



Safety of Dams: A Review of the Program of the U.S. Bureau of Reclamation for the Safety of Existing Dams (1977)

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Safety of Dams

A Review of the Program of the U.S. Bureau of Reclamation for the Safety of Existing Dams

A Report to
the U.S. Department of the Interior

Committee on the Safety of Dams
·Assembly of Engineering
National Research Council
1*

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1977

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In the wake of the Teton Dam disaster in eastern Idaho in June 1976 and the subsequent Congressional hearings and investigations and studies, the President, on April 23, 1977, issued a memorandum directing the head of each federal agency responsible for dams to undertake immediately a thorough review of the procedures and practices relating to dam safety. As part of this intense concern, the Secretary of the Interior requested the National Research Council to review the dam safety program of the Department of the Interior's Bureau of Reclamation.

The Bureau is responsible for some 330 water storage dams, including such notable concrete structures as the Hoover and Grand Coulee dams. By far, however, most of the Bureau's dams are earth-fill embankment structures, such as the Teton.

It was clear from the start of the National Research Council's study, by an ad hoc Committee on the Safety of Dams, that the cause of the Teton Dam failure was not at issue. That inquiry had been the subject of reports released in December 1976 by an independent review panel and in April 1977 by a U.S. Department of the Interior Review Group. The Committee's task was set out in a series of questions:

1. What are the elements of procedures and practices in the Bureau's safety program for operating and maintaining dams under its jurisdiction and how and by whom is this program organized and administered?
2. Based on briefings, documents, and data provided to the Committee and on the experience and judgment of its members, how good is the Bureau's dam safety program?
3. How well is the program carried out in practice?
4. What recommendations, if implemented by the Bureau, would improve the dam safety program?

In its assessment of the Bureau's procedures and practices, the Committee was specifically restricted to "existing" dams, a classification used by the agency to denote those dams that are in full operation. Therefore, the Committee did not consider such important matters

affecting dam safety as site selection, design, and construction. Because of the limitation of time in the conduct of this study, the Committee did not make any site visits to dams.

The study leading to this report was brief and intensive. Appointed in late June 1977, the Committee on the Safety of Dams held its first meeting July 7-8, 1977. During that meeting, staff of the Bureau of Reclamation presented an overview of the agency's program for dam safety and provided pertinent documents and reports to the Committee. The Committee requested additional information that was either furnished by mail or assembled for its meeting at the Bureau's Engineering and Research Center in Denver, Colorado, August 8-12, 1977.

At the Denver meeting, the Committee studied the information and discussed it and related concerns with Bureau personnel. During the final two days of the meeting, the Committee drafted the conclusions and recommendations.

The Committee is grateful to the Bureau personnel for their cooperation and assistance. Special thanks are due to Mr. William A. Wahler of W.A. Wahler and Associates who met with the Committee on August 8, 1977 to discuss results of the firm's contract with the Department of the Interior for investigating the safety of seven recently constructed Bureau dams.

Harl P. Aldrich, Jr.
Chairman

September 30, 1977

SUMMARY

BACKGROUND

Throughout history, dams have served mankind in many ways: to divert the flow of water into different channels, to produce power, to provide for better navigation and recreation, to store water for human consumption and crop irrigation, to control floods, avert erosion, and reduce silting. In recent years, the construction and operation of new dams has paralleled the increasing use of water resulting from population and industrial growth.

Every dam runs some risk of failure. Indeed, the rupture or collapse of dams is not uncommon. Such incidents generally result from inadequacies in site selection, design, or construction, as well as from such natural phenomena as floods and earthquakes. The havoc wreaked by dam failures depends upon the volume of water in the impoundment area, the topography downstream, and the extent of residential, commercial, industrial, and agricultural development in the shadow of the reservoir. In 1976 at least three catastrophic dam failures occurred in the world --with two of these in the United States, the Teton in Idaho and the Bear Wallow in North Carolina--and caused death and destruction in the path of their rushing waters. Such events have brought the subject of dam safety forcefully to public attention.

The Teton Dam disaster occurred on June 5, 1976, causing 11 deaths and at least \$400 million in damage. The dam failed while the reservoir was being filled for the first time. Since portions of the dam's works were still under construction, the structure was not considered by the Bureau to be in operation and maintenance status. Even so, the Teton was the agency's first major dam catastrophe in its 75 years.

After the failure, the U.S. Department of the Interior initiated a series of investigations and studies into the adequacy of dam safety activities of the Bureau. These studies concerned different aspects of the Bureau's dam program and emphasized (1) the explicit causes of the Teton failure, (2) the safety analyses of dams in a status of completion similar to that of Teton, (3) the dam design and construction procedures and practices throughout the Bureau and, (4) the safety programs explicitly directed at existing operating dams--that is, dams that have been transferred out of construction status and are fully

operated and maintained for water storage. The activities involved in the safety program for operating dams are the subject of this study. Neither the study nor this report has encompassed an evaluation of the full spectrum of dam safety. Nor have they attempted in any way to provide a retrospective analysis of the Teton failure.

THE BUREAU'S PROGRAM FOR THE SAFETY OF EXISTING DAMS

The U.S. Bureau of Reclamation is a major agency, within the Department of the Interior, responsible for the design, construction, and operation of dams in the western states. The Bureau is responsible for some 330 water storage dams, the majority of which were built with large earth-fill embankments.

There is not a single office or organizational entity responsible for all aspects of dam safety in the Bureau. Instead, responsibility is diffused throughout the agency from the Office of the Commissioner in Washington, D.C. and the Engineering and Research Center in Denver to the various field offices--e.g., the seven regional offices and their respective dam project offices. Maintenance and safety reviews of operational dams are coordinated by the Division of Water Operation and Maintenance at the Engineering and Research Center. The Bureau of Reclamation program for the safety of its existing dams presently includes a number of activities relating to the operation, maintenance, and safety reviews of dams under its jurisdiction. These activities include:

- Documented instructions. The Division of Design at the Engineering and Research Center prepares a Designers' Operating Criteria (DOC) manual and the regional offices prepare a Standing Operating Procedures (SOP) manual for each dam. Such manuals are used by operation and maintenance personnel in operating the facility. Both manuals are intended to provide instructions for emergency procedures in the event of floods and earthquakes that may imperil the dam. To date the Bureau has issued about 230 DOC manuals, not generally for the older dams, and about 80 SOP manuals for its storage dams. An additional 62 SOP manuals are in varying stages of draft.
- Routine maintenance and surveillance. Non-professional personnel generally provide day-to-day dam surveillance and report potential problems.

Only about half of the storage dams are instrumented to assist in monitoring structural safety. Project and regional office personnel collect the measurement data for transmittal to the Engineering and Research Center where it is evaluated by the Division of Design. Findings of the Division of Design are submitted to the regional directors and the Division of Water Operation and Maintenance at the Engineering and Research Center.

- Periodic on-site examinations. Under the Review of Maintenance Program periodic dam inspections supervised by the regional offices are held at intervals of two to three years. The program includes a periodic six-year inspection supervised by the Engineering and Research Center and involving personnel from the Division of Design and the regional and project offices. The overall program is coordinated by the Division of Water Operation and Maintenance. Deficiencies in the dams are reported and regional directors are responsible for taking remedial actions. The regional directors report to the Commissioner of Reclamation on the status of the corrective actions every six months until they are completed.
- Landslide surveillance. Under the Landslide Surveillance Program, regional geologists identify and annually inspect landslides that are considered potential threats to dam safety. A register of active landslides is maintained by the Engineering and Research Center and reported yearly to the Commissioner of Reclamation.
- Special on-site examinations. The Division of Design performs special examinations whenever problems are identified in routine surveillance or periodic examinations. Necessary corrective actions are handled in the same manner as under the Review of Maintenance Program.
- Examination of existing structures. The safety of older dams is evaluated through the Examination of Existing Structures Program initiated in 1965. The current examinations focus on the hydrological sufficiency and seismic stability of the dams. The Division of Water Operation and Maintenance is responsible for the program, but personnel from other divisions of the Engineering and Research

Center conduct the studies.

PRINCIPAL FINDINGS AND RECOMMENDATIONS

Responsibility for Dam Safety

The Committee finds that the Bureau of Reclamation does not have within it a specific organizational unit with complete responsibility for all activities related to dam safety. Responsibilities are so diffused throughout the agency that satisfactory execution is dependent upon informal cooperation and communication among the Bureau's staff.

- *The Committee recommends that the Bureau establish a dam safety office, independent of all the units of the agency and responsible directly to the Commissioner of Reclamation, to discharge the single function of dam and reservoir safety.*

Priority of Dam Safety

In view of the potential risks to human life, property, and productive capacity, the Bureau of Reclamation programs for the safety of existing dams have not been given a sufficiently high priority of funding, manpower, and work schedules. As in most organizations, manpower and funding are the fundamental constraints that limit how much can be accomplished. In this age in which the public expects scientists, engineers, and technologists to think of everything ahead of time, it is important to provide the tools to do the best job possible. Manpower and money are vital in making sure that the scope and emphasis of the Bureau's safety program are not circumscribed. Serious deficiencies that have been identified at some dams by Bureau personnel have not been corrected because the necessary authority and funding have not been provided.

- *The Committee recommends that Bureau management make certain that adequate funds and manpower are available to accomplish all essential elements of the dam safety program within the time frame established, including, most importantly, the correction of project deficiencies.*

Outside Engineering Services

In the past the Bureau has not engaged independent

experts to carry out its Examination of Existing Structures Program or any other activity related to the safety of existing dams. While the Committee recognizes the Bureau's desire to do the examinations in-house, realistic time limits should be established to complete special examinations and studies. Consideration should be given to using independent outside consulting services if available manpower is not sufficient to complete the work within the time limit. The use of outside services would have the additional advantage of providing independent reviews of original design criteria.

- *The Committee recommends that the Bureau extend the recently adopted policy to use independent consultants on future designs of major dams to encompass engineering evaluations for safety of existing dams.*

Project Documents

The Committee finds that manuals for Designers' Operating Criteria and Standing Operating Procedures have not been prepared for all major dams. The current absence of a Standing Operating Procedures manual for some projects is considered a deficiency.

- *The Committee recommends that the Bureau complete, on a reasonable schedule, the operating manuals for all its dams.*

Instrumentation

The Committee finds that the adequacy of the Bureau's current instrumentation program for dam safety is questionable. Instruments are not installed in all dams to assist in monitoring structural safety. Moreover, the Bureau has not evaluated the use of instruments to warn when the reservoir pool level reaches critical height. Indeed, the Bureau has not established priorities with respect to the need for instrumentation or for observation and evaluation.

- *The Committee recommends that field instrumentation, to monitor the behavior of dam structures and assist in safety evaluations, be installed as a requirement for all major dams. The Bureau should instrument the major concrete and embankment dams that presently lack such instrumentation.*

Review of Maintenance Program

The Committee considers the frequency of on-site inspections and examinations under the Review of Maintenance Program to be adequate, but the scope of the six-year inspection with respect to participation and technical assessment is inadequate.

- *The Committee recommends that, in order to obtain a thorough technical assessment, multidisciplinary teams perform the on-site examinations and that these examinations include reviews of design data, including stability analyses, construction and operating records, and a thorough inspection of project conditions.*

Landslide Surveillance

The Landslide Surveillance Program is an excellent concept, but it is not being carried out to the most useful extent possible in evaluating the safety at all projects. Five landslides have actually been analyzed, and it appears that the Engineering and Research Center's only involvement is to serve as a clearinghouse for incoming data sheets, and to act as an intermediary between the regional directors and the Commissioner's office. The current program receives too low a priority with respect to manpower and funds within the regions. This report outlines specific steps for improving the performance and objectives of the program.

