news media should not be relied upon as the primary means of notification.

Notification of recreation users is frequently difficult because the individuals are often alone and away from any means of ready communication. Consideration should be given to the use of standard emergency warning devices such as sirens at the dam site. Consideration should be given to the use of helicopters with bullhorns for areas further downstream. Vehicles equipped with public address systems and helicopters with bullhorns are capable of covering large areas effectively.

Telephonic communication should not be solely relied on in critical situations. A backup radio communication system should be provided and tested at least once every 3 months. Consideration should be given to the establishment of a radio communication system prior to the beginning of construction and to the maintenance of the system throughout the life of the project.

(3) Evacuation Plans. Evacuation plans should be prepared and implemented by the local jurisdiction controlling inundation areas. This would normally not be the dam agency or owner. Evacuation plans should conform to local needs and vary in complexity in accordance with the type and degree of occupancy of the potentially affected area. The plans may include delineation of area to be evacuated; routes to be used; traffic control measures; shelter, methods of providing emergency transportation; special procedures for the evacuation and care of people from institutions such as hospitals, nursing homes, and prisons; procedures for securing the perimeter and for interior security of the area; procedures for the lifting of the evacuation order and reentry to the area; and details indicating which organizations are responsible for specific functions and for furnishing the materials, equipment, and personnel resources required.

The assistance of local civil defense personnel, if available, should be requested in preparation of the evacuation plan. State and local law enforcement agencies usually will be responsible for the execution of much of the plan and should be represented in the planning effort. State and local laws and ordinances may require that other State, county, and local government agencies have a role in the preparation, review, approval, or execution of the plan. Before finalization, a copy of the plan should be furnished to the dam agency or owner for information and comment.

(4) Stockpiling Repair Materials. Suitable construction materials should be stockpiled for
emergency use. The amounts and types of construction materials needed for emergency repairs should be determined based on the structural, foundation, and other characteristics of the dam; design and construction history; and history of prior problems.

(5) Locating Local Repair Forces. Arrangements should be made with, and a current list maintained of, local entities, including contractors, and Federal, State and local construction departments, for possible emergency use of equipment and labor.

(6) Training Operating Personnel. Technically qualified project personnel should be trained in problem detection, evaluation, and appropriate remedial (emergency and non-emergency) measures. This is essential for proper evaluation of developing situations at all levels of responsibility which, initially, must be based on on-site observations. A sufficient number of personnel should be trained to assure adequate coverage at all times. If a dam is operated by remote control, arrangements must be made for dispatching trained personnel to the project at any indication of distress.

(7) Increasing Inspection Frequency. Frequency of appropriate surveillance activities should be increased when the reservoir level exceeds a predetermined elevation. Piezometers, water level gauges, and other instruments should be read frequently and on schedule. The project structures should be inspected as often as necessary to monitor conditions related to known problems and to detect indications of change or new problems that could arise. Hourly or continuous surveillance may be mandated in some instances. Any change in conditions should be reported promptly to the supervisor for further evaluation.

The supervisor should issue additional instructions, as necessary, and alert repair crews and contractors for necessary repair work if developing conditions indicate that emergency repairs or other remedial measures may be required.

d. Actions Upon Discovery of a Potentially Unsafe Condition
Action to be taken will depend on the nature of the problem and the time estimated to be available for remedial or mitigation measures. As time permits, one or more of the following actions will be required.

(1) Notification of Supervisory Personnel. This is essential, if time permits, since development of failure could vary in some or many respects from previous forecasts or assumptions, and advice may be needed.

(2) Initiation of Predetermined Remedial Action. It is imperative that at least one technically qualified individual, previously trained in problem detection, evaluation, and remedial action, be at the project or on call at all times. Depending on the nature and seriousness of the problem and the time available, emergency actions can be initiated, such as lowering the reservoir and holding water in upstream reservoirs. Other actions to be taken include notifying appropriate highway and traffic control officials promptly of any rim slides or other reservoir embankment failures which may endanger public highways.

(3) Determination of Need for Public Notification. To the extent possible, emergency situations
that will require immediate notification of public officials in time to allow evacuation of the potentially affected area should be predefined for the use of management and project personnel. If sufficient time is available, the decision to notify public officials that the dam can be expected to fail will be made at a predetermined supervisory level within the agency or owner organization. If failure is imminent or has already occurred, project personnel at the dam site would be responsible for direct notification of the public official. The urgency of the situation should be made clear so that public officials will take positive action immediately.
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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 C

## OSTP INDEPENDENT REVIEW PANEL MEMBERS

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APPENDIX D
ACKNOWLEDGMENTS

The authority for preparation of the guidelines is given in section I.B. They were prepared by an interagency guidelines task group composed of the Chairmen of the subcommittees identified in Appendix B. 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 C) 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 B).

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 the guidelines and in the editing and assembly of the working draft.
APPENDIX E
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   EP 1.08, Navigation Lock Inspections
FEDERAL GUIDELINES FOR DAM SAFETY:
SELECTING AND ACCOMMODATING
INFLOW DESIGN FLOODS FOR DAMS

prepared by the
INTERAGENCY COMMITTEE ON DAM SAFETY

U.S. DEPARTMENT OF HOMELAND SECURITY
FEDERAL EMERGENCY MANAGEMENT AGENCY
OCTOBER 1998

Reprinted April 2004
PREFACE

In April 1977, President Carter issued a memorandum directing the review of federal dam safety activities by an ad hoc panel of recognized experts. In June 1979, the ad hoc interagency committee on dam safety (ICODS) issued its report, which contained the first guidelines for federal agency dam owners. The Federal Guidelines for Dam Safety (Guidelines) encourage strict safety standards in the practices and procedures employed by federal agencies or required of dam owners regulated by the federal agencies. The Guidelines address management practices and procedures but do not attempt to establish technical standards. They provide the most complete and authoritative statement available of the desired management practices for promoting dam safety and the welfare of the public.

To supplement the Guidelines, ICODS prepared and approved federal guidelines in the areas of emergency action planning; earthquake analysis and design of dams; and selecting and accommodating inflow design floods for dams. These publications, based on the most current knowledge and experience available, provided authoritative statements on the state of the art for three important technical areas involving dam safety. In 1994, the ICODS Subcommittee to Review/Update the Federal Guidelines began an update to these guidelines to meet new dam safety challenges and to ensure consistency across agencies and users. In addition, the ICODS Subcommittee on Federal/Non-Federal Dam Safety Coordination developed a new guideline, Hazard Potential Classification System for Dams.

With the passage of the National Dam Safety Program Act of 1996, Public Law 104-303, ICODS and its Subcommittees were reorganized to reflect the objectives and requirements of Public Law 104-303. In 1998, the newly convened Guidelines Development Subcommittee completed work on the update of all of the following guidelines:

- Federal Guidelines for Dam Safety: Emergency Action Planning for Dam Owners
- Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams
- Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams
- Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams
- Federal Guidelines for Dam Safety: Glossary of Terms

The publication of these guidelines marks the final step in the review and update process. In recognition of the continuing need to enhance dam safety through coordination and information exchange among federal and state agencies, the Guidelines Development Subcommittee will be responsible for maintaining these documents and establishing additional guidelines that will help achieve the objectives of the National Dam Safety Program.

The members of all of the Task Groups responsible for the update of the guidelines are to be commended for their diligent and highly professional efforts:

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## III. SELECTING INFLOW DESIGN FLOODS

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I. INTRODUCTION

A. Purpose
The purpose of these Guidelines is to provide thorough and consistent procedures for selecting and accommodating Inflow Design Floods (IDFs). The IDF is the flood flow above which the incremental increase in water surface elevation downstream due to failure of a dam or other water retaining structure is no longer considered to present an unacceptable additional downstream threat.

B. Background
Current practice in the design of dams is to use the IDF that is deemed appropriate for the hazard potential of the dam and reservoir, and to design spillways and outlet works that are capable of safely accommodating the floodflow without risking the loss of the dam or endangering areas downstream from the dam to flows greater than the inflow. However, there are many dams whose discharge capabilities were designed using methods that are now considered unconservative and potentially unsafe.

Inflow design flood selection began primarily as a practical concern for protection of a dam and the benefits it provides. The early 1900's saw an increase in the Nation's social awareness that was demonstrated by various legislative acts designed to protect the public from certain high risk activities. The same era witnessed an increase in the number and size of dams built. When the "big dam" era began in the 1930's, safety clearly became a more dominant factor. It was recognized that dams needed to be designed to accommodate water flows that might be greater than the anticipated "normal" flow.

1. Early Periods. Before 1900, designers of dams had relatively little hydrologic data or tools to indicate flood potential at a proposed dam site. Estimates of flood potential were selected by empirical techniques and engineering judgment based on high water marks or floods of record on streams being studied.

Later, engineers began examining all past flood peaks in a region to obtain what was hoped to be a more reliable estimate of maximum flood-producing potentials than a limited record on a single stream. Designers would base their spillway design on these estimates, sometimes providing additional capacity as a safety factor. Some spillways were designed for a multiple of the maximum known flood, for example, twice the maximum known flood. The multiples and safety factors were based on engineering judgment; the degree of conservatism in the design was unknown.

By the 1930's, it became apparent that this approach was inadequate. As longer hydrologic records were obtained, new floods exceeded previously recorded maximum floods. With the introduction of the unit hydrograph concept by Sherman in 1933, it became possible to estimate floodflows from storm rainfall. The design of dams began to be based upon the transposition of major storms that had occurred within a region, \textit{i.e.},
transfer and centering of relevant storm rainfall patterns over the basin above the dam site being evaluated. It was recognized that flood peaks are dependent on topography, size of individual watersheds, and chance placement of the storm's center over the watershed. In addition, within meteorologically similar areas, observed maximum rainfall values could provide a better indication of maximum flood potentials than data on flood discharges from individual watersheds. If, in the judgment of the designer, the storm was not representative of what might occur, rainfall amounts were increased to represent a more severe event, and the dam was designed accordingly.

2. Transition. Engineers next turned to hydrometeorologists to determine if upper limits for rates of precipitation could be established on a rational basis. Careful consideration was given to the meteorology of storms that produced major floods in various parts of the country. The large scale features of the storm and measures of atmospheric moisture, such as dewpoint temperatures, were considered as well as the rainfall depth-area-duration values produced by these storms. It was then possible to increase the storm dewpoint temperature and other factors affecting rainfall to the maximum appropriate values. This increase resulted in estimates of probable maximum precipitation (PMP), and thus introduced the concept of a physical upper limit to precipitation. When translated to runoff, the estimated floodflow is known as the probable maximum flood (PMF).