- *The Committee recommends that the Landslide Surveillance Program be given higher priority and implemented to its full potential.*

Special Examinations

Based on the information provided, the Committee considers that special examinations are being performed competently by the Bureau using state-of-the-art procedures.

Examination of Existing Structures Program

To date, this program has consisted of evaluating the adequacies of spillway capacity and seismic stability and has not included other factors pertinent to safety, such as latent geologic conditions, deterioration of the facility, deficiencies in original design and construction.

Generally, state-of-practice technology is being applied to evaluate the safety of dams for the hazards of floods and earthquakes. The Bureau now gives inadequate attention to the safety of upstream dams, which, in the event of their failure, could endanger a Bureau dam.

- *The Committee recommends that a higher priority be given to the Examination of Existing Structures Program, particularly for the evaluation of dams in high risk locations. The Bureau also should give higher priority to the safety assessment of all dams located upstream of Bureau dams where failure would adversely affect the agency's dams. For this purpose, the Bureau needs to seek necessary authority and funding.*

Hydrology

The methodology and criteria used in determining spillway design floods are consistent with those generally used in current practice, and they are in close agreement with those in use by other comparable agencies. However, the Bureau's methodology does not provide a spectrum of possible design hydrographs representing various likely combinations of design assumptions and parameter values. Although Bureau personnel appear well informed on new methods based on mathematical modeling of the rainfall run-off process, they do not appear to be moving aggressively to test such methods and to assess objectively their value in Bureau applications.

With respect to hydrologic considerations, the current Examination of Existing Structures merely provides for computation of the spillway design flood. It does not, however, routinely provide for the analysis of possible downstream impacts likely to be caused by either catastrophic dam failures or successful passage of the spillway design flood, let alone more likely events such as the 50- or 100-year floods, whose occurrence are based on historical records. The Technical Analysis Section of the Dams Branch is in the process of developing computer programs for the computation of breach hydrographs and dynamic flood routing. The methods being used represent state-of-the-art procedures, and, when completed, the computations will be invaluable aids in the preparation of inundation maps.

- *The Committee recommends that the Bureau become more aggressive in developing, testing, and, where applicable, applying mathematical watershed models and establish closer liaison with government organizations such as the Corps of*

Engineers' Hydrologic Engineering Center and private firms that have expertise in this field. The methodology for spillway design flood should be modified in such a way that a spectrum of possible design hydrographs could be computed, representing various likely combinations of assumptions.

Seismology

The Bureau's procedure for selecting specific earthquakes and seismic design criteria used for stability evaluations is based primarily on a thorough and up-to-date review of available information. At present, little or no new geologic, seismologic, geophysical, or remote sensing data are being gathered in the field. While the Bureau's staff is familiar with state-of-the-art procedures, limitations of budget and personnel now preclude widespread application of appropriate methods.

- *The Committee recommends that the Bureau obtain more complete geologic and seismological data for estimating maximum credible earthquakes and potential for surface faulting of dams in regions of moderate to high seismic activity.*

Emergency Preparedness

The Committee finds that while operating criteria and procedures for Bureau dams provide instructions for dealing with flood emergencies and other unusual events, the agency's emergency preparedness programs, especially for dams with high hazard potential, are inadequate. Deficiencies include inadequate instructions and training of Bureau and water user personnel, insufficient coordination with, and education of, civil defense and community leaders, and lack of inundation maps and suitable alarm systems.

- *The Committee recommends that the Bureau establish a more effective emergency preparedness program. Project operating personnel should receive more extensive training on emergency procedures, and there should be better coordination between operating personnel and authorities downstream regarding emergency warnings. Also, inundation maps should be prepared for dams whose failure would endanger lives or damage property.*

Engineering Geology

Extremely important factors that should receive close review in a dam safety evaluation include a number of geologic conditions which are best examined by personnel trained in engineering geology. Engineering and Research Center geologists have not participated in the six-year examinations and generally have not played a significant role in dam safety activities. The Committee believes that organizational change could improve and strengthen the Bureau's capabilities in engineering geology.

- *The Committee recommends that the Bureau consider such organizational changes at the Engineering and Research Center that would be required to strengthen the role and responsibility of engineering geologists.*

Risk-Based Analyses

The Committee considers that risk-based analysis is important in improving dam safety programs because it provides a more rational basis for determining priorities in (1) frequency and intensity of inspections, (2) investigations and examinations, (3) correction of deficiencies, (4) allocations of funds, and (5) emergency preparedness.

The Bureau has not implemented a risk analysis based program to determine potential risks and hazards due to failure of major dams

- *The Committee recommends that the Bureau implement a probabilistic or risk analysis based program for the purpose of ranking existing Bureau dams in accordance with risk, as based on hazard potential and the probability of a failure.*

OBSERVATIONS

The Committee observes that many of the recommendations in this report have already been considered useful by the Bureau, but budgetary limitations and other constraints have prevented the agency from putting them into practice. The Committee appreciates that the adoption of such procedures and practices depend largely upon the availability of money and manpower and upon program priorities in the Bureau. A necessary next step is that the recommendations in this report be evaluated in light of the objectives of dam safety, the anticipated costs, and the prospective benefits.

I. INTRODUCTION

1.1 PURPOSE AND SCOPE

On June 5, 1976, the Teton Dam in eastern Idaho collapsed while its reservoir was being filled for the first time. In the aftermath, the U.S. Department of the Interior and others initiated several investigations and studies intended to determine the cause of the failure and to minimize the risk of another dam failure. This report results from one such study.

The National Research Council organized the Committee on the Safety of Dams at the request of the Department of the Interior to provide assistance to the Department in the examination of Bureau of Reclamation activities for ensuring the safety of existing dams. In the context of the Department's request and the Committee's study, "existing" dams mean structures that are completed and transferred out of the construction phase into an operational and maintenance status. This report, therefore, does not concern Teton Dam, because construction had not been completed when the structure collapsed and, at the time of the disaster, it had not been placed under the existing dams safety program.

This report presents the findings, conclusions, and recommendations of the Committee on the Safety of Dams.

1.2 METHODOLOGY OF THE REVIEW

1.2.1 The Review Plan

The Committee on the Safety of Dams planned a brief and intensive review. It scheduled a two-day meeting in Washington, D.C., on July 7-8, 1977, to initiate the effort and a workshop in Denver from August 8-12, 1977, to examine in depth the Bureau's dam safety activities. The Committee prepared for the Denver meeting by reviewing selected documents and reports which were furnished at the Washington, D.C. meeting and also by mail. At the Denver workshop, the Bureau provided additional material which had been requested by the Committee.

1.2.2 Initiation of the Review

At the July 7-8, 1977 meeting in Washington, D.C., the Committee completed plans for its review and gained preliminary insight into the Bureau of Reclamation's safety activities for existing dams. The Chief of the Bureau's Division of Water Operation and Maintenance met with the Committee to present an overview of the Bureau's safety program. His presentation helped the Committee identify the various organizational responsibilities within the Bureau and the capabilities and coordination requirements of the units and program elements involved in dam safety.

From the presentation, the Committee learned that no single organizational unit is responsible for dam safety and that it would be necessary for the Committee to review a number of program elements, primarily within the Division of Water Operation and Maintenance at the Bureau's Engineering and Research Center in Denver.

The Committee next began to list the kinds of information considered necessary to gain a comprehensive view of all of the Bureau's dam safety activities. Such material was furnished to Committee members either by mail prior to the Denver workshop or made available at the workshop.

In general, the information reviewed by the Committee prior to and during the workshop focused on the Engineering and Research Center's Examination of Existing Structures Program, Review of Maintenance Program, Landslide Surveillance Program, Instrumentation Program, and the Special Examinations Program. Sample copies of Standing Operating Procedures manuals were included in the items presented to the Committee. Because the Division of Design also becomes involved in the safety of existing structures, it was necessary for the Committee to become familiar with that Division's role and the Designers' Operating Criteria manuals prepared by the Division.

1.2.3 The Denver Workshop

The final method used by the Committee as a means of gaining insight into the Bureau's activities was interviewing personnel at the Engineering and Research Center during August 8-12. The discussions concerned specific activities in the Bureau's dam safety program regarding managerial and technical aspects. These included subjects such as seismology, landslide surveillance, hydrology, dam inspections, instrumentation, and emergency preparedness.

From the above information, the Committee gained insight into dam safety as practiced by the Bureau, and the Committee's comprehension of those activities and comments upon them are presented in Chapter IV. The Committee also developed a basis upon which to evaluate and critique its understanding of the Bureau's programs, and that background is presented in Chapter III. From that basis, the Committee drew conclusions and made the recommendations presented in Chapter V. The emphasis throughout the report is upon existing large dams with high hazard potential, as is characteristic of most dams under the jurisdiction of the Bureau of Reclamation.

II. BACKGROUND

2.1 THE DAM SAFETY PROBLEM

2.1.1 Teton Dam Failure

The failure of the Teton Dam resulted in the death of 11 persons, caused an estimated \$400 million in property damage, and disrupted the lives of thousands of people in the downstream river basin. It occurred during the first filling of the reservoir.

The Bureau of Reclamation of the U.S. Department of the Interior designed and owned Teton Dam, a multipurpose project embodying irrigation, flood control, and power. The dam was 305 feet high above the riverbed and impounded about 240,000 acre-feet of water at failure. It was the highest dam to have failed within the United States. The catastrophic failure of a structure engineered and supervised by a highly respected and experienced federal dam building agency attracted worldwide attention. Understandably, the Congress, executive departments, the public, and the press demanded to know the reasons for the Teton failure and to institute whatever was considered necessary to avert similar disasters in the future.

2.1.2 Federal Legislation

The Teton disaster was the first catastrophic failure of a dam built by a major federal water resource development agency, and it introduced for the first time a question as to the engineering competence of such agencies' dam safety practices and procedures. Earlier tragedies such as the collapse of two nonfederal dams, the Buffalo Creek coal waste embankment in West Virginia and the Rapid City Dam in South Dakota, both occurring in 1972, led to the passage of federal dam safety legislation.

The Dam Inspection Act (PL 92-367), signed into law August 8, 1972, authorized the Secretary of the Army, through the Chief of Engineers, to initiate a national program of safety inspections of dams. Under this authority the Corps of Engineers has: (1) compiled data for an

inventory of federal and nonfederal dams; (2) conducted a survey of each state and federal agency's capabilities, practices, and regulations regarding the design, construction, operation, and maintenance of dams; (3) developed guidelines for safety inspections and evaluation of dams; and (4) formulated recommendations for a comprehensive national dam safety program. The Assistant Secretary of the Army (Civil Works) forwarded the report on these activities¹ to the Congress on November 16, 1976.

The Corps of Engineers' inventory identified about 49,000 dams within the United States that are 25 feet or more in height or have a maximum impounding capacity of at least 50 acre-feet of water. The report revealed that only about 18 percent of such dams had been inspected under existing state or federal authority and that about 20,000 dams are located in areas where their failure could cause loss of life and damage to homes, buildings, public utilities, highways, and/or railroads.

2.1.3 Involvement of Professional Groups

Prior to the national awareness which led to the enactment of PL 92-367, the professional engineering community was concerned with the need for improved dam safety procedures. Following the 1959 failure of the Malpasset Dam in France, the 1963 disaster at Viaoant Dam in Italy due to a landslide, and the 1963 Baldwin Hills Dam failure in California, the United States Committee on Large Dams (USCOLD) undertook a survey of state practices and regulations controlling the design and construction of dams in the United States. Disturbed by the survey's finding of many instances where adequate supervision of dams was lacking, USCOLD drafted a Model Law² in 1970 for state supervision of dams and reservoirs. USCOLD furnished copies of the Model Law to the governors and appropriate officials in all 50 states. The Model Law outlines requirements for the safety supervision of dams and reservoirs in all stages of design, construction, operation, maintenance, enlargement, modification, and removal or abandonment.

In 1964, the International Commission on Large Dams (ICOLD), the parent organization of USCOLD, undertook a study of known dam failures and incidents arising from the foundations of large dams. In 1965, ICOLD modified the study to include all failures and accidents to large dams-- large dams being defined as any dam higher than 45 feet. In 1974 ICOLD published the data collected on incidents occurring prior to December 31, 1965, in a book titled "Lessons from Dam Incidents."³ A new effort by ICOLD is now underway to update the data to include all incidents to June 30, 1976.

The American Society of Civil Engineers and USCOLD jointly published data on dam incidents in the United States up to December 31, 1972, in a publication titled "Lessons from Dam Incidents, USA," 1975.⁴ Recently, USCOLD collected and reported to ICOLD the data on incidents from December 31, 1972 to June 30, 1976. To date, these data have not been published.

In 1970, ICOLD undertook a study of "Risks to Third Parties from Large Dams."⁵ The objectives were to identify factors concerned with the world insurance market and to review risk areas and levels of design, construction, maintenance, and operation of dams. The report on this activity outlines main risk areas associated with dams, procedures for minimizing risks, and the levels of supervision and control to be adopted during construction and operation in order to maximize safety of dams.

Since the enactment of the Dam Inspection Act of 1972, four national conferences on dam safety have been sponsored by the Engineering Foundation. These were: (1) the September 1973 Asilomar Conference on "Inspection, Maintenance and Rehabilitation of Old Dams,"⁶ (2) the August 1974 Henniker, N.H. Conference on "Safety of Small Dams,"⁷ (3) the September 1975 Asilomar Conference on "Legal Aspects of Dam Safety,"⁸ and (4) the November 1976 Asilomar Conference on "The Evaluation of Dam Safety."⁹

2.2 DAMS OF THE U.S. BUREAU OF RECLAMATION

The Reclamation Act of 1902 (43 USC 371 et seq.) authorized the Secretary of the Interior to plan, build, operate, and maintain water projects designed to reclaim arid and semi-arid lands in the 17 western states. The Secretary performs this function through the Bureau of Reclamation which consists of the Office of the Commissioner in Washington, D.C., the Engineering and Research Center in Denver, seven regions, and project and other operating offices within the seven regions. The Bureau of Reclamation presently supervises 330 storage dams and 145 diversion dams. Water user organizations operate and maintain about half of these dams, however, the Bureau retains responsibility for the projects, including safety surveillance, and can require that repairs and modifications be made if deemed necessary. The Bureau operates and maintains dams other than those of the water users with assigned Bureau personnel under the jurisdiction of the regional directors.

2.3 OTHER ACTIVITIES PRECIPITATED BY THE TETON DISASTER

In addition to the review which is the subject of this report, the Teton Dam failure was responsible for the initiation of a number of other studies which consisted of Congressional and engineering investigations into the Teton Dam failure, reviews of Bureau of Reclamation procedures and practices pertinent to dam safety, and other reviews pertaining to the procedures of all federal dam building activities. Of particular interest with respect to the effort of the Committee on the Safety of Dams are the reviews discussed in paragraphs 4.1, 4.3 and 4.4 of Appendix A.

A non-technical review of Bureau procedures (paragraph 4.1, Appendix A) was concerned with management procedures that affect dam safety and compared Bureau procedures with those of the Corps of Engineers and the Tennessee Valley Authority. This study produced no recommendation for changes in present Bureau management procedures.

An in-house review of technical procedures and practices affecting dam safety (paragraph 4.3, Appendix A) was completed by mid-August 1977 and included a broad review of activities throughout the planning, design, construction and operation stages. The portion of this effort relating to the operation stage concerns the safety of existing dams and, therefore, overlaps the review by the NRC Committee on Dam Safety. The Committee on Dam Safety did not review the findings of this in-house effort in order that it could develop an assessment completely independent of the Bureau's.

The Secretary of the Interior also plans an in-depth review of Bureau of Reclamation Technical procedures by an independent engineering firm (paragraph 4.4, Appendix A). The review will encompass the safety of existing dams but is not expected to be available prior to late 1978.

III. ELEMENTS OF A SAFETY PROGRAM FOR EXISTING DAMS

3.1 PURPOSE

In order to provide a basis upon which to compare the adequacy of the safety program for existing dams of the Bureau of Reclamation, the Committee on the Safety of Dams established basic concepts for any dam safety program and these are outlined in this Chapter. It should be noted that the recommended establishment of an independent dam safety office conforms in principle to the Model Law for State Supervision of Dams and Reservoirs prepared by the United States Committee on Large Dams.²

3.2 BASIC PRINCIPLES

- All dams are founded on natural materials, exposed to the natural environment, and are designed and operated by humans and, therefore, are subject to a non-zero probability of failure. The reductions in probability of failure and in the consequences, with respect to life and property should failure occur, are the principal objectives of a dam safety program.

- Safety measures and actions should be chosen so as to achieve optimum benefits consistent with good engineering practice, social values regarding loss of life and property, and environmental improvement. Future losses due to dam failure depend on the hazard potential as well as on the probability of failure. The hazard potential refers to the sum of the potential losses in the event of failure; that is, human lives and injuries, property losses, environmental damage, and loss of function of the reservoir.

- All dams require competent surveillance and evaluation for safety. Surveillance consists of the procurement of information by visual inspection and appropriate instrumentation. Technical procedures and approaches relative to safety evaluations should not be inflexible. The procedures and approaches should be systematic and thorough, recognizing the uniqueness of each dam and reservoir. Flexibility should be practiced in adapting advanced state-of-the-art analytical techniques,

and there should be a minimum of rules and standards that restrict the application of professional judgment.

- In determining the priority for inspection, analysis, or upgrading of existing dams, some plan of risk analysis or hazard classification should be used to assist the judgment and experience of professionals. Also, information about the relative frequency of dam failures attributed to various causes (e.g., foundation, hydrology, earthquakes, etc.), which is available from ICOLD and USCOLD reports,³⁻⁵ should be used in establishing priorities in a dam safety program.

- Liability for losses resulting from failure or the operation of dams and reservoirs resides with the owner and not with any independent safety review and approval entity. "Owner" includes those identified in the USCOLD Model Law,² Section 1005, but in the context of this report does not exclude the United States government or any of its agencies.

- Dam owners should provide for familiarization of operating personnel with design requirements and proper operating procedures for dams and reservoirs under their control, and should recruit and train competent staff to execute programs in accordance with proper procedures.

- The dam owner or proponent should make specific assignment to a responsible and qualified staff individual to assure coordination of all matters relating to dam and reservoir safety. This responsible person would provide strong continuity through all phases of project development from planning into operational status.

- Within any state or major owner organization there should be an independent organization for dam and reservoir safety to review and approve, as pertains to safety only, designs, plans and specifications, construction procedures, and operating procedures, whether such are developed and performed by or for the owner.

3.3 INDEPENDENT DAM SAFETY ORGANIZATION

An independent dam safety office should discharge the single responsibility of dam and reservoir safety in the public interest. The purpose of the office should be to safeguard the public in its life and property from the failure of dams and reservoirs. The office should have clearly stated authority, responsibility, and accountability to make or otherwise obtain findings and reports on the safety of dams and reservoirs under its jurisdiction.

The authority of the office should extend to the use of police power in the case of state jurisdictions and, in the case of federal intra-agency affairs, it should carry that force and effect.

The full scope of responsibility of the office should extend to review and approval of plans and specifications for construction, construction supervision for reasons of dam safety, inspection and evaluation of existing dams, and issuance of certificates of approval for the operation of dams and reservoirs. For the purpose of enabling it to make decisions as compatible with economy and public safety as possible, the office should make, or cause to be made by the owner, such investigations, data collection, and studies as may be needed for proper review and evaluation of the dam and reservoir.

The dam safety office should have an oversight role and be independent from all other organizational units. It should report directly to the highest officer of the total organization, and should be free to make findings on the basis of safety alone without being constrained by economic factors or owner influences. It should be free of having to determine remedies for problems revealed in its findings.

The office should be staffed by persons of recognized competence and professional recognition, and staff training should be performed routinely to improve professional skills and to keep in the forefront of emergent concepts.

Functions of the office should include the following:

(1) Review the agency system of ranking of existing dams, using risk analysis or hazard classification concepts, so that priority attention will be focused on the most critical dams and reservoirs.

(2) Analyze and interpret independently and expeditiously, or have analyzed and interpreted, all performance data on existing dams.

(3) Monitor a program of comprehensive inspections and evaluations of each existing dam and reservoir on not longer than a five or six-year cycle, with intervening inspections and evaluations as appropriate.

(4) Review for the purpose of approval all reports of safety evaluations and forward results to the highest authority immediately. Also, within the federal agencies, distribute such reports to all organizational units responsible for project facilities.

(5) Issue a certificate of approval for operation, as to safety, containing such terms and conditions as it may prescribe for each dam and reservoir under its jurisdiction. Furthermore, the office should revoke, suspend, or amend the terms and conditions of any certificate of approval whenever it determines that a dam or reservoir constitutes a danger to life and property.

(6) Review contingency plans, for the purpose of approval, to communicate emergency warnings to local officials in the event of major incidents compromising the safety of dams and reservoirs under its jurisdiction.

(7) Observe and be informed of all aspects of the dam and reservoir performance during first filling.

The office should have an explicit policy to retain independent consultants to provide the diversity of judgment, knowledge, and expertise which are essential to the design, construction, and maintenance of dams. (An "independent consultant" is an expert not on the permanent staff of the agency.) Consultants may not necessarily be required in all cases, but they can make valuable contributions, particularly for exceptional problems and where unusual conditions exist or develop. The use of consultants by the office should not be impaired by the owner having otherwise retained consultants on the same project.

3.4 EVALUATION OF EXISTING DAMS

A system of ranking all dams and reservoirs in terms of hazard potential and physical characteristics should be established and updated periodically so that priority attention can be given to the most critical projects.

Initial evaluations of existing dams should include the review of records, field inspections, and appropriate supplemental investigations. Provision should be made for reanalysis and study of hydrology, hydraulics, geology, seismology, seepage, monitoring systems, structural stability, rehabilitation performed, maintenance history, and any other appropriate subject matter pertinent to a comprehensive evaluation.

Subsequent evaluations of existing dams should be based on surveillance and instrumental records to detect changes and rates of changes. New analyses should be made when deemed appropriate by performance data or changes in operating requirements.

3.5 EMERGENCY PREPAREDNESS

An emergency preparedness plan should be prepared for dams and reservoirs. The plan should include monitoring instruments, communication and warning systems, inundation mapping for the presumption of catastrophic failure, operator training for emergency responses, and prearranged notification procedures to local police or civil defense officials.

The dam safety office should review and approve these contingency plans for emergency preparedness.

IV. BUREAU OF RECLAMATION DAM SAFETY PROGRAM

4.1 SUMMARY OF PROGRAM

The Bureau of Reclamation program for the safety of its existing dams presently includes a number of activities relating to the operation, maintenance and safety reviews of dams under its jurisdiction. These activities include:

(1) Preparation and updating of documented instructions for the operation and maintenance of each dam, including emergency preparedness procedures.

(2) Routine maintenance and surveillance of dam behavior including day-to-day observations and periodic reading, reporting and evaluation of field instrumentation.

(3) Periodic on-site examinations and evaluations of each dam by personnel assigned to the project and regional office, and by representatives of the water user and personnel from the Engineering and Research Center.