At first, the terms maximum possible precipitation and maximum possible flood were used. However, the terminology was changed to probable maximum to recognize the uncertainties in the estimates of the amount of precipitation, and the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the region. Today, the PMF is generally accepted as the standard for the safety design of dams where the incremental consequences of failure have been determined to be unacceptable.

In the late 1940's, the ability to estimate the consequences of dam failure, including the loss of life, was still quite limited. The height of the downstream flood wave and the extent of wave propagation were known to be a function of dam height and reservoir volume. Thus, early standards for dam design were based upon the size of the dam in terms of its height, the reservoir storage volume, and the downstream development.

The practice of setting inflow design flood standards based upon the size of a dam, its reservoir volume, and current downstream development resulted in an inconsistent level of design throughout the country. The determination of the consequences of a dam failure is more complex than can be evaluated by these simple relationships.

3. Current Practices. In 1985, the National Academy of Sciences (NAS) published a study of flood and earthquake criteria which contained an inventory of current practices in providing dam safety during extreme floods. The inventory showed considerable diversity in approach by various federal, state, and local government agencies,
professional societies, and private firms. While the inventory shows a fair consensus on spillway requirements for dams having a high-hazard potential, there is a wide range of criteria being applied to dams with lower hazard classifications.

Several observations about the evaluation of hydrologic conditions were made in the NAS study. Use of PMP for evaluating spillway capacity requirements for large, high-hazard dams predominates, although some state agencies have standards that do not require such dams to pass the full estimated PMF based on the PMP. The influence of the principal federal dam-building and dam safety agencies is evident in the majority of the standards for large, high-hazard dams, but the practices of those agencies have had less effect on current state standards for small dams in less hazardous situations.

As a result of inspections authorized by Public Law 92-367, the National Dam Inspection Act, and carried out by the U.S. Army Corps of Engineers from 1977 to 1981, several states have adopted the spillway capacity criteria used in those inspections. Several other states have adopted the standards used by the Natural Resources Conservation Service (formerly the Soil Conservation Service) for the design of smaller dams constructed under that agency's programs.

Most agencies draw a distinction between design criteria that are applied to existing dams and those that are applied to new dams. However, because dam failures present the same consequences to life and property, it is desirable that existing dams meet the criteria established for new dams.

Today, hydrologically safe designs should be based on current state-of-the-art criteria. Now that engineers can estimate downstream flood levels resulting from dam failure, safety design standards can be tied specifically to a detailed evaluation of the impacts of a flood if a dam were to fail. Although debate continues over the proper criteria and degree of conservatism warranted when evaluating and designing modifications to existing dams, and when designing new dams, criteria used by dam designers, regulators, and owners now focus on ensuring public safety.

C. Scope
1. General. These Guidelines are not intended to provide a complete manual of all procedures used for estimating inflow design floods; the selection of procedures is dependent upon available hydrologic data and individual watershed characteristics. All studies should be performed by an engineer experienced in hydrology and hydraulics, directed and reviewed by engineers experienced in dam safety, and should contain a summary of the design.

2. Philosophy and Principles. The basic philosophy and principles are described in sufficient detail to achieve a reasonable degree of uniformity in application, and to achieve a consistent and uniform nationwide treatment among federal agencies in the design of dams from the standpoint of hydrologic safety.
3. **Content.** The following topics are discussed in these Guidelines:

- **Selecting the IDF** - The selection of the appropriate IDF for a dam is related to the hazard potential classification and is the result of the incremental hazard evaluation.

- **Accommodating the IDF** - Site-specific considerations are necessary to establish hydrologic flood routing criteria for each dam and reservoir. The criteria for routing the IDF or any other flood should be consistent with the reservoir regulation procedure that is to be followed in actual operation.
II. DEFINITION OF TERMS

This chapter contains definitions of technical terms used in these Guidelines.

**Breach:** An opening through a dam which drains the reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional discharge from the reservoir.

**Concurrent Inflows:** Flows expected on tributaries to the river system downstream of the dam at the same time a flood inflow occurs.

**Concurrent Floods:** Flows expected on the river to which the river system with a dam is a tributary at the same time a flood inflow occurs at the reservoir.

**Dam Failure:** The catastrophic breakdown of a dam, characterized by the uncontrolled release of impounded water. There are varying degrees of failure.

**Deterministic Methodology:** A method in which the chance of occurrence of the variable involved is ignored and the method or model used is considered to follow a definite law of certainty, and not probability.

**Dewpoint Temperature:** The temperature at which dew begins to form or vapor begins to condense into a liquid.

**Dynamic Routing:** Hydraulic flow routing based on the solution of the St.-Venant Equation(s) to compute the changes of discharge and stage with respect to time at various locations along a stream.

**Embankment Dam:** Any dam constructed of excavated natural materials (includes both earthfill and rockfill dams).

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

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

**Flood:** A temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year such as one-percent-chance flood, or expressed as a fraction of the probable maximum flood or other reference flood.
**Flood Plain:** The downstream area that would be inundated or otherwise affected by the failure of a dam or by large flood flows.

**Flood Routing:** A process of determining progressively the amplitude of a flood wave as it moves past a dam and continues downstream.

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

**Freeboard:** Vertical distance between a specified stillwater reservoir surface elevation and the top of the dam, without camber.

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

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

**Hazard:** A situation which creates the potential for adverse consequences such as loss of life, property damage, or other adverse impacts. Impacts in the area downstream of a dam are defined by the flood waters released through spillways and outlet works of the dam or waters released by partial or complete failure of the dam. There may also be impacts upstream of the dam due to backwater flooding or landslides around the reservoir perimeter.

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

**Hydrograph, Flood:** A graphical representation of the flood discharge with respect to time for a particular point on a stream or river.

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

**Hydrometeorology:** The study of the atmospheric and land-surface phases of the hydrologic cycle with emphasis on the interrelationships involved.

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

**Intake:** Placed at the beginning of an outlet-works waterway (power conduit, water supply conduit), the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

**Inundate:** To overflow, to flood.

**Inundation Map:** A map showing areas that would be affected by flooding from an uncontrolled release of a dam's reservoir.

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

**Maximum Wind:** The most severe wind for generating waves that is reasonably possible at a particular reservoir. The determination will generally include results of meteorologic studies which combine wind velocity, duration, direction, fetch, and seasonal distribution characteristics in a realistic manner.

**Meteorological Homogeneity:** Climates and orographic influences that are alike or similar.

**Meteorology:** The science that deals with the atmosphere and atmospheric phenomena, the study of weather, particularly storms and the rainfall they produce.

**One-Percent-Chance Flood:** A flood that has 1 chance in 100 of being equaled or exceeded during any year.

**Orographic:** Physical geography that pertains to mountains and to features directly connected with mountains and their general effect on storm path and generation of rainfall.

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

**Probable Maximum Flood (PMF):** The flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study.
**Probable Maximum Precipitation (PMP):** Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location during a certain time of the year. Reservoir Regulation Procedure (Rule Curve): Refers to a compilation of operating criteria, guidelines, and specifications that govern the storage and release function of a reservoir. It may also be referred to as operating rules, flood control diagram, or water control schedule. These are usually expressed in the form of graphs and tabulations, supplemented by concise specifications and are often incorporated in computer programs. In general, they indicate limiting rates of reservoir releases required or allowed during various seasons of the year to meet all functional objectives of the project.

**Reservoir Rim:** The boundary of the reservoir including all areas along the valley sides above and below the water surface elevation associated with the routing of the IDF.

**Risk:** The relationship between the consequences resulting from an adverse event and its probability of occurrence.

**Risk-based Analysis:** A procedure in which the consequences and risks of adverse events and alternatives for mitigation are evaluated and arranged in a manner that facilitates a decision on the action to be taken. A risk-based analysis may be the basis for the selection of the IDF for a particular dam.

**Seiche:** An oscillating wave in a reservoir caused by a landslide into the reservoir or earthquake-induced ground accelerations or fault offset.

**Sensitivity Analysis:** An analysis in which the relative importance of one or more of the variables thought to have an influence on the phenomenon under consideration is determined.

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

**Significant Wave Height:** Average height of the one-third highest individual waves. May be estimated from wind speed, fetch length, and wind duration.

**Spillway:** A structure over or through which flow is discharged from a reservoir. If the rate of flow can be 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. Definitions of specific types of spillways follow:

**Service 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 is also referred to as principal spillway.
**Auxiliary Spillway:** Any secondary spillway which is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

**Emergency Spillway:** A spillway that is designed to provide additional protection against overtopping of dams, and is intended for use under extreme flood conditions or misoperation or malfunction of the service spillway and/or the auxiliary spillway.

**Spillway Capacity:** The maximum spillway outflow which a dam can safely pass with the reservoir at its maximum level.

**Stillwater Level:** The elevation that a water surface would assume if all wave actions were absent.

**Storm:** The depth, area, and duration distributions of precipitation.

**Storm Center:** Location of the storm pattern such that the precipitation falls on a specific drainage basin to create the runoff at the site under consideration.

**Storm Transposition:** The application of a storm from its actual location of occurrence to some other area within the same region of meteorological homogeneity. Storm transposition requires the determination of whether the particular storm could occur over the area to which it is to be transposed.

**Surcharge:** The volume or space in a reservoir between the controlled retention water level and the maximum water level. Flood surcharge cannot be retained in the reservoir but will flow out of the reservoir until the controlled retention water level is reached.

**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 the ground surface is called the heel or the upstream toe.

**Topographic Map:** A detailed graphic delineation (representation) of natural and man-made features of a region with particular emphasis on relative position and elevation.

**Tributary:** A stream that flows into a larger stream or body of water.

**Unit Hydrograph:** A hydrograph with a volume of one inch of direct runoff resulting from a storm of a specified duration and areal distribution. Hydrographs from other storms of the same duration and distribution are assumed to have the same time base but with ordinates of flow in proportion to the runoff volumes.

**Watershed:** The area drained by a river or river system.
Wave Runup: Vertical height above the stillwater level to which water from a specific wave will run up the face of a structure or embankment.

Wind Setup: The vertical rise of the stillwater level at the face of a structure or embankment caused by wind stresses on the surface of the water.
III. SELECTING INFLOW DESIGN FLOODS

A. Introduction
Many thousands of dams have been constructed in the United States, and new dams continue to add to this total. The proper operation of dams to withstand natural forces, including extreme hydrologic events, is an important matter of public safety and concern.

In today's technical world, extreme hydrologic events resulting in dam failures are classified as "low-probability, high-consequence" events. In addition, the potential for losses due to increased downstream development may increase the consequences of a dam failure.

There has been a growing concern and increased attention to dam safety over the past two decades, primarily as a result of a number of catastrophic dam failures. As a result, the inspection of non-federal dams authorized by Public Law 92-367, the National Dam Inspection Act, identified some 2,900 unsafe dams of which 2,350 had inadequate spillway capacities. Since there are approximately 23,772 high and significant-hazard dams in the present National Inventory of Dams, the number of dams which have inadequate spillways could be significantly higher.

The adequacy of a spillway must be evaluated by considering the hazard potential, which would result from failure of the project works during flood flows. (See Chapter II for a definition of hazard potential.) If failure of the project works would present an unacceptable downstream threat, the project works must be designed to either withstand overtopping for the loading condition that would occur during a flood up to the probable maximum flood, or to the point where a failure would no longer cause an unacceptable additional downstream threat.

The procedures used to determine whether or not the failure of a project would cause an unacceptable downstream threat vary with the physical characteristics and location of the project, including the degree and extent of development downstream.

Analyses of dam failures are complex, with many historical dam failures not completely understood. The principal uncertainties in determining the outflow from a dam failure involve the mode and degree of failure. These uncertainties can be circumvented in situations where it can be shown that the complete and sudden removal of the dam would not result in unacceptable consequences. Otherwise, reasonable failure postulations and sensitivity analyses should be used. Suggested references regarding dam failure studies are listed in Appendix A. If it is judged that a more extensive mode of failure than that normally recommended for the type of structure under investigation is possible, then analyses should be done to determine whether remedial action is required. Sensitivity studies on the specific mode of failure should be performed when failure is due to overtopping.

B. Hazard Potential Evaluation
A properly designed, constructed, and operated dam can be expected to improve the safety of downstream developments during floods. However, the impoundment of water by a dam can
create a potential hazard to downstream developments greater than that which would exist without the dam because of the potential for dam failure. There are several potential causes of dam failure, including hydrologic, geologic, seismic, and structural.

These Guidelines are limited to the selection of the inflow design flood (IDF) for the hydrologic design of a dam.

1. General. Once a dam is constructed, the downstream hydrologic regime may change, particularly during floods. The change in hydrologic regime could alter land use patterns to encroach on a flood plain that would otherwise not be developed without the dam.

Consequently, evaluation of the consequences of dam failure must be based on the dam being in place, and must compare the impacts of with-failure and without-failure conditions on existing development and known and prospective future development when evaluating the downstream hazard potential.

2. Hydrologic Modes of Failure. Many dam failures have resulted because of an inability to safely pass flood flows. Failures caused by hydrologic conditions can range from sudden, with complete breaching or collapse, to gradual, with progressive erosion and partial breaching.

The most common modes of failure associated with hydrologic conditions include overtopping, erosion of earth spillways, and overstressing the dam or its structural components. The following paragraphs describe briefly each of the modes of failure caused by hydrologic conditions.

a. Overtopping. Overtopping of a dam occurs when the water level in the reservoir exceeds the height of the dam and flows over the crest. Overtopping will not necessarily result in a failure. Failure depends on the type, composition, and condition of the dam and the depth and duration of flow over the dam.

Embarkment dams are very susceptible to failure when overtopped because of potential erosion. If the erosion is severe, it can lead to a breach and failure of the dam. During overtopping, the foundation and abutments of concrete dams also can be eroded, leading to a loss of support and failure from sliding or overturning. In addition, when a concrete dam is subjected to overtopping, the loads can be substantially higher than those for which the dam was designed. If the increased loading on the dam itself due to overtopping is too great, a concrete dam can fail by overturning or sliding.

b. Erosion in Earth Spillways. High or large flows through earthen spillways adjacent to dams can result in erosion that progresses to the dam and threatens it. Erosion can also cause headcutting that progresses toward the spillway crest and eventually leads to a breach. Discontinuities in slope, nonuniform vegetation or bed materials, and concentrated flow areas can start headcuts and accelerate the erosion process. Flood depths that exceed the safe design parameters can produce erosive forces that may cause serious erosion in the spillway.

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Erosion that occurs due to flow concentrations can start where roads or trails are devoid of vegetation or have ruts that run parallel to the spillway flow. A varied mix of earth materials, unlevel cross sections, uneven stands of vegetation, and obstructions such as trash accumulations can cause turbulent, concentrated flow conditions that start gullies that can widen and migrate upstream to breach the spillway crest.

Runoff brought into a spillway channel by a side inlet may also disrupt the desirable uniform flow pattern and increase the erosion in the channel.

The probability of failure of an earthen auxiliary spillway due to erosion is increased when the capacity of the service spillway inlets (outlet works) or gates are reduced due to trash accumulations. These accumulations reduce the available capacity through these appurtenances and increase the volume, depth, frequency, and duration of flow in the auxiliary spillway.

c. Overstressing of Structural Components. As flood flows enter the reservoir, the reservoir will normally rise to a higher elevation. Even though a dam (both concrete and earth embankment dams) may not be overtopped, the reservoir surcharge will result in a higher loading condition. If the dam is not properly designed for this flood surcharge condition, either the entire dam or the structural components may become overstressed, resulting in an overturning failure, a sliding failure, or a failure of specific structural components (such as the upstream face of a slab and buttress dam). Embankment dams may be at risk if increased water surfaces result in increased pore pressures and seepage rates, which exceed the seepage control measures for the dam.

3. Defining the Hazard Potential. The hazard potential is the possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or misoperation of the dam or appurtenances. Hazard potential does not indicate the structural integrity of the dam itself, but rather the effects if a failure should occur. The hazard potential assigned to a dam is based on consideration of the effects of a failure during both normal and flood flow conditions.

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

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

The hazard potential classification assigned to a dam should be based on the worst-case failure condition, i.e., the classification is based on failure consequences resulting from the failure condition that will result in the greatest potential for loss of life and property damage. For example, a failure during normal operating conditions may result in the released water being confined to the river channel, indicating a low-hazard potential. However, if the dam were to fail during a floodflow condition, and the resultant incremental flood flow would be a potential loss of life or serious damage to property, the dam would have high-hazard potential classification.

In many cases, the hazard potential classification can be determined by field investigations and a review of available data, including topographic maps. However, when the hazard potential classification is not apparent from field reconnaissance, detailed studies, including dambreak analyses, are required. These detailed studies are required to identify the floodflow condition above which the additional incremental increase in elevation, due to failure of a dam, is no longer considered to present an unacceptable threat to downstream life and property.

The hazard potential classification of a project determines the level of engineering review and the criteria that are applicable. Therefore, it is critical to determine the appropriate hazard potential of a dam because it sets the stage for the analyses that must be completed to properly evaluate the integrity of any dam.

4. Evaluating the Consequences of Dam Failure.
There have been about 200 notable dam failures resulting in more than 8,000 deaths in the Twentieth Century. Dam failure is not a problem confined to developing countries or to a compilation of past mistakes that are unlikely to occur again.

Many dam owners have a difficult time believing that their dams could experience a rainfall many times greater than any they have witnessed over their lifetimes. Unfortunately, this attitude leads to a false sense of security because floods much greater than those experienced during any one person's lifetime can and do occur.

Estimates of the potential for loss of human life and the economic impacts of damage resulting from dam failure are the usual bases for defining hazard potential. Social and environmental impacts, damage to national security installations, and political and legal ramifications are not easily evaluated, and are more susceptible to subjective or qualitative evaluation. Because their actual impacts cannot be clearly defined, particularly in economic terms, their consideration as factors for determining the hazard potential must be on a case-by-case basis.

In most situations, the investigation of the impacts of failure on downstream life and property is sufficient to determine the appropriate hazard potential rating and to select the appropriate IDF for a project. However, in determining the appropriate IDF for a project, there could be
circumstances beyond loss of life and property damage, particularly when a failure would have minimal or no impact on downstream life and property, which would dictate using a more conservative hazard potential and IDF. For example, the reservoir of a dam that would normally be considered to have a low-hazard potential classification based on insignificant incremental increases (in elevation) due to a failure may be known to contain extensive toxic sediments. If released, those toxic sediments would be detrimental to the ecosystem. Therefore, a low-hazard potential classification would not be appropriate. Instead, a higher standard should be used for classifying the hazard potential and selecting the IDF.

5. Studies To Define the Consequences of Dam Failure.
The degree of study required to sufficiently define the impacts of dam failure for selecting an appropriate IDF will vary with the extent of existing and potential downstream development, the size of the reservoir (depth and storage volume), and type of dam. Evaluation of the river reach and areas impacted by a dam failure should proceed only until sufficient information is generated to reach a sound decision, or until there is a good understanding of the consequences of failure. In some cases, it may be apparent from a field inspection or a review of aerial photographs, Flood Insurance Rate Maps, and recent topographic maps, that consequences attributable to dam failure would occur and be unacceptable. In other cases, detailed studies, including dambreak analyses, will be required. It may also be necessary to perform field surveys to determine the basement and first floor elevations of potentially affected habitable structures (such as residential and commercial).

When conducting dambreak studies, the consequences of the incremental increase due to failure under both normal (full reservoir with normal streamflow conditions prevailing) and floodflow conditions up to the point where a dam failure would no longer significantly increase the threat to life or property should be considered. For each flood condition, water surface elevations with and without dam failure, flood wave travel times, and rates of rise should be determined. This evaluation is known as an incremental hazard evaluation (See Appendix B, Flowchart 2). Since dambreak analyses and flood routing studies do not provide precise results, evaluation of the consequences of failure should be conservative.

The type of dam and the mechanism that could cause failure require careful consideration if a realistic breach is to be assumed. Special consideration should be given to the following factors:

- Size and shape of the breach
- Time of breach formation
- Hydraulic head
- Storage in the reservoir
- Reservoir inflow
In addition, special cases where a dam failure could cause *domino-like* failure of downstream dams resulting in a cumulative flood wave large enough to cause a threat should be considered.

The area affected by dam failure during a given flow condition on a river is the additional area inundated by the incremental increase in flood elevation due to failure over that which would occur normally by flooding without dam failure. The area affected by a flood wave resulting from a theoretical dam breach is a function of the height of the flood wave and the downstream distance and width of the river at a particular location. An associated and important factor is the flood wave travel time. These elements are primarily a function of the rate and extent of dam failure, but also are functions of channel and floodplain geometry and roughness and channel slope.

**The flood wave should be routed downstream to the point where the incremental effect of a failure will no longer result in unacceptable additional consequences.** When routing a dambreak flood through the downstream reaches, appropriate concurrent inflows should be considered in the computations. Downstream concurrent inflows can be determined using one of the following approaches:

- Concurrent inflows can be based on historical records if these records indicate that the tributaries contributing to the flood volume are characteristically in a flood stage at the same time that flood inflows to the reservoir occur. Concurrent inflows based on historical records should be adjusted so they are compatible with the magnitude of the flood inflow computed for the dam under study.