(4) Identification and surveillance of potential landslides which are deemed hazardous to dam safety or to persons and property in the landslide area.

(5) Special on-site examinations when unusual events occur or when a potential problem is revealed by visual observation or instrumentation.

(6) Evaluations of existing dams, primarily the older structures, for which new information, technology, or occurrences relative to hydrologic, seismic, or structural conditions indicate possible deficiencies significant to safety. This activity includes the detection and reporting of conditions of upstream dams belonging to others which may pose a hazard to Bureau of Reclamation structures.

Prior to 1948, the Bureau's maintenance and safety activities were primarily the responsibility of project staffs in local offices. In 1948, a formal Review of Maintenance Program was implemented to provide a coordinated and comprehensive program of on-site examinations. More recently, the Bureau initiated other activities concerned

with safety, including a formal Landslide Surveillance Program and an Examination of Existing Structures Program. The latter provides for the introduction of new technologies into the evaluation of older dams.

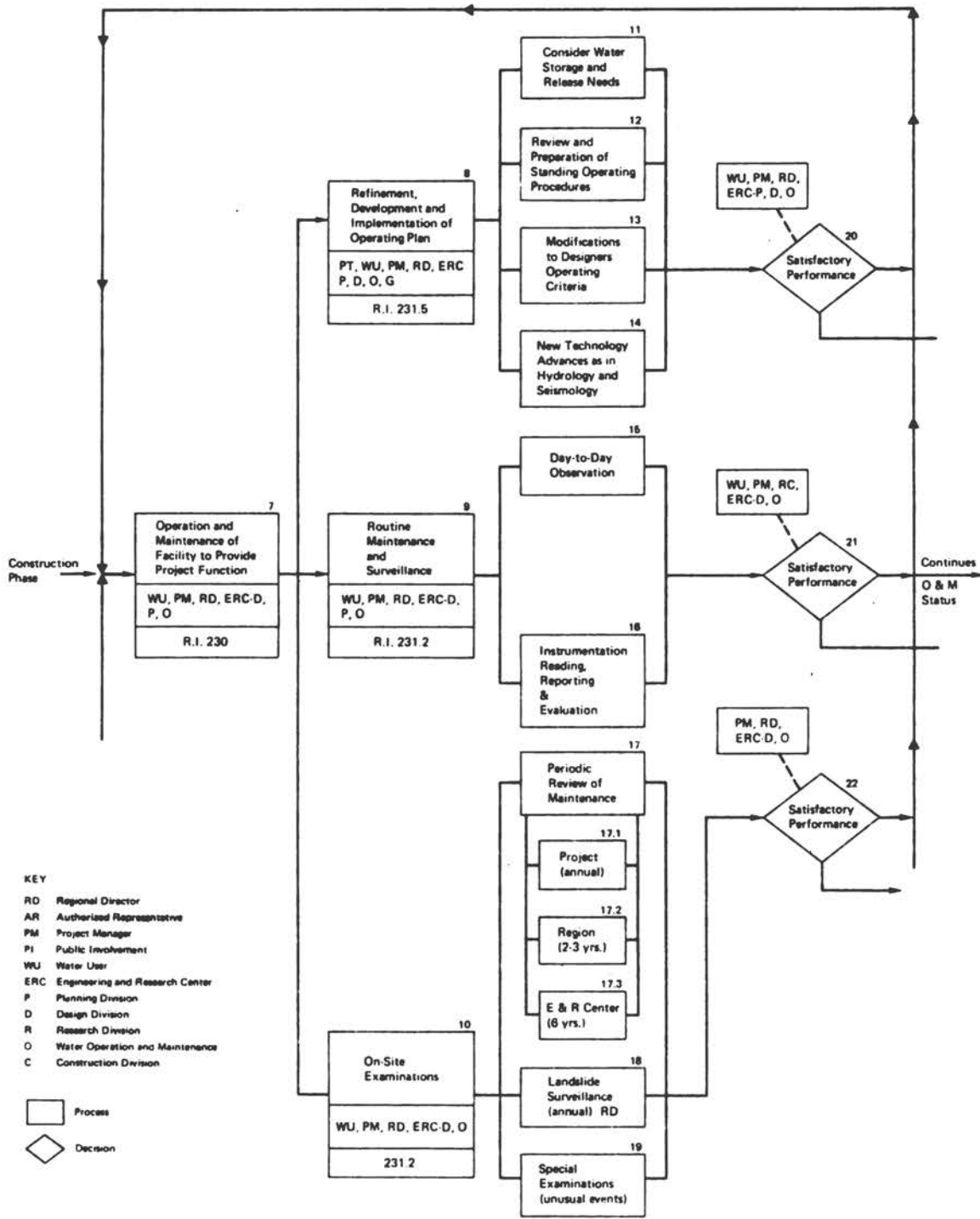
Figure 1 outlines the Bureau's Operations and Maintenance procedures and safety programs for dams after the completion of project construction. Activities related to dam safety fall in boxes 12 through 19. This chapter of the report discusses each of these major activities as well as their management and comments on the roles of Engineering Geology and Risk Analysis.

COMMENTS

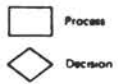
The overall Bureau program for ensuring the continued safety of existing dams is generally good. The program compares favorably with programs of other federal and state dam building agencies, based on the Committee's knowledge of these programs. The components of the program are generally well conceived and appear to be carried out generally in accordance with state-of-the-art criteria and practices by competent personnel.

In its 75-year history during which the Bureau has designed and constructed about 475 storage and diversion dams, it has never experienced a catastrophic failure prior to the Teton Dam disaster in June, 1976. Since the Teton failure occurred during the first filling of the reservoir, prior to the time the dam was to have been transferred to the Division of Water Operation and Maintenance, it was not included in the Bureau dam safety program which falls under the scope of this Committee's review. In effect, the Bureau has a perfect record in its safety of existing dams program. This record speaks for itself. Nevertheless, the Committee believes the safety program must be improved in the interest of preventing future failures and to protect the public.

Deficiencies exist in the program, primarily in its organization and management, which the Committee identifies and discusses in the applicable sections of this Chapter.



- KEY
- RD Regional Director
 - AR Authorized Representative
 - PM Project Manager
 - PI Public Involvement
 - WU Water User
 - ERC Engineering and Research Center
 - P Planning Division
 - D Design Division
 - R Research Division
 - O Water Operation and Maintenance
 - C Construction Division



*Flow Chart for Operation and Maintenance Procedures for Bureau of Reclamation Dams

* Adapted from "Review of the Bureau of Reclamation's Dam Building Procedures" 16

4.2 ORGANIZATION AND MANAGEMENT

The Bureau of Reclamation does not have a distinct and separate organizational unit having complete responsibility for all activities related to the safety of dams. While the primary responsibility for the Review of Maintenance Program and the Examination of Existing Structures Program falls within the Division of Water Operation and Maintenance at the Engineering and Research Center in Denver, the responsibility for some elements of these programs and for other safety-related programs are shared with seven regional offices, with numerous project offices and water users, and with other divisions at the Engineering and Research Center. The extent to which personnel from regional and project offices and from various divisions at the Engineering and Research Center participate in the Bureau dam safety programs is identified in Figure 1.

Furthermore, within the Bureau there is a division of responsibility involving administrative and technical control of construction personnel between the regions and the Engineering and Research Center.

Present Bureau policy is covered in Chapters 231.2 of the Reclamation-Instructions¹⁰ which establishes the responsibility, requirements for examinations and reporting procedures.

4.2.1 Operating Organization

After assuming responsibility for care, operation, and maintenance of completed project works, the operating organization, whether the Bureau or a water user, is responsible under regional supervision for the day-to-day observance of structures and their performance. Under ordinary circumstances, the Bureau or water user also is responsible for the correction of or arrangements necessary for the correction of observed structural or operational deficiencies. The operating organizations are responsible for the collection and transmittal of data from installed performance instruments, although regional office assistance is furnished as required.

4.2.2 Regional Office

The regional office prepares and maintains the Standing Operating Procedures manual, performs landslide surveillance and participates in periodic examinations under the Review of Maintenance Program. Regional Directors are responsible for the initiation of actions to correct identified deficiencies.

4.2.3 Division of Design

The Division of Design in the Engineering and Research Center, in addition to its general design function, is responsible for the preparation of Designers' Operating Criteria (DOC) manuals issue instructions for operating project facilities in a manner required to meet conditions for which they were planned. Section 4.3.1 further discusses the DOC manuals.

The Division of Design also is responsible for the development of instrumentation for Bureau structures, for the installation of the structural behavior analysis instruments, and the interpretation of data both during and after the construction period.

Personnel from the Division of Design represent the Engineering and Research Center on field reviews of major structures and facilities under the Review of Maintenance Program. The Division of Design maintains lists of the dams in or on which performance instruments have been placed, the type of instrumentation, and general remarks concerning data obtained. The branches of the Division of Design responsible for the development of design criteria currently review and maintain the field instrument data.

The Division of Design also makes dam safety studies and recommends corrective action under the Examination of Existing Structures Program and under Special Examinations activities.

4.2.4 Division of Water Operation and Maintenance

The Division of Water Operation and Maintenance is responsible for the coordination of maintenance programs; monitoring the collection, processing, and evaluation of data; examination activities; and steps taken to inform the Regional Directors and Commissioner of the development of any unusual conditions or deficiencies. The Division also conducts periodic Bureau-wide followups to ascertain that repairs and improvements recommended by the Review of Maintenance examiners are being carried out.

The Division prepares budget documents, controls appropriated funds and has coordination and general management responsibility for dam safety investigations.

COMMENTS

Responsibility for dam safety is diffused throughout the organizational structure of the Bureau. Although safety activities for existing dams appear to be executed satisfactorily, largely through cooperation and informal communication within the entire Bureau organization, the Committee considers the lack of an independent safety office a significant deficiency.

The problems of operating dams are minimized by providing the best quality of construction so as to translate design into the most safe and competent results possible. To that end there should be complete single-source administration and technical control of both design and construction personnel to achieve strong dam development, continuity and coordination. On each dam project specific assignment should be made to a qualified staff person to provide responsible coordination in order to better assure accountability for construction of safe structures to be transferred to Operation and Maintenance. Such delegation of responsibility would provide continuity of safety surveillance through the critical period of first filling when often, as in the case of Teton Dam, construction has not been completed and the project not yet transferred to the Operation and Maintenance Program.

In view of the high risks involved, the Bureau of Reclamation activities for the safety of existing dams have not been given a sufficiently high priority in terms of funding, manpower and scheduling. Considering the importance of upgrading surveillance programs and obtaining knowledge about operating dams, management should assure that adequate funds are available to accomplish all essential elements within the time frame established.

Important project deficiencies which have been identified by the Bureau in some dams have not been corrected because of lack of the necessary authority and funding. Although some funds are available for emergency situations, the Bureau does not have authority or funds under existing laws to

make major modifications to dams which are deemed unsafe. Unless the remedial work required is minor and can be accomplished with Operations and Maintenance funds, reports must be prepared for submittal to Congress to obtain the necessary authority and funding.

Unlike other Governmental organizations responsible for the design, construction, and maintenance of dams, the Bureau of Reclamation prior to 1977 did not use independent consultants, except in special cases, to participate on consulting boards, to perform dam design services and reviews, or to conduct inspections and evaluations concerned with the safety of existing dams. The Committee considers this a deficiency.

The importance of independent review was stressed by the Commissioner of Reclamation in January, 1977, who stated, "that the Bureau will use independent consultants to evaluate Bureau designs for all future major dams....this review process will be applied to all Bureau storage dams."¹¹ The Committee endorses this approach also for the evaluation of existing dams.