- Concurrent inflows can be developed from flood studies for downstream reaches when they are available. However, if these concurrent floods represent inflows to a downstream reservoir, suitable adjustments must be made to properly distribute flows among the tributaries.

- Concurrent inflows may be assumed equal to the mean annual flood (approximately bankfull capacity) for the channel and tributaries downstream from the dam. The mean annual flood can be determined from flood flow frequency studies. As the distance downstream from the dam increases, engineering judgment may be required to adjust the concurrent inflows selected.

In general, the study should be terminated when the potential for loss of life and property damage caused by routing floodflows appears limited. This point could occur when the following takes place:

- There are no habitable structures, and anticipated future development in the floodplain is limited.

- Floodflows are contained within a large downstream reservoir.
- Floodflows are confined within the downstream channel.
- Floodflows enter a bay or ocean.

The failure of a dam during a particular flood may increase the area flooded and also alter the flow velocity and depth of flow as well as the rate of rise of flood flows. These changes in flood flows could also affect the amount of damage. To fully evaluate the hazard created by a dam, a range of flood magnitudes needs to be examined. Water surface profiles, flood wave travel times, and rates of rise should be determined for each condition.

The results of the downstream routing should be clearly shown on inundation maps with the breach-wave travel time, maximum depth of flow, and maximum velocity, indicated at critical downstream locations. The inundation maps should be developed at a scale sufficient to identify downstream habitable structures within the impacted area. The current recommended method for dambreak analysis is the unsteady flow and dynamic routing method used in the National Weather Service (NWS) model.

Most of the methods used for estimating dambreak hydrographs, including the widely used NWS model, required selecting the size, shape, and time of formation of the dam breach as input parameters for the computations. Therefore, sensitivity analyses are considered necessary. Sensitivity analyses, based on varying flood inflow conditions and breach parameters, should be performed only to the extent necessary to make a decision.

Dambreak studies should be performed in accordance with accepted Guidelines. Refer to Appendix A for a list of sources of information related to dambreak studies.

6. Incremental Hazard Evaluation for Inflow Design Flood Determination. The appropriate IDF for a project is selected based on the results of the incremental hazard evaluation. This evaluation involves simulating a dam failure during normal and floodflow conditions and routing the water downstream. The additional down-stream threat due to the incremental increase in water surface elevation from dam failure is assessed for each failure scenario.

To evaluate the incremental increase in consequences due to dam failure, begin with the normal inflow condition and the reservoir at normal full reservoir level with normal streamflow conditions prevailing. That condition should be routed through the dam and downstream areas, with the assumption that the dam remains in place. The same flow should then be routed through the dam with the assumption that the dam fails.

The incremental increase in downstream water surface elevation between the with-failure and without-failure conditions should then be determined, i.e., how much higher would the water downstream be if the dam failed than if the dam did not fail? The consequences that could result should then be identified. If the incremental rise in flood water downstream results in unacceptable additional consequences, assess the need for remedial action.
If the study under normal flow conditions indicates no adverse consequences, the same analyses should be done for several larger flood levels to determine the greatest unacceptable consequences. Under each incrementally larger inflow condition, identify the consequences of failure. For each larger assumed flood inflow condition (which can be percentages of the probable maximum flood (PMF)):

- assume the dam remains in place during the nonfailure conditions; and
- assume the dam fails when the peak reservoir elevation is attained for the assumed inflow condition.

_It is not appropriate to assume that a dam fails on the rising limb of the inflow hydrograph._ For example, current methods cannot accurately determine the extent of overtopping that an earth dam can withstand or how rapidly the dam will erode and ultimately breach from overtopping. Therefore, until such methodologies are available and proven, a conservative approach should be followed which assumes that failure occurs at the peak of the flood hydrograph. The assumption should also be made that the dam has been theoretically modified to contain or safely pass all lower inflow floods. This is an appropriate assumption because this procedure requires that the dambreak analyses start at the normal operating condition, with incremental increases in the flood inflow condition for each subsequent failure scenario up to the point where a failure no longer constitutes unacceptable additional consequences. In summary, before selecting larger floods for analysis, determine what failure at a lower flood constituted a threat to downstream life and property.

The above procedure should be repeated until the flood inflow condition is identified such that a failure at that flow or larger flows (up to the PMF) will no longer result in unacceptable additional consequences. The resultant flood flow is the IDF for the project. The maximum IDF is always the PMF, but in many cases the IDF will be substantially less than the PMF.

A PMF should be determined if it is needed for use in the evaluation. If a PMF value is already available, it should be reviewed to determine if it is still appropriate. The probable maximum precipitation (PMP) for the area should be determined either through the use of the Hydrometeorological Reports (HMR's) developed by the NWS or through the services of a qualified hydrometeorologist. In addition, the hydrologic characteristics of the drainage basin that would affect the runoff from the PMP into the reservoir should be determined. After this information is evaluated, the PMF can be determined.

Once the appropriate IDF for the dam has been selected (whether it is the PMF or something less), it should then be determined whether the dam can safely withstand or pass all floodflows up through the IDF. If it can, then no further evaluation or action is required. If it cannot, then measures must be taken to enable the project to safely accommodate all floods up through the IDF to alleviate the incremental increase in unacceptable additional consequences a failure may have on areas downstream.
It is important to investigate the full range of flood flow conditions to verify that a failure under flood flows larger than the selected IDF up through the PMF will not result in any additional hazard. In addition, once the design for remedial repairs is selected, the IDF should be verified for that design.

Appendix B provides specific guidance and procedures, including a comprehensive flowchart, for conducting an incremental hazard evaluation to select the appropriate IDF for a dam and determine the need for remedial measures.

7. Criteria for Selecting the Inflow Design Flood. Ideally, dams should be able to safely accommodate floodflows in a manner that will not increase the danger to life and property downstream. However, this situation is not always the case, and may not always be achievable.

There are various methods or reasons for selecting the inflow design flood and determining whether the dam can safely accommodate the flood. The method chosen may be determined by the amount of time and/or funds available to conduct an evaluation. For example, if time and funds are scarce, a conservative inflow design flood (e.g., the PMF) can be selected.

Sometimes, inflow design flood selection is straightforward, i.e., given certain criteria, a specific inflow design flood must be used, due to political decisions and policies established by government agencies. For example, statutes may require that a flood such as the PMF, a specific fraction of the PMF, or a flood of specific frequency be selected for a dam with a certain hazard classification. Fortunately, the most widely accepted approach involves incremental hazard evaluations to identify the appropriate IDF for a dam.

There is not a separate IDF for each section of a dam. A dam is assigned only one IDF, and it is determined based on the consequences of failure of the section of the dam that creates the greatest hazard potential downstream. This should not, however, be confused with the design criteria for different sections of a dam which may be based on the effect of their failure on downstream areas.

The PMF should be adopted as the IDF in those situations where consequences attributable to dam failure for flood conditions less than the PMF are unacceptable.

A flood less than the PMF may be adopted as the IDF in those situations where the consequences of dam failure at flood flows larger than the selected IDF are acceptable. In other words, where detailed studies conclude that the risk is only to the dam owners' facilities and no increased damage to downstream areas is created by failure, a risk-based approach is acceptable. Generally, acceptable consequences exist when evaluation of the area affected indicates the following:
• There are no permanent human habitations, known national security installations, or commercial or industrial developments, nor are such habitations or commercial or industrial developments projected to occur within the potential hazard area in the foreseeable future.

• There are permanent human habitations within the potential hazard area that would be affected by failure of the dam, but there would be no significant incremental increase in the threat to life or property resulting from the occurrence of a failure during floods larger than the proposed IDF. For example, if an impoundment has a small storage volume and failure would not add appreciably to the volume of the outflow flood hydrograph, it is likely that downstream inundation would be essentially the same with or without failure of the dam.

The consequences of dam failure may not be acceptable if the hazard potential to these habitations is increased appreciably by the failure flood wave or level of inundation. When a dambreak analysis shows downstream incremental effects of approximately two feet or more, engineering judgment and further analysis will be necessary to finally evaluate the need for modification to the dam. In general, the consequences of failure are considered acceptable when the incremental effects (depth) of failure on downstream structures are approximately two feet or less. However, the two-foot increment is not an absolute decision-making point. Sensitivity analyses and engineering judgment are the tools used in making final decisions. For example, if it is determined that a mobile home sitting on blocks can be moved and displaced by as little as six inches of water, then the acceptable incremental impact would be much less than two feet. As a second example, if a sensitivity analysis demonstrates that the largest breach width recommended is the only condition that results in an incremental rise of two feet, then engineering judgment becomes necessary to determine whether a smaller breach having acceptable consequences of failure is more realistic for the given conditions, e.g., flow conditions, characteristics of the dam, velocity in vicinity of structures, location, and type of structures.

In addition, selection of the appropriate magnitude of the IDF may include consideration of whether a dam provides vital community services such as municipal water supply or energy. Therefore, a higher degree of protection may be required against failure to ensure those services are continued during and following extreme flood conditions when alternate services are unavailable. If losing such services is economically acceptable, the IDF can be less conservative. However, loss of water supply for domestic purposes may not be an acceptable public health risk.

Flood frequency and risk-based analyses may be used to hold operation and maintenance costs to a reasonable level, to maintain public confidence in owners and agencies responsible for dam safety, and to be in compliance with local, state, or other regulations
applicable to the facility. Generally, it would not be an appropriate risk to design a dam having a potential for failure at a flood frequency of less than once in 100 years.

When determining the effect flood inflows will have on dam safety, a hydrologic approach may be used. Simply stated, when determining the effect flood inflows will have on dam safety, the following approach establishes the IDF for the project, and either:

- determines whether an existing project can safely accommodate the IDF; or
- determines how a new project will be designed to safely accommodate the IDF.

Because the entire spectrum of floods up to the PMF level generally needs to be considered in selecting the IDF, it is usually necessary to determine the PMP magnitudes and to develop the PMF based on that information.

The effort involved in conducting PMP and PMF analyses is quite detailed. Depending on the significance of the study being pursued, these analyses should be directed by an engineer trained and experienced in this specialized field.

The incremental hazard evaluation procedure presented in the previous section is the most direct method for selecting an inflow design flood. However, there are times when selection becomes difficult and it may be necessary to conduct further analyses with a risk-based approach. The incremental hazard evaluation is, in essence, a risk-based approach.

C. PMFs for Dam Safety. The PMF is the upper limit of floods to be considered when selecting the appropriate IDF for a dam.

1. General. A deterministic methodology should be used to determine the PMF. In the deterministic methodology, a flood hydrograph is generated by modeling the physical atmospheric and drainage basin hydrologic and hydraulic processes. This approach attempts to represent the most severe combination of meteorologic and hydrologic conditions considered reasonably possible for a given drainage basin. The PMF represents an estimate of the upper limit of run-off that is capable of being produced on the watershed. Refer to Appendix A for a list of sources of information related to flood studies.