Although in the Bureau there is desire to retain and do the work in-house, consideration should be given to utilizing outside services, particularly if available manpower is not sufficient to complete special examinations and studies within realistic and prudent time limits. The use of outside services would have the additional advantage of providing independent reviews of original designs.

4.3 OPERATING CRITERIA AND PROCEDURES

The Bureau prepares two manuals for use by maintenance and operations personnel prior to and following transfer of the project from construction status to the Bureau or Water User Operation and Maintenance. As stated in Section 4.2.3, the Division of Design in the Engineering and Research Center prepares a Designers' Operating Criteria (DOC) manual to provide criteria for operation of project facilities to meet conditions for which they were planned. In addition, staff personnel in the regional offices are currently preparing a Standing Operating Procedures manual for each project.

4.3.1 Designers' Operating Criteria Manual

Reclamation Instructions, Part 131,¹² states: "In order that Bureau works may be used, operated, and maintained in conformity with the requirements of their design and consistent with operating limitations, adequate criteria shall be made available to employees responsible for operation and maintenance, and actual operations shall be guided by these criteria. These operating criteria shall be made available during the construction period just prior to the initial operation of the facility. The operating criteria stress the designers intended use and operation of equipment and structures in the interest of safe, proper, and efficient utilization of the facilities. Operating criteria will not be required for installations that are relatively simple and which involve no special operating limitations."

The Division of Design, Engineering and Research Center, is responsible for preparing DOC manuals. The manuals contain structural descriptions, drawings, and maintenance instructions for all hydraulic, mechanical, and electrical equipment. DOCs also include instructions for dam behavior measurements and recording. The data contained therein are incorporated in the Standing Operating Procedures.

In 1949, the Bureau prepared its first DOC manual, and some 233 have been prepared for Bureau dams constructed thereafter. Some of these DOCs are revisions required because of the addition of features or drastic changes in operating instructions. Many addenda have also been issued throughout this period to revise and update operating instructions for dams. However, manuals for a number of older dams have not been prepared.

COMMENTS

Representative DOC documents reviewed by the Committee indicate thorough, detailed coverage of descriptions and instructions pertinent to the operation of the facility. However, a determination of whether or not omissions may exist in such documents which could affect the safety of the dams, could be made only through a meticulous survey of each facility. The Committee did not interview project operating personnel to determine if they understand the manuals and are using them effectively.

While the Committee believes that DOC manuals should be prepared for all projects, their lack at

a number of older Bureau dams is not considered a serious deficiency.

4.3.2 Standing Operating Procedures Manual

In 1965, the Bureau of Reclamation implemented a program for preparing Standing Operating Procedures (SOP) manuals for each of its storage dams and reservoirs. To facilitate the preparation of SOP's, the Division of Water Operation and Maintenance, Engineering and Research Center, published a guide for their preparation (latest revision 21 February 1973).¹³ To date, the Bureau has completed and issued 82 SOPs and has 62 others in draft form.

The purpose of the SOPs is "to establish in one primary document with associated supporting documents, controlled, complete, accurate, current, structure-oriented operating instructions for each storage reservoir and its related structures." The instructions "will also permit responsible persons...to operate the dam and reservoir during emergency situations...." The SOP is prepared "primarily for the use of the person or persons (dam tenders) located at or nearest the dam and their immediate supervisors...."¹³

Regional Offices prepare the SOPs which are then reviewed by personnel of the Division of Water Operation and Maintenance at the Engineering and Research Center. SOPs are coordinated with and supplement the Designers' Operating Criteria manuals.

The more important items related to dam safety which appear in the SOPs include:

(1) Information and instructions concerning communications, administration, and assignment of responsibilities.

(2) Detailed instructions for operation and maintenance of the dam and its appurtenant structures and equipment.

(3) Requirements for reporting of routine data concerning reservoir operations and structural items, such as structural measurements for earth and concrete dams, landslide movement measurements, seepage measurements, and ground-water level measurements.

(4) Reporting of unusual occurrences "...not normally encountered in the routine operation of the dam and reservoir and which may endanger the dam...." "Floods requiring the use of surcharge storage, slumping or cracking of the dam, landslides, earthquakes, a rapid increase in

seepage, and failure of any portion of the structure or related equipment are typical unusual occurrences."¹²

(5) Instructions and schedules for regular inspections of the dam, abutments, and adjoining areas.

(6) Civil defense and sabotage security plans.

(7) Reservoir operations related to the inflow design flood, flood routing, filling and release procedures, inflow forecasting and special reporting during flood or high water conditions.

The mechanical and electrical equipment required for the operation of Bureau dams varies widely. Consequently, the instructions for operation and maintenance of the equipment at each installation are comprehensive and detailed. Sources of standby power are provided as required for operation of gates, outlet works, supervisory operational equipment, or communications equipment. Protection of the public against unauthorized operation or vandalization of equipment is provided by security measures as necessary.

COMMENTS

The SOP manuals appear to be well prepared and satisfactory operating guides for dam facilities under normal operating conditions. However, the instructions covering emergency procedures for the protection of the public and the facility itself are considered inadequate (also see comments in Section 4.8). SOP manuals have not been prepared for all major dam projects, which is considered a major deficiency.

Potential weaknesses that might exist in the design or construction procedures of a specific dam should be identified in the SOP manual. If the design or construction was such that a difficulty might occur in operating and maintaining the facility, the signs of the weakness should be called specifically to the attention of operating personnel.

4.4 ROUTINE MAINTENANCE AND SURVEILLANCE

Routine maintenance and surveillance programs related to dam safety can be divided into two components: (1) day-to-day observation by resident personnel and (2) periodic reading of field instruments followed by reporting of data and interpretation of results.

4.4.1 Day-to-Day Observation

The project operating organization, whether Bureau or water users, is responsible under regional supervision for the day-to-day observance of structures and their performance, and for the correction of or arrangements necessary for the correction of observed structural or operational deficiencies. This day-to-day operation, surveillance and maintenance is generally provided by dam tenders. The dam tender is not expected to analyze and correct all problems which may arise, but to recognize a potential problem and report it promptly.

COMMENTS

Because of time limitations for the review, the Committee did not make field visits and interview project or regional personnel. Thus, the Committee did not evaluate the qualifications of operating personnel to determine whether this aspect of dam safety is being adequately executed.

4.4.2 Field Instrumentation Program

While in the past the principal purpose of instrumentation has been to verify design assumptions, the Bureau does incorporate instruments in selected structures for measuring conditions relative to structural safety and stability. The responsibility for making periodic readings and measurements rests with project personnel and personnel assigned to the regional offices. These field offices transmit data and reports to the Engineering and Research Center where personnel in the Division of Design reduce, plot and interpret the data. The data are not systematically furnished to the Division of Water Operation and Maintenance. However, summaries of the Division of Design's findings, comments and instructions to the Regional Director responsible for the dam are circulated to Operation and Maintenance, appropriate Section Heads, and individuals involved in the assessment of the performance of a particular facility.

A requirement exists that field personnel under the Review of Maintenance Program assure themselves that field instruments are performing satisfactorily. The Division of Design, Engineering and Research Center, prepares schedules for data gathering and forms for presentation of the data; and instructs field personnel on the use of instruments, procedures to check the reliability of the observations, and proper maintenance of the instruments. Importantly, instructions include a requirement for field personnel to

report immediately to their superior any anomalies or unexpected change in the readings or measurements once it has been established that an instrument is not malfunctioning.

The Bureau has incorporated instruments for measuring hydrostatic uplift pressures at the foundations of most concrete gravity dams and similar masonry structures, irrespective of age. Thirty-seven out of 56 concrete dam structures contain instruments for measuring uplift pressures, internal stresses, and movements. Depending on site conditions and the type and arrangement of the concrete dam, readings and measurements are made periodically at intervals of one to three months.

The Bureau has installed instruments in 147 of its 300 dams which have major embankment components, primarily to measure seepage and pressures. Instruments to measure internal horizontal and vertical movement are being installed only in those dams having unusual foundation conditions. Measurements of change in elevation of crest and in the downstream slopes are made periodically for most dams. Seepage is channeled and measured where it appears at the downstream toe and abutments. Water is sampled for change in chemistry at sites where dissolving minerals and/or solutioning are potential safety hazards.

Piezometers are read twice during the filling cycle of a reservoir generally between May and July, and following any period of rapid drawdown. Depending on site conditions, piezometric readings are taken three and four times each year in accordance with an established schedule.

For those structures built in the 1940s and 1950s, instrumentation is elaborate and extensive. During the 1960s, instruments were installed for unusual conditions and/or special purposes such as to check a design assumption. Beginning in the 1970s to date, instruments are being installed in earth dams to check critical performance zones such as drainage blankets.

Data and plots are kept in an orderly manner, in loosely bound files in a central file of the office of the Division of Design. Six members of the Division of Design devote full time to reducing, plotting and interpreting field data; two are assigned to earth dams and four to concrete dams. From the date of observation to plotting and evaluation, the time elapsed ranges, generally, from 4 to 8 weeks.

COMMENTS

The Committee believes the Bureau should reevaluate its current practices relative to instrumentation. The Committee questions the adequacy of the current program, particularly as it exists relative to dam safety. Personnel appear to be well-informed on the types and applicability of new instruments in the instrumentation program and understand the need and use of instrumentation for monitoring dam safety. Apparently, the lack of adequate staff and funds is the principal reason for existing deficiencies.

The Bureau has not installed instruments in all dams where they are needed to serve a safety function. In addition, the Bureau has not systematically ranked or categorized its dams relative to the need for instrumentation and has not established priorities for observation and evaluation of existing instruments. The Bureau has not evaluated the possible use of instruments to warn of a rapid rise in reservoir pool level or when the pool reaches a critical level in the freeboard zone.

The Bureau is considering installation of strong-motion seismographs on some major structures in seismic regions. The agency has not normally installed seismic networks to monitor earthquake activity near most of its major dams.

Except in special cases where a potential for solutioning has been recognized, the Bureau does not make measurements of temperature, turbidity, and chemistry of water emanating beneath the dam and through the abutments relative to similar characteristics of water at varying depths in the reservoir near the upstream face.

4.5 ON-SITE EXAMINATIONS

The Bureau of Reclamation on-site examinations programs comprise three elements: (1) a review of maintenance program, (2) a landslide surveillance program and (3) special examinations when called for by unusual events.

4.5.1 Review of Maintenance Program

The Commissioner of Reclamation, by administrative directive¹⁴ dated July 6, 1948, initiated a comprehensive

Review of Maintenance Program, primarily to maximize life of facilities and equipment so as to protect the federal investment. Subsequently, the program became a principal element of safety activities in that it provided the Bureau an awareness of potential safety problems as well as assurance that adequate maintenance was being performed.

The Program provides for periodic examinations of Bureau dams and other major facilities by investigating teams selected by the regional office and the Engineering and Research Center. Principally, these periodic reviews document visual observations and provide, where appropriate, the basis for indepth safety investigations under the Examination of Existing Structures Programs or the Special Examinations Program.

The periodic examinations are made at 2 or 3-year intervals (depending on the quality of maintenance programs exhibited in prior reviews and on the complexity of the project) by regional offices and at a 6-year interval by the Engineering and Research Center. Regional engineers participate in the 6-year examination and when requested by the Regional Director, Engineering and Research Center engineers may participate in the 2 to 3-year review.

The program covers approximately 374 major projects, including about 330 storage dams. About 250 minor facilities such as canals and other distribution and drainage systems are included only in the regional offices' 2 to 3-year examinations. The formal examination of major facilities begins with the transfer of facilities from the construction stage to an operation and maintenance status.

The Division of Water Operation and Maintenance is responsible for the coordination of the review of maintenance program for all structures and facilities except for power and certain other specifically designated features which are the responsibility of the Division of Power Operation and Maintenance.

Usually, members of Operation and Maintenance staff do not participate in the field examinations. Instead, two representatives of the Division of Design, one civil engineer and one mechanical engineer, supported by personnel of the project and regional offices, perform the 6-year examinations.

Examinations take into consideration a project's individual features. Team members review past reports and recommendations prior to the field examinations and use prepared checklists to assure complete examination of all pertinent features. At the site the team is concerned principally with the adequacy of maintenance and any

abnormalities that may exist. Team members observe earth embankments for cracks, slides, sloughs, subsidence, springs, seeps, boggy areas, and for any outward appearing deterioration of slope protection. They examine the general appearance of concrete dams in a similar manner, inspect electrical and mechanical equipment, operate spillway and outlet gates, and test emergency power units. All spillway, outlet works and emergency gates and valves are required to be operated periodically and the adherence to the operating schedule is reviewed by the Team. Team members also evaluate the proficiency of dam tenders to operate spillway and outlet facilities. They also review instrumentation for structural behavior to determine if performance is satisfactory and if readings and transmittal of data are current.

Team members prepare reports of the examinations which are transmitted to appropriate officials after a supervisory review. The Regional Director approves regional 2 or 3-year reports, whereas the Chief, Division of Water Operation and Maintenance and the Director of Design and Construction, Engineering and Research Center, jointly approve the 6-year examination reports which are prepared by team representatives of the Division of Design.

The Review of Maintenance Program is managed with the help of a computer program to handle the large amount of data. The data include name of structure, project, dates of previous reviews, next scheduled review, uncompleted recommendations, transfer date, operating entity, operating documents, structural performance status, and other pertinent information. The computer data are updated annually and are submitted to the Commissioner as part of an annual summary report on the Review of Maintenance Program. The annual report outlines accomplishments in terms of reviews made and status of actions taken on recommendations.

COMMENTS

Although the examining team members review past examination reports and instrumentation data prior to the site visit, they do not, on a regular basis, review project data such as original design criteria, construction information, subsurface soil profiles and logs, and stability analyses. Such reviews would be helpful in evaluating changed conditions and should be particularly beneficial to the 6-year inspection by personnel of the Engineering and Research Center. In the case of older structures, these reviews would provide comparisons with current criteria and methods of analyses which, together with the performance and

condition observations, would provide the basis for deciding whether or not additional stability investigations are needed.

The disciplines of engineering geology, hydraulics, and either soil mechanics or structural engineering, depending on the type of structure being inspected, are not represented on inspection teams in the review of maintenance examinations. All disciplines pertinent to dam engineering should be represented on the 6-year examination in order to obtain a thorough technical assessment of project condition and operation.

While the Chief of Water Operation and Maintenance has responsibility for the review of maintenance examinations, funding and programming of resulting remedial work are the responsibility of the Regional Directors. This precludes an orderly and priority-based program to correct discovered deficiencies such as could be prosecuted more effectively by single direction at the Engineering and Research Center.

4.5.2 Landslide Surveillance Program

The Bureau implemented a landslide surveillance program in accordance with directives from the Commissioner's Office. A Bureau of Reclamation document entitled "Procedures for Landslide Surveillance Program,"¹⁵ dated October 1972, revised July 1973, outlines the essential features of the program including landslide classification, an automatic data processing program for machine listing of landslides, and requirements for inspection, monitoring, and remedial measures. Standing Operating Procedures manuals also list surveillance procedures for the project.

The purpose of the program is to register "...all significant landslides or potential slide areas which have been or could be aggravated by the construction or operation of existing project facilities designed and constructed by the Bureau and all significant landslide areas which could endanger existing project facilities (or persons using them) for which the Bureau has responsibility of examination for maintenance and safety purposes."

Regional geologists examine landslide areas annually, prepare reports on landslide examinations, and include recommendations as warranted for posting, observing, implementing operating restrictions, and stabilizing.

The Engineering and Research Center has the responsibility to maintain an up-to-date Landslide Register, based on reports and updated information provided by regional geologists. In addition, the Engineering and Research Center furnishes to the Commissioner, by April 1 of each year, a Register printout of major active slides and slides having significant new activity which pose high or very high risks.

The Landslide Register lists the following items, among others, for each landslide:

- (1) Location and identification of slide area.
- (2) Date of last comprehensive examination of slide by Bureau Geologist.
- (3) Classification of landslide (active, inactive, potential, rockfall).
- (4) Date of first and last known movements.
- (5) Failure speed (slow, moderate, rapid, fast).
- (6) Approximate volume of earth and rock in the failure mass.
- (7) Mode of action of the agent which causes the landslide.
- (8) Risk to primary and secondary Bureau structures from the landslide induced wave action (nil, low, moderate, high).
- (9) Risk to non-Bureau property (nil to high).
- (10) Risk to life (number of people who might be killed or injured by rapid movement).
- (11) Summation of actual cost of damage done by the landslide, and of past remedial treatment.
- (12) Treatment required and performed to stabilize slide (yes or no).
- (13) Whether landslide has been posted to warn of possible danger.
- (14) Status of various regional and Engineering and Research Center reports.

The Bureau "Guide for Preparation of Standing Operating Procedures" identifies the following actions which may be

included as responsibilities to Operation and Maintenance Personnel for a particular project:

(1) Posting of maintenance or specifically identified signs to warn of landslide areas.

(2) Identification of names and locations of persons and entities in established locations which would be affected by either slow or sudden movement of a critical landslide and establishment and implementation of related emergency communication procedures.

(3) Maintenance and observation of landslide monitoring instruments.

(4) Measurement by land surveying of landslide area.

(5) Examination of and reporting on critical landslide areas between annual examinations as directed by the Regional Geologist.

(6) Preparation of reports on landslide investigations as directed by the regional geologist.

(7) Adherence to special limitations on reservoir drawdown rates.

(8) Immediate reporting of unusual landslide activity.

In addition, the Guide states that "The Landslide Surveillance Section should describe landslide observations and measurements to be made following an earthquake and should refer to the section on unusual occurrence reporting for reporting procedures."¹⁵

COMMENTS

The landslide surveillance program is, in concept, an excellent program which, if properly executed, would serve as a basis for identification of those slides which could be hazardous to project facilities, to life, or which could be a potential threat to the safety of the project. Inquiries by the Committee into the details of the program, however, have revealed that although the program is well defined, it is not being executed to the extent that it is useful in the evaluation of safety at all of the Bureau's projects.

At the present time, it appears that the Engineering and Research Center's total effort on the program (which now amounts to about 30 man-days

per year) is to act as a clearinghouse for incoming data sheets and as an intermediary between the regional offices and Commissioner's office for letter transmittal purposes. There is no involvement of the Engineering and Research Center in the field inspection phase except at the invitation of a region, although any analyses to be performed would be done by the Engineering and Research Center (but again, only at the request of the region).

It is acknowledged that the program is generally a low-priority item with regard to manpower and funds allocation within the regions and recent improvement in the program has been accomplished only by persistent request from the Engineering and Research Center. From this, it would appear that this program which is clearly defined and required by Standing Operating Procedures, is only partially and not satisfactorily being implemented (with the exception of sophisticated monitoring installations at a very few projects such as at Grand Coulee Dam).

For this program to be of use in a dam safety program, certain steps should be taken to improve the performance and objectives of the program. As a minimum, the Committee believes the following steps should be expedited:

- (1) Every significant active, inactive, and potential landslide at every reservoir in the Bureau's inventory should be identified.
- (2) The inventory should be completed.
- (3) A risk analysis should be performed to identify for further study and rank each slide that does or could create a hazard to facilities, life, or to the safety of the project. A discussion of the role of risk analysis in a dam safety program is included in Section 4.10.
- (4) Priorities for instrumentation and analytical study should be established and where risk is high, the instrumentation and study should be initiated.
- (5) Where possible by analyses, threshold values should be established for each potentially high-risk slide such as maximum credible

earthquakes, height of ground water, maximum rate of drawdown, and rate of lateral movement.

(6) Acceptable designs and plans should be available where remedial measures are required.

(7) Contingency plans should be developed for unexpected failure of a high-risk slide.

(8) Documentation for the entire slide surveillance program should be centralized at one location in each region. According to information provided, data are dispersed to various groups of the Engineering and Research Center and the regional offices. Means of direct communication of data gathering, collating, and evaluating relative to dam safety are lacking. Indeed it would be difficult to obtain rapidly all background data on any particular slide.

Considering the importance and consequences of failure of a high-risk slide, adequate emphasis has not been given this program since its inception in 1966 even since revised procedures were issued in 1973. The Committee believes that the Bureau management should give a higher priority to this program in allocation of manpower and funds. A primary reason for this initial high priority is to determine how many, if any, landslides should be continuously studied. We believe that accomplishing this objective would reduce the Bureau inventory efforts and enable their relevant manpower to be used more effectively.

Also, the Engineering and Research Center should become more directly involved in the field identification of high-risk slides, and procedures and budgeting should be so established that involvement of personnel of the Engineering and Research Center in field examinations, instrumentation, and analysis is not dependent on invitations from the Regions. If, with the Bureau's manpower resources it is not possible to accomplish this phase of the work in the near future, consideration should be given to obtaining help from qualified professional organizations outside of the Bureau.

4.5.3 Special Examinations

Special on-site examinations or investigations are conducted whenever events or observations of an unusual nature occur such as seismic activity, evidence of possible deterioration, or abnormal behavior as established by either instrumentation or observation.

The Bureau conducts the special investigations under this program whenever problems are identified by day-to-day observations of the project or by a periodic examination under the Review of Maintenance Program, or whenever another agency or entity requests help from the Bureau. The Bureau has available emergency funding for accomplishing examinations of an urgent nature.

COMMENTS

The effectiveness of this program depends upon the thorough, competent prosecution of the Review of Maintenance Program and upon alert observations by project personnel to identify potential problems needing investigation.

The Bureau performs investigations under this program competently and timely, using state-of-the-art engineering procedures.

4.6 EXAMINATION OF EXISTING STRUCTURES PROGRAM

4.6.1 Scope and Status of Program

In 1965, the Bureau of Reclamation initiated an Examination of Existing Structures Program, under the Division of Water Operation and Maintenance, to evaluate the safety of those older dams which were designed using criteria and technology which do not conform to present day standards. The Program includes analyses of the ability of the structures to withstand safely the currently estimated floods and seismic loadings and to prescribe corrective action necessary to ensure the safety of the dams. This program is identified by box No. 14 in Figure 1.

The Examination of Existing Structures Program covers 234 of the 249 Reclamation storage reservoirs. Initially, the program focused on structural and hydrological aspects of the dam projects. Based on an analysis of historical floods, together with judgments concerning relative importance of the facilities, a total of 88 reservoir projects were identified as needing new studies to determine their abilities to withstand the currently estimated inflow

design floods safely. New inflow design floods have been established for 83 of the 88 projects, and the remaining 5 are scheduled for completion in fiscal years 1977 and 1978. Flood routings have been completed for 75 of these reservoirs and the decision as to whether corrective measures are required has been completed for 65.

Seismic studies are scheduled for the 234 reservoirs in priority order based on results of the hydrology studies as well as proximity to high seismic risk areas. Seismic studies of 27 reservoir projects have been completed; and studies of all reservoirs in high seismic risk areas will be completed by the end of fiscal year 1979.