2. PMP. The concept that the PMP represents an upper limit to the level of precipitation the atmosphere can produce has been stated in many hydrometeorological documents. The commonly used approach in deterministic PMP development for non-orographic regions is to determine the limiting dew point temperature at the surface (used to obtain the moisture maximization factor) and to collect a "sufficient" sample of extreme storms. These extreme storms are moved to other parts of the study area. The latter are done through a method known as storm transposition, *i.e.*, the adjustment of moisture observed in a storm at its actual site of occurrence to the corresponding moisture level at the site from which the PMP is to be determined. Storm transposition is based on the concept that all storms within a meteorologically
homogeneous region could occur at any other location within that region with appropriate adjustments for effects of elevation and moisture supply. The maximized transposed storm values are then enveloped both depth-durationally and depth-areally to obtain PMP estimates for a specific basin. Several durations of PMP should be considered to ensure the most appropriate duration is selected.

In orographic regions, where local influences affect the delineation of meteorological homogeneity, transposition is generally not permitted. Alternative procedures are offered for these regions that are less reliant on the adequacy of the storm sample. Most of these procedures involve development of both nonorographic and orographic components (sometimes an orographic intensification factor is used) of the PMP. Orographic and nonorographic PMPs are then combined to obtain total PMP estimates for an orographic basin. Currently, generalized PMP estimates are available for the United States (see Figure 3).

As our understanding and the availability of data increases, the "particular" PMP estimates that appear in NWS HMRs may require adjustment to better define the conceptual PMP for a specific site. Therefore, it may be appropriate to refine PMP estimates with site-specific or regional studies. The results of available research, such as that developed by the Electric Power Research Institute, should be considered in performing site-specific studies. Because these studies can become very time consuming and costly, the benefit of a site-specific study must be considered carefully. Currently, generalized NWS PMP estimates are available for the entire conterminous United States, as well as Alaska, Hawaii, and Puerto Rico.

D. Floods To Protect Against Loss of Benefits During the Life of the Project - Applicable Only to Low-Hazard Dams
Dams identified as having a low-hazard potential should be designed to at least meet a minimum standard to protect against the risk of loss of benefits during the life of the project, hold operation and maintenance costs to a reasonable level, maintain public confidence in owners and agencies responsible for dam safety, and be in compliance with local, state, or other regulators applicable to the facility. Floods having a particular frequency may be used for this analysis. In general, it would not be appropriate to design a dam having a low-hazard potential for a flood having an average return frequency of less than once in 100 years.
IV. ACCOMMODATING INFLOW DESIGN FLOODS

A. Flood Routing Guidelines

1. General. Site-specific considerations should be used to establish flood routing criteria for each dam and reservoir. The criteria for routing any flood should be consistent with the reservoir regulation procedure that is to be followed in actual operation. The general guidelines to be used in establishing criteria are presented below and should be used if applicable.

2. Guidelines for Initial Elevations. In general, if there is no allocated or planned flood control storage (i.e., run-of-river), the flood routing usually begins with the reservoir at the normal maximum pool elevation. If regulation studies show that pool levels would be lower than the normal maximum pool elevation during the critical inflow design flood (IDF) season, then the results of those specific regulation studies should be analyzed to determine the appropriate initial pool level for routing the IDF.

3. Reservoir Constraints. Flood routing criteria should recognize constraints that may exist on the maximum desirable water surface elevation. A limit or maximum water surface reached during a routing of the IDF can be achieved by providing spillways and outlet works with adequate discharge capacity. Backwater effects of floodflow into the reservoir must specifically be considered when constraints on water surface elevation are evaluated. Reservoir constraints may include the following:

   - Topographic limitations on the reservoir stage which exceed the economic limits of dike construction; public works around the reservoir rim, which are not to be relocated, such as water supply facilities and sewage treatment plants; dwellings, factories, and other developments around the reservoir rim, which are not to be relocated. If there is a loss of storage capacity caused by sediment accumulation in portions of the reservoir, then this factor should be accounted for in routing the IDF. Sediment deposits in reservoir headwater areas may build up a delta, which can increase flooding in that area, as well as reduce flood storage capacity, thereby having an effect on routings.

   - Geologic features that may become unstable when inundated and result in landslides, which would threaten the safety of the dam, domestic and/or other developments, or displace needed storage capacity.

   - Flood plain management plans and objectives established under federal or state regulations and/or authorities.

4. Reservoir Regulation Requirements. Considerations to be evaluated when establishing flood routing criteria for a project include the following:
Regulation requirements to meet project purposes, the need to impose a maximum regulated release rate to prevent flooding or erosion of downstream areas and control rate of drawdown, the need to provide a minimum regulated release capacity to recover flood control storage for use in regulating subsequent floods, the practicability of evacuating the reservoir for emergencies and for performing inspection, maintenance, and repair. Spillways, outlet works, penstocks, and navigation locks for powerplants are sized to satisfy project requirements and must be operated in accordance with specific instructions if these project works are relied upon to make flood releases, subject to the following limitations:

- Only those release facilities which can be expected to operate reliably under the assumed flood condition should be assumed to be operational for flood routing. Reliability depends upon structural competence and availability for use. Availability and reliability of generating units for flood release during major floods should be justified. Availability of a source of auxiliary power, for gate operation, effects of reservoir debris on operability and discharge capacity of gates and other facilities, accessibility of controls, design limits on operating head, reliability of access roads, and availability of operating personnel at the site during floods are other factors to be considered in determining whether to assume release facilities are operational. A positive way of making releases to the natural watercourse by use of a bypass or wasteway must be available if canal outlets are to be considered available for making flood releases. Bypass outlets for generating units may be used if they are or can be isolated from the turbines by gates or valves.

- In flood routing, assumed releases are generally limited to maximum values determined from project uses, by availability of outlet works, tailwater conditions including effects of downstream tributary inflows and wind tides, and downstream nondamming discharge capacities until allocated storage elevations are exceeded. When a reservoir's capacity in regulating flows is exceeded, then other factors, particularly dam safety, will govern releases. During normal flood routing, the rate of outflow from the reservoir should not exceed the rate of inflow until the outflow begins to exceed the maximum project flood discharge capacity at normal pool elevation, nor should the maximum rate of increase of outflow exceed the maximum rate of increase of inflow. This is to prevent outflow conditions from being more severe than pre-dam conditions. An exception to the above would be where streamflow forecasts are available and pre-flood releases could reduce reservoir levels to provide storage for flood flows.

5. Evaluation of Domino-like Failure. If one or more dams are located downstream of the site under review, the failure wave should be routed downstream to determine if any of the
downstream dams would breach in a domino-like action. The flood routing of flows entering the most upstream of a series of such dams may be either dynamic or level pool. The routing through all subsequent downstream reservoirs should be a dynamic routing. Tailwater elevations should consider the effect of backwater from downstream constrictions.

**B. Spillway and Flood Outlet Selection and Design**

**1. General.** Spillways and flood outlets should be designed to safely convey major floods to the watercourse downstream from the dam. They are selected for a specific dam and reservoir on the basis of release requirements, topography, geology, dam safety, and project economics.

**2. Gated or Ungated Spillways.** An ungated spillway releases water whenever the reservoir elevation exceeds the spillway crest level. A gated spillway can regulate releases over a broad range of water levels.

Ungated spillways are more reliable than gated spillways. Gated spillways provide greater operational flexibility. Operation of gated spillways and/or their regulating procedures should generally ensure that the peak flood outflow does not exceed the natural downstream flow that would occur without the dam.

The selection of a gated or ungated type of spillway for a specific dam depends upon site conditions, project purposes, economic factors, costs of operation and maintenance, the IDF itself, and other considerations.

The following paragraphs focus on considerations that influence the choice between gated and ungated spillways:

- **Discharge capacity -** For a given spillway crest length and maximum allowable water surface elevation, a gated spillway can be designed to release higher discharges than an ungated spillway because the crest elevation may be lower than the normal reservoir storage level. This is a consideration when there are limitations on spillway crest length or maximum water surface elevation.

- **Project objectives and flexibility -** Gated spillways permit a wide range of releases and have capability for pre-flood drawdown.

- **Operation and maintenance -** Gated spillways may experience more operational problems and are more expensive to construct and maintain than ungated spillways. Constant attendance or several inspections per day, by an operator during high water levels, is highly desirable for reservoirs with gated spillways, even when automatic or remote controls are provided. During periods of major flood inflows, the spillway should be closely monitored. Gated spillways are more subject to clogging from debris and jamming from ice, whereas properly designed ungated spillways are basically free from these problems. Gated spillways require regular maintenance and periodic testing of gate operations. However, ungated spillways can have flashboards, trip gates, and stop log
sections, which can have operational problems during floods and may require constant attendance or several inspections per day during high water levels.

- **Reliability** - The nature of ungated spillways reduces dam failure potential associated with improper operation and maintenance. Where forecasting capability is unreliable, or where time from the beginning of runoff to peak inflow is only a few hours, ungated spillways are more reliable, particularly for high-hazard structures. Consequences of failure of operation equipment or errors in operation can be severe for gated spillways.

- **Data and control requirements** - Operational decisions for gated spillways should have real time hydrologic and meteorologic data to make proper regulation possible.

- **Emergency evacuation** - Unless ungated spillways have removable sections, such as flashboards, trip gates, or stop log sections, they cannot be used to evacuate a reservoir during emergencies. The capability of gated spillways to draw down pools from the top of the gates to the spillway crest can be an advantage when emergency evacuation to reduce head on the dam is a concern.

- **Economics and selection** - Designs to be evaluated should be technically adequate alternatives. Economic considerations often indicate whether gated or ungated spillways are selected. The possibility of selecting a combination of more than one type of spillway is also a consideration. Final selection of the type of crest control should be based on a comprehensive analysis of all pertinent factors, including advantages, disadvantages, limitations, and feasibility of options.

3. **Design Considerations.** Dams and their appurtenant structures should be designed to give satisfactory performance. These Guidelines identify three specific classifications of spillways (service, auxiliary, and emergency) and outlet works that are used to pass floodwaters, each serving a particular function. The following paragraphs discuss functional requirements.

**Service spillways** should be designed for frequent use and should safely convey releases from a reservoir to the natural watercourse downstream from the dam. Considerations must be given to waterway free-board, length of stilling basins, if needed, and amount of turbulence and other performance characteristics. It is acceptable for the crest structure, discharge channel (e.g., chute, conduit, tunnel), and energy dissipator to exhibit marginally safe performance characteristics for the IDF. However, they should exhibit excellent performance characteristics for frequent and sustained flows, such as up to the 1-percent chance flood event. Other physical limitations may also exist that have an effect on spillway sizing.
Auxiliary spillways are usually designed for infrequent use and it is acceptable to sustain limited damage during passage of the IDF. The design of auxiliary spillways should be based on economic considerations and should be subject to the following requirements:

- The auxiliary spillway should discharge into a watercourse sufficiently separated from the abutment to preclude abutment damage and should discharge into the main stream a sufficient distance downstream from the toe of the dam so that flows will not endanger the dam's structural integrity or usefulness of the service spillway. The auxiliary spillway channel should either be founded in competent rock or an adequate length of protective surfacing should be provided to prevent the spillway crest control from degrading to the extent that it results in an unacceptable loss of conservation storage or a large uncontrolled discharge which exceeds peak inflow.

Emergency spillways may be used to obtain a high degree of hydrologic safety with minimal additional cost. Because of their infrequent use, it is acceptable for them to sustain significant damage when used and they may be designed with lower structural standards than those used for auxiliary spillways.

An emergency spillway may be advisable to accommodate flows resulting from misoperation or malfunction of other spillways and outlet works. Generally, they are sized to accommodate a flood smaller than the IDF. The crest of an emergency spillway should be set above the normal maximum water surface (attained when accommodating the IDF) so it will not overflow as a result of reservoir setup and wave action. The design of an emergency spillway should be subject to the following limitations:

- The structural integrity of the dam should not be jeopardized by spillway operation. Large conservation storage volumes should not be lost as a result of degradation of the crest during operation. The effects of a downstream flood resulting from uncontrolled release of reservoir storage should not be greater than the flood caused by the IDF without the dam.

Outlet works used in passing floods and evacuating reservoir storage space should be designed for frequent use and should be highly reliable. Reliability is dependent on foundation conditions, which influence settlement and displacement of waterways, on structural competence, on susceptibility of the intake and conduit to plugging, on hydraulic effects of spill-way discharge, and on operating reliability.

C. Freeboard Allowances
1. General. Freeboard provides a margin of safety against overtopping failure of dams. It is generally not necessary to prevent splashing or occasional overtopping of a dam by waves under extreme conditions. However, the number and duration of such occurrences should not threaten the structural integrity of the dam, interfere with project operation, or create hazards to personnel. Freeboard provided for concrete dams can be less conservative than for embankment
dams because of their resistance to wave damage or erosion. If studies demonstrate that concrete dams can withstand the IDF while overtopped without significant erosion of foundation or abutment material, then no freeboard should be required for the IDF condition. Special consideration may be required in cases where a powerplant is located near the toe of the dam. The U.S. Bureau of Reclamation has developed guidelines (See Appendix A) that provide criteria for freeboard computations.

Normal freeboard is defined as the difference in elevation between the top of the dam and the normal maximum pool elevation. Minimum freeboard is defined as the difference in pool elevation between the top of the dam and the maximum reservoir water surface that would result from routing the IDF through the reservoir. Intermediate freeboard is defined as the difference between intermediate storage level and the top of the dam. Intermediate freeboard may be applicable when there is exclusive flood control storage.

2. Freeboard Guidelines. Following are guidelines for determining appropriate freeboard allowances:

- Freeboard allowances should be based on site-specific conditions and the type of dam (concrete or embankment). Both normal and minimum freeboard requirements should be evaluated in determining the elevation of the top of the dam. The resulting higher top of dam elevation should be adopted for design. Freeboard allowances for wind-wave action should be based upon the most reliable wind data available that are applicable to the site. The significant wave should be the minimum used in determining wave runup, and the sum of wind setup and wave runup should be used for determining requirements for this component of freeboard.

- Computations of wind-generated wave height, setup, and runup should incorporate selection of a reasonable combined occurrence of pool level, wind velocity, wind direction, and wind durations based on site-specific studies. It is highly unlikely that maximum winds will occur when the reservoir water surface is at its maximum elevation resulting from routing the IDF, unless the reservoir capacity is small compared to flood volume because the maximum level generally persists only for a relatively short period of time (a few hours). Consequently, winds selected for computing wave heights should be appropriate for the short period the pool would reside at or near maximum levels. Normal pool levels persist for long periods of time. Consequently, maximum winds should be used to compute wave heights.

- Freeboard allowance for settlement should be applied to account for consolidation of foundation and embankment materials when uncertainties exist in computational methods or data used yield unreliable values for camber design. Freeboard allowance for settlement should not be applied where an accurate determination of settlement can be made and is included in the camber. Freeboard allowance for embankment dams for estimated earthquake-generated movement, resulting seiches, and permanent embankment displacements or deformations should be considered if a dam is located in
an area with potential for intense seismic activity. Reduction of freeboard allowances on embankment dams may be appropriate for small fetches, obstructions that impede wave generation, special slope and crest protection, and other factors.

- Freeboard allowance for wave and volume displacement due to potential landslides, which cannot be economically removed or stabilized, should be considered if a reservoir is located in a topographic setting where the wave or higher water resulting from displacement may be destructive to the dam or may cause serious downstream damage.

- Total freeboard allowances should include only those components of freeboard which can reasonably occur simultaneously for a particular water surface elevation. Components of freeboard and combinations of those components, which have a reasonable probability of simultaneous occurrence, are listed in the following paragraphs for estimating minimum, normal, and intermediate freeboards. The top of the dam should be established to accommodate the most critical combination of water surface and freeboard components from the following combinations.

For **minimum** freeboard combinations, the following components, when they can reasonably occur simultaneously, should be added to determine the total minimum freeboard requirement:

- Wind-generated wave runup and setup for a wind appropriate for the maximum reservoir stage for the IDF.

- Effects of possible malfunction of the spillway and/or outlet works during routing of the IDF.

- Settlement of embankment and foundation not included in crest camber.

- Landslide-generated waves and/or displacement of reservoir volume (only cases where landslides are triggered by the occurrence of higher water elevations and intense precipitation associated with the occurrence of the IDF).

For **normal** freeboard combinations, the most critical of the following two combinations of components should be used for determining normal freeboard requirements:

Combination 1 -

- Wind-generated wave runup and setup for maximum wind, and settlement of embankment and foundation not included in camber.
Combination 2 -

- Landslide-generated waves and/or displacement of reservoir volume, settlement of embankment and foundation not included in camber, and settlement of embankment and foundation or seiches as a result of the occurrence of the maximum credible earthquake.

For *intermediate* freeboard combinations, in special cases, a combination of intermediate winds and water surface between normal and maximum levels should be evaluated to determine whether this condition is critical. This may apply where there are exclusive flood control storage allocations.
Appendix A - References By Topic

Flood Studies


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Selecting and Accommodating Inflow Design Floods Studies


**Dam Failure/Dambreak Studies**


G. Soil Conservation Service, *Simplified Dam-Breach Routing Procedure*, (To be used only for flood routing technique, not dambreak discharge), March 1979.


Appendix B – Inflow Design Flood Selection Procedures

IDF SELECTION PROCEDURES: OVERVIEW

HOW IS THE IDF SELECTED?

The purpose of this Appendix is to describe the procedures used to select the appropriate inflow design flood (IDF) for a dam, and to determine the need for remedial action. These procedures are presented in two flowcharts. The first flowchart describes the steps needed to determine:

- If the probable maximum flood (PMF) was used in the original design of the dam.
- If the PMF or some lesser flood is the appropriate IDF.
- Whether remedial action at the dam is needed to enable it to safely accommodate the appropriate IDF.

To determine whether the PMD or some lesser flood is the appropriate IDF, it may be necessary to conduct an incremental hazard evaluation. This process is presented in the second flowchart.

Following each flowchart is a breakdown of the procedures. Each block is presented individually, and includes an explanation of the steps taken.
IDF SELECTION PROCEDURES: SELECTING THE APPROPRIATE IDF

INTRODUCTION

PROCEDURES FOR DETERMINING THE APPROPRIATE IDF AND THE NEED FOR REMEDIAL ACTION

Flowchart 1 presents a logical, step-by-step approach for evaluating the hydrologic design of an existing dam, and determining the appropriate IDF for the dam and whether remedial action is needed in order for the dam to safely accommodate the IDF.

Flowchart 1 is on the next page.
FLOWCHART 1 – PROCEDURES FOR DETERMINING THE APPROPRIATE INFLOW DESIGN FLOOD (IDF) AND THE NEED FOR REMEDIAL ACTION

1. Review the flood used for the original design.

2. Was the PMF used for the original design?
   - YES
   - NO

3. Is the original PMF methodology acceptable (including flood routing)?
   - YES
   - NO

4. Is the dam safe for the PMF?
   - YES
   - NO

5. Is the dam safe for the appropriate IDF?
   - YES
   - NO, OR
   - NOT APARENT

6. Conduct an incremental hazard evaluation to determine the appropriate IDF (See Flowchart 2).

7. Based on the incremental hazard evaluation, is the PMF the appropriate IDF?
   - YES
   - NO

8. Conduct a new PMF study and flood routing based on current criteria, as necessary.

9. Is the dam safe for the new PMF?
   - YES
   - NO

10. Remedial action is required for the dam to safely accommodate the new PMF.
    - STOP. No further action is required.

11. Remedial action is required for the dam to safely accommodate the appropriate IDF.

12. STOP. No further action is required.
EXPLANATION OF FLOWCHART 1 – An explanation of the IDF flowchart is presented below.

The initial step in selecting the appropriate IDF and determining the need for dam safety modification is to review the basis for the original hydrologic design of an existing dam. This information will provide valuable insight regarding whether the flood originally used for design purposes satisfies current criteria or whether detailed investigations and analyses will be required to determine the appropriate IDF for the dam.

In those situations where the original design information has been lost, detailed investigations and analyses will normally be required.

Once you have identified the basis for the original hydrologic design, the next step is to determine if the flood used for the original design is the probable maximum flood (PMF). This question is important, since the upper limit of the IDF is the PMF.

If your answer is YES, continue to Block 3.

If your answer is NO, go to Block 7. In Block 7 you will perform an incremental hazard evaluation to determine the appropriate IDF.

To ensure the reliability of the original PMF study or the assumptions made on the various parameters affecting the study, it is necessary to determine if the PMF methodology originally used is still acceptable under current criteria.

If your answer is YES, continue to Block 4.

If your answer is NO, go to Block 6. In Block 6, you will answer the question: Is the PMF the appropriate IDF?

Continued...
IDF SELECTION PROCEDURES: DETERMINING THE APPROPRIATE IDF

EXPLANATION OF FLOWCHART 1 (Continued)

Determine if the dam is safe for the PMF. Your answer to this question will indicate whether remedial action will be required.