After the hydrologic and seismic studies are completed, a formal report is prepared for those reservoir structures with significant deficiencies. The report includes information on the need for structural modification, the hazards to the public, the recommended corrective action and alternatives, the environmental impacts, and the repayment ability of the water users. The condition of any upstream dam belonging to others is investigated and the possible effects on the Bureau dams are included. The completed reports form the bases for recommending corrective actions, when needed.

The Engineering and Research Center issues an annual summary indicating the investigation schedule and report status for each dam in the Examination of Existing Structures Program. The summary provides information about the proposed modifications, including estimated costs.

Of the reservoirs for which studies have been completed, modifications have been completed or are in progress for 12 dams, and major work is authorized for two others. Thirteen dams which require major work have been identified, although reports have not been completed. Twelve of these dams were determined to be incapable of passing or storing safely the currently estimated maximum probable flood. The remaining dam may be incapable of withstanding the maximum credible earthquake event.

COMMENTS

The Committee considers the Examination of Existing Structures Program to be a very important element of the Bureau's safety activities for existing dams. In this program to date, emphasis has been on adequacies of spillway capacity and seismic stability. It has not included all factors pertinent to safety and has not been pursued with a

sense of urgency commensurate with growth of the population endangered by potential dam failures.

Some factors relative to strength and stability which are not systematically addressed by the Evaluation of Existing Structures Program as it is presently operating include:

- (1) Independent review and assessment of the original design and construction, along with reasonable investigation of the current quality of the dam construction materials, particularly for the older dams.
- (2) Changed conditions necessitating revision of original assumptions; e.g., uplift increase, concrete strength deterioration, spillway erosion, and structural damage.
- (3) Adequate consideration of the hazard of liquefaction, during an earthquake, of foundations and/or embankments containing liquefaction-susceptible materials.
- (4) Adequate instrumentation of types which might warn of developing instability, not visible nor detectable during the Review of Maintenance Program.
- (5) Adequate evaluation of geologic and geotechnical conditions, including the presence of possible active faults, which are not readily visible and might eventually pose a hazard.

Only when such other factors become of significant concern due to distress signals is attention focused on the specific problem. Such attention is generally directed through the Special Examinations activity (block 19, Figure 1).

A comprehensive review and safety examination of each structure taking into account all such aspects as well as those currently studied, is needed. Such a review might indicate the need for supplemental investigations such as core drilling, laboratory work, or installation of added instrumentation. Particular attention should be given during such comprehensive reviews, to the monitoring and surveillance role of instrumentation in contrast to the instrumentation installed primarily for verification of design.

4.6.2 Criteria Used to Establish Order of Priority for Evaluation

For the hydrologic studies, the selection of projects to be examined and the order of investigations were based on historical flood data and relative importance of the facilities. It was done by first assembling data for historical floods observed in a particular area and plotting these data vs. drainage area. From these plots, envelope curves of flood history in that area were established. The design floods for dams in the same general area were then plotted in similar fashion and examined in terms of their relation to the envelope curves. Those design values observed to be close to or below the envelope curves were deemed to be inadequate and in need of reanalysis. In general, it was observed that those dams designed prior to the adoption of design-storm/unit-graph methods in the early 1950s were most likely to have inadequate spillway capacity. The schedule of studies was generally based on this analysis and on facility importance.

The order of priority for seismic studies follows the Recommended Guidelines for Safety Inspection of Dams prepared by the Corps of Engineers,¹⁶ except where modified by results of the hydrologic studies. According to a Bureau memorandum¹⁷ dated January 28, 1977, the schedule of seismic studies is based on the following considerations:

Priority 1 - Those dams now identified as having the greatest need for remedial construction to accommodate new inflow design floods.

Priority 2 - Those dams with initial indications that substantial modifications will be required for inflow design flood reasons.

Priority 3 - Storage dams in high seismic risk locations.

Priority 4 - Storage dams in low seismic risk locations which do not require modifications due to the updated inflow design flood.

COMMENTS

In determining priorities, in general, differences in hazard potential and in likelihood of failure should be considered. Priorities for the Bureau's reevaluation of the flood hydrology of existing dams appear to be consistent with a categorization according to hydrologic risk. The order of priority for seismic studies of existing dams, however, lacks consistent relationship to seismic risk since it is based principally on results of the hydrological analyses.

4.6.3 Hydrologic Studies and Criteria

The principal hydrologic concern of the Evaluation of Existing Structures Program is with the adequacy of spillway capacity. The question of adequacy derives from the fact that new methods of analysis and new hydrometeorological data may indicate the use of a larger spillway design flood than was used in the original design. Thus, the principal hydrologic analysis in the Program is a redetermination of the spillway design flood for those dams where there is reason to believe that a previous design value may have been inadequate.

The process of establishing a new spillway design flood (SDF) takes place from an administrative point of view in four parts:

(1) Hydrometeorological Design Storm. The staff meteorologist in the Engineering and Research Center conducts a study to develop an appropriate design storm (or temperature sequence for snowmelt studies) for the drainage basin under investigation.

(2) Flood Analysis. The design storm is transmitted to the appropriate regional office where the regional hydrologist conducts an analysis to establish the inflow design flood (IDF). The regional hydrologist may also recommend criteria to be used in routing this flood through the reservoir and spillway.

(3) Review and Approval. The regional study is reviewed by the hydrologist at the Engineering and Research Center for verification and approval. Iteration and modification may be required with final approval authority retained by the Engineering and Research Center staff hydrologist.

(4) Spillway Design Flood. The approved IDF and criteria for its routing are provided to the spillway and

outlet works design personnel who perform the routings necessary to establish the spillway design flood and determine spillway adequacy.

The meteorologic and hydrologic analysis procedures used in reevaluating spillway adequacy were summarized by Bertle.^{18 19}

COMMENTS

The methodology and criteria used in determining the spillway design flood are generally consistent with the current state of practice and are in close agreement with those used by comparable agencies such as the Corps of Engineers and the Tennessee Valley Authority. The selection of parameters and design assumptions requires the exercise of judgment and appears to be made in such a manner as to yield conservative estimates of the spillway design flood. The Bureau is to be commended on the professional role it has played over the past 3 decades in bringing these methods to their current state of development. However, new methods based on mathematical modeling of the rainfall runoff process have come into existence during the past decade and are rapidly advancing in applicability and acceptance. Although Bureau personnel appear to be reasonably informed of these developments, they do not appear to be moving aggressively to test such methods and objectively assess their value in Bureau applications.

Presentation of the results of a spillway design flood analysis in terms of a single design hydrograph tends to obscure the fact that a large number of parameter estimates and design assumptions are involved. From the standpoint of risk analysis and clarification of the degree of uncertainty inherent in the design process, it would be desirable to compute a set of hydrographs which depict the likely range of results.

Although the Bureau does not currently provide such a sensitivity analysis, it does compare the peak and volume of their IDF with an envelope curve established from analysis of historical events in the region. These consistently show the revised IDF to be several times larger than the envelope values. This is an important confirmation of the extreme nature of the IDF and should be continued as an integral part of the analysis. Nonetheless, addition of the several values obtained by a

sensitivity analysis and an explicit statement of the rationale for selection of a particular design value would strengthen the process.

The hydrologic analysis is considered to be complete with specification of the IDF and criteria for routing it to the spillway. The analysis of spillway adequacy is considered to be complete in most cases with the reservoir operation and routing studies. Only in special cases, such as those in which overtopping or dam failure is indicated, is an analysis made of downstream impacts. Impacts due to successful passage of the spillway design flood, or even due to passage of more likely events such as the 50 or 100-year floods are not routinely analyzed. However, a capability for doing so does exist within the Bureau and is in the process of being incorporated into state-of-the-art computer programs. These programs will be invaluable aids in the preparation of inundation maps.

4.6.4 Earthquake Studies and Criteria

Prior to about 1972, the U.S. Bureau of Reclamation's procedure for determining seismic loads was based on an assumed horizontal force of gravity. A more thorough and analytical site-specific methodology was developed with rapid growth of basic data, advances in seismologic instrumentation and analytical methods, development of new insight into tectonic processes based on new plate tectonic models, and widespread use of strong motion methods for seismic design of structures. The methodology involves a thorough search and review of geologic and seismologic data and consultation with appropriate governmental, university, and other sources of information. Seismic risk maps and average return period concepts are used as aids in determining operating and design basis earthquakes. The geologic evaluation and seismologic analysis include selection of near and far field epicenters and maximum credible earthquakes for the main faults likely to generate earthquakes affecting the site. State-of-the-art methods are used to attenuate ground motions due to distance to the site, and seismic response curves are then developed for use in the dynamic analysis.

Since 1972, this type of approach has been used for dams reviewed in the Examination of Existing Structures program. Analyses of approximately 27 of 234 reservoir projects have been completed by the end of FY 1976 using the priority order outlined in Section 4.6.2.

COMMENTS

The current practice for selecting specific earthquake and seismic design criteria to be used in stability evaluations for concrete and earth dams is primarily a thorough and up-to-date review of available information. There is little or no generation of new field geologic, seismologic, geophysical, or remote sensing data. The staff is familiar with state-of-the-art methods of analysis, but evidently budget and staff limitations preclude widespread use of all appropriate methods.

The methodology being used by the Bureau to define maximum credible earthquakes is likely to be adequate for dams in locations where the seismic risk is low. However, an analysis utilizing only currently available data is not sufficient for dams in a high risk situation as defined by probability of significant seismic events and hazard potential.

A review of available information is only one phase of an earthquake seismologic study. When a dam in a highly seismic area that has a large damage potential is being investigated, the studies should include a review of historical evidence and also investigations of regional and local faulting. Investigative techniques available include stratigraphic, structural, and geomorphic analyses, geodetic and geophysical surveys, subsurface exploration methods (including trenching), and photogeologic and imagery analyses.

The Committee recognizes that a complete earthquake hazard study using several of the enumerated investigative methods would cost more in manpower and dollars than has been spent on previous studies. However, it is considered inappropriate to conduct a sophisticated and expensive analytical study of a high risk dam without assurance that the maximum credible earthquake is based on adequate data and state-of-the-art methods. An error in selection of maximum credible earthquake could invalidate the entire analyses.

Faults passing through or trending toward a dam must also be evaluated with regard to their potential activity. It is unlikely that a proper assessment of possibly active faults can be made without field inspection, some detailed geologic mapping and possibly subsurface explorations.

The Bureau's final decision on seismic attenuation and site-amplification of seismic waves at the site does not always include a complete and site specific input with a final review from the geology and seismology staff.

Within the Bureau and among other agencies concerned with safety of dams, there are significant differences in basic terminology, approach, criteria, and scope of work used for establishing design earthquakes from the historic seismologic record and geologic evidence based on evaluation of active faults. In general, state-of-the-art methods have not been applied to establish proper seismic design values for most existing structures.

4.6.5 Stability Evaluations

Under the Examination of Existing Structures Program, the Concrete Dams Section of the Engineering and Research Center has completed seismic stability analyses for 13 concrete dams and the concrete portions of 2 composite dams. The analyses of 37 additional concrete dams are yet to be completed. The methods of analysis described as being employed are procedures using either trial load or finite element methods of dynamic analyses.

Three-dimensional programs are used for concrete arch dams and two-dimensional finite element programs for concrete gravity dams. The dam-foundation interaction and dam-reservoir interaction are handled by procedures currently considered as state-of-the-art in engineering practice. The rationale described for evaluation of the results of these dynamic stress analyses depends to some extent on engineering judgment when comparing resulting stresses with design strength values determined for the concrete.

The Earth Dams Section has completed seismic analyses for 12 earth dams. Maximum credible earthquakes have been established for 4 other earth dams for which the sampling of construction and foundation materials will be completed during FY 1977.