If your answer is YES, continue to Block 5.

If your answer is NO, go to Block 6. In Block 6, you will answer the question:

Is the PMF the appropriate IDF?

If the PMF is considered to be the appropriate IDF for the dam, no further investigations or remedial work for hydrologic conditions will be required.

Continued...
IF...

In Block 3 you determined that the original PMF methodology is NOT acceptable,

OR...

In Block 4 you determined that the dam is NOT safe for the PMF,

THEN...

You need to determine if the PMF is the appropriate IDF.

In some cases, such as when the dam is totally submerged during the PMF, it may be obvious that the appropriate IDF is something less than the PMF. In other cases, it will not be apparent whether the IDF should be the PMF or something less. In these two cases, it will be necessary to perform an incremental hazard evaluation to determine the appropriate IDF for the dam. Continue to Block 7.

Sometimes, based on the size and volume of the dam and reservoir, the proximity of the dam to downstream communities, or even because of political decisions, it will be obvious that the IDF should be the PMF. If this is the case, a new PMF study will be required. Go to Block 9.

Continued…
IDF SELECTION PROCEDURES: DETERMINING THE APPROPRIATE IDF

EXPLANATION OF FLOWCHART 1 (Continued)

Block 7

IF...

In Block 2 you determined that the flood used in the original design is NOT the PMF,

OR...

In Block 6, you determined that it is obvious that the IDF should be less than the PMF or it is not apparent if the IDF should be the PMF or something less,

THEN...

You need to perform an incremental hazard evaluation to determine the appropriate IDF. Performing the incremental hazard evaluation involves:

Conducting dambreak sensitivity studies, reviewing incremental rises between with-failure and without-failure conditions for a range of flood inflows (see Flowchart 2), and

Selecting the appropriate IDF on the basis of the dambreak studies and incremental impacts on downstream areas.

A procedural flowchart for performing a hazard evaluation appears in Flowchart 2, followed by an explanation of the procedure.

Continued...
IDF SELECTION PROCEDURES: DETERMINING THE APPROPRIATE IDF

EXPLANATION OF FLOWCHART 1 (Continued)

Block 8

Based on the incremental hazard evaluation, is the PMF the appropriate IDF?

YES → Block 9

NO → Block 13

You should use the results of the incremental hazard evaluation and dambreak studies conducted in Block 7 to determine if the PMF is the appropriate IDF.

The IDF should be the PMF when the incremental consequences of failure are unacceptable, regardless of how large the assumed flood inflow becomes.

If your answer is YES, continue to Block 9.

If your answer is NO, go to Block 13. In Block 13 you will answer the question: Is the dam safe for the appropriate IDF?

Block 9

IF...

In Block 6 you determined that the PMF is obviously the appropriate IDF,

OR...

If, based on the incremental hazard evaluation conducted in Block 8, the PMF is the appropriate IDF,

THEN...

You should conduct a new PMF study and flood routing based on current criteria, unless it was determined in Block 3 that the original PMF is acceptable under current criteria.

Continued...
IDF SELECTION PROCEDURES: DETERMINING THE APPROPRIATE IDF

EXPLANATION OF FLOWCHART 1 (Continued)

Once the new PMF is calculated, you should determine if the dam is safe for the new PMF.

If the dam is SAFE for the new PMF no further investigations or remedial actions for hydrologic conditions are required.

If the dam is NOT SAFE for the new PMF, remedial action is required for the dam to safely accommodate the PMF.

IF...

In Block 8 you determined that the PMF is NOT the appropriate IDF,

THEN...

You need to determine if the dam is safe for the appropriate IDF.

If the dam is SAFE for the appropriate IDF, no further investigations or remedial action for hydrologic conditions are required.

If the dam is NOT SAFE for the appropriate IDF, remedial action is required for the dam to safely accommodate the appropriate IDF.

Depending on the type of remedial action considered, it may be necessary to reevaluate the IDF to ensure that the appropriate IDF has been selected for the design of any modification.
IDF SELECTION PROCEDURES: PERFORMING A HAZARD EVALUATION

INTRODUCTION

As stated previously, if the PMF was not used for the original design of a dam, or if the PMF is not the appropriate IDF, an incremental hazard evaluation must be performed to determine the appropriate IDF.

PROCEDURES FOR CONDUCTING AN INCREMENTAL HAZARD EVALUATION

Flowchart 2 shows the procedures for performing an incremental hazard evaluation. This flowchart is an expansion of Block 7 in Flowchart 1.

Flowchart 2 is on the next page.
FLOWCHART 2 – PROCEDURES FOR CONDUCTING AN INCREMENTAL HAZARD EVALUATION

1. Assume that the normal reservoir level with normal streamflow conditions prevailing is the initial failure condition.

2. Conduct dambreak analysis and route the dambreak flood downstream to the point where the flood no longer constitutes a threat.

3. Is the incremental increase in consequences due to failure acceptable?
   - NO
   - YES

4. Could a failure at a larger flood inflow result in unacceptable consequences?
   - YES
   - NOT SURE
   - NO

5. Select the appropriate IDF on the basis of dambreak studies and incremental impacts on downstream areas.

6. Assume a new (larger) flood inflow condition (up to the PMF, if necessary) as the new failure condition.

7. Continue with the procedures in Flowchart 1, beginning with Block 8.
EXPLANATION OF FLOWCHART 2 – An explanation of the Hazard Evaluation Flowchart is presented below.

Assume that the normal reservoir level with normal streamflow conditions prevailing is the initial failure condition. Starting at this point will ensure that the full range of flood inflow conditions will be investigated and will include the “sunny day” failure condition. It will also assist in verifying the initial hazard assigned to the dam. Using the normal maximum water surface level as the initial condition is particularly important if the initial hazard rating was low.

Next, conduct dambreak sensitivity studies (of various breach parameters) and route the dambreak flood to the point downstream where it no longer constitutes a threat to downstream life and property.

It is important to remember that the incremental increases should address the differences between the nonfailure condition with the dam remaining in place and the failure condition. Also, the dam should not be assumed to fail until the peak reservoir water surface elevation is attained for the assumed flood inflow condition being analyzed. Dams should be assumed to fail as described in these guidelines.

Continued…
Now, determine – if the additional increase in consequences due to failure is acceptable. Answering this question is critical in the incremental hazard evaluation, and doing so involves an estimate of loss of life and property with and without dam failure.

If the consequences of failure under the assumed floodflow condition are NOT ACCEPTABLE go to Block 4.

If the consequences of failure ARE ACCEPTABLE, continue to Block 5.

IF...

In Block 3 it was determined that the consequences of failure under the assumed floodflow conditions are NOT ACCEPTABLE, THEN...

Assume a new (larger) flood inflow condition (e.g., some percentage of the PMF) and perform a dambreak analysis (see Block 2). This procedure should be repeated until an acceptable level of flooding is identified, or the full PMF has been reached.

Continued...
IF...

In Block 3 you determined that the consequences of failure under the assumed floodflow conditions are ACCEPTABLE; i.e., failure of the dam under “sunny day” conditions was insignificant,

THEN...

Determine if failure at a larger flood inflow condition will result in unacceptable consequences. This question is very important. For example, situations exist where a failure during normal water surface conditions results in the flood wave being contained completely within the banks of a river and obviously would not cause a threat to life and property downstream. However, under some floodflow conditions, the natural river flows may go out-of-bank, and a failure on top of that flood condition will result in an additional threat to downstream life and property.

If failure at another flood level will result in UNACCEPTABLE additional incremental consequences, or if you are NOT SURE, return to Block 4. Assume larger flood inflow conditions and perform new dambreak studies. This procedure should be repeated to determine the acceptable level of flooding.

If failure at another flood level will NOT result in unacceptable consequences, continue to Block 6.

You should now select the appropriate IDF based on the results of dambreak studies and incremental impacts on downstream areas.

Continued ...
Explain the flowchart 2 (continued)

Continue this process with the steps in Flowchart 1, starting with Block 8. In Block 8 you will answer the question: Based on the incremental hazard evaluation, is the PMF the appropriate IDF?
IDF SELECTION PROCEDURES: SUMMARY

SUMMARY: INFLOW DESIGN FLOOD (IDF) SELECTION PROCEDURES

This Appendix described the procedures used to select the appropriate IDF for a dam and to determine the need for remedial action.

The steps involved to select the appropriate IDF for a dam were presented in Flowchart 1. If you determine that the PMF was used for the original design of the dam, and that the PMF is the appropriate IDF, further investigation or remedial action for hydrologic conditions is not necessary.

If you determine that the PMF was not used for the original design of the dam, or if the PMF was not the appropriate IDF, conduct an incremental hazard evaluation to determine the appropriate IDF. Flowchart 2 presented the procedures for conducting an incremental hazard evaluation.

Then, if it is determined that the dam is not safe for the new PMF or the appropriate IDF, remedial action must be taken.
FIGURE 1 – ILLUSTRATION OF INCREMENTAL INCREASE DUE TO DAM FAILURE

FIGURE 2 – ILLUSTRATION OF INCREMENTAL AREA FLOODED BY DAM FAILURE
FIGURE 3 – REGIONS COVERED BY PMP STUDIES

Note:
* HMR 58 to be Published in 1997
The purpose of this paper is to discuss the Federal Energy Regulatory Commission’s (Commission) current practice in evaluating the adequacy of the spillway capacity of hydroelectric projects under its jurisdiction, and to suggest areas where future research would be a benefit to these projects.

**Current Practice**

Regulations and Procedures

Since Order 122 was issued in 1981, the current practice of the Commission to ensure that the spillway capacity of all high and most significant hazard potential project is adequate has been governed by Sections 12.35(b) and 12.35(b)(1) of the Commission’s regulations, which are as follows:

12.35(b) *Evaluation of spillway adequacy*. The adequacy of any spillway must be evaluated by considering the hazard potential which would result from failure of the project works during flood flows.

12.35(b)(1) If structural failure would present a hazard to human life or cause significant property damage, the independent consultant must evaluate (i) the ability of the project works to withstand the loading or overtopping which may occur from a flood up to the probable maximum flood (PMF), or (ii) the capacity of spillways to prevent the reservoir from rising to an elevation that would endanger the project works.

The Commission’s regulations require that for all high hazard potential dams and most significant hazard potential dams, an independent consultant must inspect the project and evaluate its stability and spillway adequacy every five years. To give the Commission staff and the independent consultant guidance and criteria for this evaluation, the Commission developed the Engineering Guidelines for the Evaluation of Hydropower Projects.

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2 Lead Engineer, Federal Energy Regulatory Commission, Office of Energy Projects, Division of Dam Safety and Inspections, Chicago Regional Office.

3 Order 122 established the current regulations for independent consultants inspecting and evaluating projects on a five-year cycle.

4 Any significant hazard potential dam that is less than 32.8 feet high and impounds less than 2,000 acre-feet is not subject to this regulation.
For most projects, the first step for the independent consultant is to develop the PMF for the project and to evaluate the spillway capacity and stability of the project during the PMF. If the project can safely pass the PMF, then the spillway is adequate and no further studies are needed. If, however, the PMF exceeds the spillway capacity of the project, then the independent consultant is required to perform a dambreak analysis in accordance with Chapter 2 of our engineering guidelines, or the licensee may choose to modify the dam to safely pass the PMF.

If the dambreak analysis for all flood flows between the existing spillway capacity and the PMF show that the incremental increase in downstream flooding due to the failure is not a threat to downstream life or could cause significant property damage, then the spillway is adequate and no further studies are needed. However, this may need to be re-evaluated during future inspections if there are any changes downstream.

If there is a potential hazard to life or property downstream for these flood flows, then remedial measures are required to either increase the spillway capacity or increase the stability of the project structures to withstand the overtopping. Usually, an inflow design flood (IDF) analysis is done considering various alternatives for increasing the spillway capacity or the stability of the structures, and the IDF can vary depending on the type of fix. But once a fix is proposed for a flood less than the PMF, the license must demonstrate that the incremental increase in downstream flooding due to failure of the dam for all flood flows between the IDF and the PMF is not a threat to downstream life or could cause significant property damage.

In a few cases, a PMF study is not needed if the consultant can demonstrate through a dambreak analysis that either the spillway capacity is adequate or that the IDF will be considerably less than any estimates of the PMF. But in most cases, a PMF study is needed to establish the upper bound of the IDF.

Probable Maximum Flood Studies

Chapter 8 of the Commissions Engineering Guidelines, entitled, “Determination of the Probable Maximum Flood”, was first developed in 1993, and was recently revised in September 2001. The purpose of these guidelines is to provide systematic procedures that will consistently produce a reasonable PMF hydrograph and appropriate reservoir flood levels for evaluation of project safety, given the limitations of basic hydrologic and meteorological data. Although the guidelines give procedures and make recommendations for parameters, alternate procedures and parameters outside the recommended ranges can be used provided they are justified for the basin under study and supported with adequate documentation.

Runoff Model. This chapter recommends the use of the unit-hydrograph theory as the preferred runoff model. It also recommends that the Corps of Engineer’s HEC-1 or
HEC-HMS computer programs be used to model the runoff because of their widespread use and experience.

**Channel Routing.** Channel routing should be done using the Muskingum-Cunge method, which is incorporated into these computer models. However, any acceptable dynamic routing model such as the National Weather Service (NWS) DAMBRK computer program can be used instead if the consultant chooses to refine the model.

**Probable Maximum Precipitation (PMP).** The PMP should be developed from the latest NWS Hydrometeorological Reports (HMR). However, a licensee may choose to develop a site-specific PMP study, although this is usually very costly. This may be done if the basin under study (1) is not adequately covered by the HMRs, has unusual site conditions that may not be addressed by the HMRs, or can benefit from a refinement of the HMR PMP values. To conduct a site-specific PMP study, the Commission requires that a Commission-approved Board of Consultants consisting of at least a hydrologist, a meteorologist, and a hydrometeorologist review the study. As an example of an approved study, the Commission accepted the 1993 EPRI PMP study for the States of Wisconsin and Michigan, which resulted in PMP values as much as 15 percent lower than HMR No. 51. The 1993 EPRI study also refined the procedures in HMR 52 for developing the probable maximum storm from the PMP values. As a result, the PMF’s for many projects in these two States were reduced considerably, resulting in a significant cost savings to the licensee’s of these projects. Figure 8.8-1 of Chapter 8 shows the limitations of the latest HMRs and the 1993 EPRI study.

**Antecedent and Coincident Conditions.** Rather than route an antecedent storm through the model, this chapter recommends that the reservoir level be assumed at its annual maximum operating level and that saturated conditions exist in the entire basin at the onset of the PMP. Several alternatives for the starting reservoir level may be considered which would required an analysis of the historical records or routing of the 100-year 24-hour antecedent storm 3 days prior to the start of the PMP. In most cases, using the annual maximum operating level gives satisfactory results.

**Loss Rates** This subject received the most attention when Chapter 8 was recently revised. The preferred method is to use the uniform loss rate method. Consistent with the premise that saturated antecedent conditions exist in the basin prior to the start of the PMP, it is acceptable to assume the initial loss rate is set to zero.

The losses in a basin can be developed either by the area-weighted basin-averaging of the loss rates of the hydrologic soil groups, or by a distributed loss rate method. The basin-averaged method is the traditional method that has been used for many years, and simply involves computing the average loss rate based on the percentage of the four hydrologic soil groups. Chapter 8 recommends that the minimum loss rates from the National Resources Conservation Services (NRCS) 1955 Yearbook of Agriculture be used unless higher loss rates could be justified.
Instead of lumping the loss rates together in each basin, the distributed loss rate method divides each basin into pseudo subbasins corresponding to each loss rate class. The rainfall is then applied to each pseudo subbasin to determine the rainfall excess hyetographs. Then the rainfall excess hyetographs for all pseudo subbasins within a basin are summed to determine the rainfall excess hyetograph for that basin. These rainfall excess hyetographs are then input in HEC-1 with the loss rates set to zero for that basin. This method also works for larger basins that are subdivided into subbasins.

The distributed loss rate method was developed in the 1990’s primarily to address an inconsistency with the basin-average method. Our procedures allows you to calibrate loss rates based on 3 to 5 historical events that meet certain criteria. However, loss rates calibrated using the basin-average method were found to be storm specific, particularly for basins with spatially diverse characteristics. A basin with a calibrated average loss rate for a specific storm may actually have a significantly higher loss rate for the PMF since significantly more portions of the basin contribute to the runoff during the PMF than did during the specific storm.

The second reason this method was developed was to incorporate the availability of the digitalization of soil databases such as NRCS State Soil Geographic (STATSGO) database. The STATSGO database contains many properties of the soil for several layers up to 60 inches deep. One such property is the hydraulic conductivity, which is the rate of flow through saturated soil, normally given as a range of values. The Commission’s current criteria is to use the minimum value of the range for the least permeable layer, unless higher values can be justified through calibration or additional investigation of the geological make-up of the soils, the review of more detailed soils information such as county or local soils maps, or actual data obtained from any site investigations within the basin.

Dam Break Studies

Guidelines and Criteria

The Commission’s criteria for conducting dam break studies is discussed in Chapter 2 of the Engineering Guidelines. The NWS DAMBRK and FLDWAV computer programs are the recommended unsteady flow model computer programs that can be used to route the flow downstream of the dam. However, the Commission has accepted studies using other programs as well. The NWS SMPDBK program has been accepted in a few cases where the accuracy of the results is not as critical. In some cases, if a field reconnaissance shows that there are no structures downstream, a computer analysis is not necessary.

In general, the consequences are considered to be acceptable when the incremental increase in flooding on downstream structures due to dam failure is approximately 2.0 feet or less. However, the 2.0-foot increment is not an absolute
decision-making point. Sensitivity analyses and engineering judgment are required. For instance, inhabited trailers sitting on blocks can be moved with less than 2.0 feet of rise, and should be considered in this evaluation.

The Commission’s guidelines for breach parameters is given in Table 1 of Appendix A of Chapter 2. In general, the average breach width should be between 2 and 4 times the height of the dam for earth or rock fill dams, and one or more monoliths up to one-half the length of the dam for gravity dams. Failure times range from 0.1 to 1.0 hours for earth or rock fill dams, and from 0.1 to 0.3 hours for gravity dams. For arch dams, it’s appropriate to assume the entire dam fails in 0.1 hours or less.

Because of the uncertainty of breaches, the consultant should perform a sensitivity analysis of these parameters. For projects with large reservoirs, conservative breach parameters should be adopted since the rate of draw down of the reservoir during a breach is significantly slower than it is for projects with smaller reservoirs. In some cases, larger breach widths with longer failure times should be considered, such as for a long 20-foot high earth embankment that impounds a large storage reservoir.

**Common Modeling Problems**

1. Failure to model the entire reservoir. If dynamic routing of the reservoir instead of level pool routing is done, the consultant needs to make sure the cross-sections extend upstream of the reservoir to the point where backwater effects no longer exist. The shape of the cross-sections also needs to be examined to make sure all the storage between the cross-sections is accounted for. In some cases, the consultant extended the cross-sections only part way into the reservoir, effectively negating the storage upstream that could be released through a breach.

2. No sensitivity studies. Although the selected breach width may be at the conservative end of the accepted range given in our criteria, a larger breach width may result in a substantially higher incremental rise downstream. If the incremental rise is highly sensitive to the breach width, then this needs to be considered when selecting the breach width.

3. Improper use of the Manning’s n values. The NWS DAMBRK program requires the user to provide the composite Manning’s n values at each elevation. Therefore, for out-of-bank flood elevations the consultant needs to compute the composite Manning’s n value based on the weighted wetted perimeter. In many cases, the consultant will select too high of a Manning’s value for the out-of-bank elevations. Although not a major factor, this can effect the results in some analyses.

4. Improper spillway rating curve. In some cases, the reservoir was allowed to draw down during the beginning of the routing because the consultant did not
adjust the rating curve for when the gates are closed to maintain the normal pool level. In other cases, the consultant adjusted the rating curve to correct this, but the simulation then appeared as though the licensee closed all the gates instantaneously when the reservoir receded below the normal maximum pool after the breach developed.

5. The breach was assumed to initiate on the rising limb of the inflow hydrograph. It’s imperative that a non-failure case be run first so that the peak headwater elevation at the dam can be determined and used in the failure case. This becomes more complex when conducting a domino-type failure analysis of downstream dams.

**Research Needs**

The following items are research needs that should be considered:

**Probable Maximum Flood Studies**

1. PMP. Many of the HMR’s cover very large areas that don’t take into account local terrain affects that may reduce the PMP for that area. Other refinements can be done that could reduce the probable maximum storm such as the EPRI Wisconsin/Michigan study.

2. Snowmelt. The HMR’s in the western states have very approximate methods for combining snowmelt with the PMP. More research is needed in this area as it may be too conservative in some cases to combine 100-year snowpack with extreme temperatures, and the PMP.

3. Loss Rates. The changes in our guidelines point out the need for more research in using the distributed loss rate method with STATSGO data, particularly since the PMF can be very sensitive to the selected loss rates.

**Dam Break Studies.**


2. Computer models. Research is needed on ways the current computer models for unsteady flow can be made easier to use and more flexible to allow users to model more complex dams with multiple spillways.