The Bureau found that none of the dams for which seismic stability analyses have been completed would fail, although little consideration was given to risk of liquefaction in foundations having liquefaction-susceptible materials in high-seismic risk areas.

COMMENTS

The technical procedures and methods used by the Bureau in seismic stability analyses of both earth and concrete dams are generally in accord with the state-of-the-art for such analyses as currently practiced, but there should be a proper accounting of liquefaction-susceptible materials. Limitations of the analytical methods as currently developed are recognized as is the need for exercising sound engineering judgment in evaluating the results. The rationale on which such judgment is founded is logical and evaluation of the safety of dams relative to the described seismic stress and stability analyses will be amply conservative.

Research into methods of improving and refining the analysis procedures is being carried out. Although such sophisticated dynamic analytical procedures were indicated as having been used on all the dams thus far evaluated under the Examination of Existing Structures Program, the committee believes it is not necessary to carry out such timetaking and complex analyses for concrete gravity dams classified as being in a low risk category when the seismic design loads determined for the dam are of low order. In such cases, the procedures described in the Manual, Design of Gravity Dams,²⁰ would be applicable.

Static stability analyses, while not specifically described as part of the program, must necessarily be carried out in the course of completing a seismic stability analyses. Related static versions of the dynamic methods described are used. The reliability of these analyses procedures to provide accurate results is well documented.

No efforts are underway to assess the effects on dam stability of factors such as deteriorating conditions, latent geologic defects, or original design and construction deficiencies.

4.6.6 Evaluation of Upstream Dams

In performing hydrologic studies under the Examination of Existing Structures Program, the Bureau evaluates the structural and operational conditions at existing upstream dams. These evaluations include a field examination of the upstream dams to determine if any deficiencies exist which pose an undue hazard of failure. Reports of such

evaluations are being prepared for the flood studies, but no actions have been taken to date regarding existing deficiencies pending proposed national legislation on dam safety. Examination results are being furnished to appropriate state officials.

COMMENTS

The Committee believes this activity to be essential to ensuring the safety of Bureau dams and that the Bureau should prosecute such examinations expeditiously. These examinations should be made for storage dams upstream of all Bureau dams and not just for those dams upstream of projects undergoing hydrological investigations.

The Committee recognizes that the Bureau must be provided necessary authority and funds to accomplish the examination of upstream dams belonging to others.

4.7 IDENTIFICATION AND CORRECTION OF DEFICIENCIES

The Bureau requires that field examinations be made of all facilities constructed or financed by the agency to assure protection of the federal investment in such facilities (Section 4.5). The formal reports on such examinations identify all deficiencies which were detected and evaluated and categorize them into one of three groups, together with appropriate recommendations, as follows:

Category 1 - Recommendations in this category involve matters of great importance, and the report sets forth remedial action to be completed in a prescribed period, usually 6 months or less, to insure the structural safety or to avoid serious malfunctioning of a facility. The state of the recommended work in this category is followed-up by Operation and Maintenance at 6-month intervals.

Category 2 - Recommendations in this category cover a wide range of important matters where action is needed to prevent or reduce further damage or preclude operational failure. The remedial measures prescribed and the timing may be indefinite, depending on the circumstances involved, but are generally expected to be programmed and completed as part of the project's normal maintenance program. Responsible offices follow up yearly to assure reasonable progress by the operating agency.

Category 3 - Recommendations in this category cover matters of less importance which the examining team believes to be sound and beneficial to the project or project feature. No follow-up records are kept.

Personnel at the Engineering and Research Center monitor the recommendations and publish an annual summary of the status of all recommendations, which is made available to responsible Bureau offices and other pertinent operating entities. The recommendations are repeated each year until the deficiency is corrected.

The Examination of Existing Structures Program is concerned generally with the hydrological and seismic stability aspects of the structures. In January 1974, the Commissioner approved the present policy and procedures for obtaining authority to correct major deficiencies identified under this Program. With respect to some older dams, a major deficiency is the inadequacy of the spillways to pass safely the currently estimated inflow design floods. In brief summary, the Bureau policy for coping with this situation is to: (1) identify the structural modification or changes in operational criteria needed to permit passage, without failure of the dam, of an inflow design flood commensurate with that used in the design of new dams, and implement the changes as soon as possible; (2) accept reduced design standards for the structural modifications in an effort to keep costs as low as possible, providing the modification would result only in damage to the dam or spillway but not in failure of the dam, (3) negotiate repayment of the costs for the structural modifications with the water users, consistent with their repayment ability; (4) modify the operating criteria until structural modifications are completed and inform the water users of the need for so doing; (5) inform water users, public officials, and downstream residents of the risks remaining after the operating restrictions have been implemented; and (6) where appropriate, adopt warning procedures so that downstream residents can be alerted or evacuated in the event a major flood threatens failure of the dam.

For those structures where significant deficiencies are disclosed under the seismic stability program, procedures will be similar to those outlined above.

COMMENTS

The review by the Committee of the problems and ramifications inherent in dealing with major deficiencies in existing dams was, perforce, quite limited. The Committee recognizes, however, that due principally to funding arrangements, a number

of years could elapse between the approval to proceed and the actual accomplishment of the structural modifications. Despite normally appropriate restrictions on operating criteria during this interim period, the occurrence of a major flood could create a hazard of failure of the dam.

A case in point is the 13 dams identified under the Examination of Existing Structures Program as deficient under flood or earthquake conditions. Although these deficiencies were identified 5 or more years ago, repairs have not been accomplished and only very recently has draft legislation to authorize their repair been forwarded to the Office of Management and Budget. Routine, timely procedures have not been established to handle such situations. Even the question of whether the Water Users or government should fund the repairs has not been resolved.

4.8 EMERGENCY PREPAREDNESS PROGRAMS

Several different Bureau documents include instructions to dam operation personnel (dam tenders) in regard to potential or actual emergencies. The primary documents in which these instructions are contained are the Designers' Operating Criteria (DOC) and the Standing Operating Procedures (SOP), described in Sections 4.3.1 and 4.3.2. The regions have Emergency Operation Plans which also include plans for emergency situations at Bureau reservoirs and dams.

Both the DOC and the SOP manuals contain specific instructions for the dam tender in the event of unusual occurrences such as floods, earthquakes, bomb threats, fire, and vandalism. The dam tenders are instructed to recognize potential hazards and to perform emergency operations as part of their training.

Generally the procedures in the event of an unusual occurrence are:

(1) Detecting personnel contact the project or regional office and give details of the occurrence (communications information is in the DOCs and SOPs and each region has a communication directory for dams for emergency communications,)

(2) Project or regional office personnel instruct operational personnel at the location as to what action to

take and which people to contact to determine further action.

(3) Other organizations such as local law enforcement agencies and radio and TV stations are contacted if appropriate. This is not a uniform instruction in all SOPs.

During certain periods of the year (usually spring runoff) many reservoirs require frequent or continual monitoring, depending on snowpack, weather and other conditions. During this time, communications between regional river operations personnel and the dam tender are frequent, and surveillance frequency of the situation depends on how critical it is. Operations personnel are to be made aware of snowpack and weather conditions and how they may affect the safety of the dam or of people downstream.

Contact is also to be made with River Forecast Centers of the National Weather Service, to be aware of all impending weather conditions. These Centers also provide information relative to predicted flows for rivers in their areas. Many of the centers have models whereby they can forecast the effects of a given storm. In some cases the Bureau has developed more detailed models which may be used along with the Forecast Center's model to predict river flows and impending critical situations.

An unusual occurrence which may happen quickly and without warning, such as an earthquake, may require quick action by the dam tender if the occurrence could cause dam failure. The dam tender is instructed to follow the normal Bureau communication system unless he is unable to, or he believes that immediate evacuation of people is necessary. In this case he is supposed to contact local police forces and radio and TV stations and then contact project and regional personnel as soon as possible and inform them of the occurrence and the action taken, however this is by no means set forth in all of the SOPs reviewed.

By agreement with the National Earthquake Information Center, all earthquakes of magnitude equal to or less than 5 are to be reported during office hours, and all those of magnitude greater than 5 are to be reported immediately to appropriate personnel in the Engineering and Research Center, who then immediately notify operations personnel in the field.

COMMENTS

Emergency preparedness programs, especially for dams with high hazard potential, are

inadequate. Deficiencies include inadequate instructions and training of Bureau and water user personnel, inadequate coordination with, and education of, civil defense and community leaders and lack of inundation maps and suitable alarm systems.

Although the causes of these deficiencies may be complex, the general philosophy that "dams are safe, hence will not fail" undoubtedly is a contributing factor. Published SOPs are available for only 82 dams. Those SOPs that are published follow no standard form with respect to emergency preparedness and are often incomplete and vague (e.g., the reservoir supervisor will by best available means, warn the public downstream of unusual discharge). In the absence of proper inundation maps, for example, the "downstream" area is inadequately defined. Many SOPs include no instructions at all regarding procedure in the event of sudden failure or flooding caused by unusual events without dam failure.

Inundation maps are available for very few of the Bureau's dams and are not designed with routine emergency preparedness in mind. The maps provide only a rough picture of the areas of risk without indicating the severity of the hazard for specific structures in the flood plain. Furthermore, the maps only display the effects of sudden failure under spillway design flood conditions and fail to show the effects of lesser but more probable floods.

Dam tenders are not put through a rigorous and systematic program of training and testing to prepare them to deal appropriately with emergencies related to dam safety.

The Bureau does not have an emergency training and evacuation system coordinated with other relevant agencies. Typically, discussions have not been held between Bureau staff and local police, media, and civil defense personnel or residents to ensure that an adequate emergency plan is developed, understood, and followed.

The tragic consequences of this deficiency were highlighted in the GAO report¹¹ on the Teton Dam disaster, where a sheriff, after receiving a call from the project construction engineer, failed to understand that the situation was urgent enough to require notification of residents. Many failed

to appreciate the seriousness of a dam failure, in relation to other floods they had lived through. Sheriffs reported that they had established no emergency plans because no one thought that the dam would fail. In the 14 months since the Teton Dam disaster, no changes in the general emergency preparedness system appear to have been made. In January 1974, in connection with certain high risk dams, the Commissioner of Reclamation mandated (1) that water users, public officials, and downstream residents be informed of the hazards posed by the dams and (2) that appropriate warning and evacuation procedures be adopted. The Committee agrees with this policy and urges that it be fully implemented to encompass all Bureau dams.

4.9 The Role of Engineering Geology

The activities pursued by the Bureau to ensure the safety of existing dams do not include routine consideration of important geologic factors which could affect dam safety.

The engineering geology capability of the Engineering and Research Center is located within the Division of Design of the Office of Design and Construction. For the most part, the geologic staff provides input only as requested by other elements in the Office of Design and Construction or by the Division of Water Operation and Maintenance. These inputs range from detailed evaluation of geologic and seismological conditions to a cursory examination to provide a basis for further engineering evaluation.

Geologists of the Engineering and Research Center have not been members of the 6-year dam inspection teams, have not participated, except upon special invitation from the regions, in the field inspection phase of the Landslide Surveillance Program, and generally have not played a prominent role in the Examination of Existing Structures Program.

COMMENTS

Many aging dams in the Bureau's inventory have little or no geologic or foundation information. Many of these structures have been constructed by others and have been added to the Bureau's inventory for operation and maintenance. Particularly because old dams are statistically more vulnerable to failure there should be a concern that dams are being operated without full

knowledge of the inherent geologic factors which can affect dam safety.

Important factors which should receive close review in a dam safety evaluation include a number of geologic conditions which are best examined and investigated by personnel trained in engineering geology. Some of the important geologically related factors requiring investigation include:

(1) Latent geologic conditions, including presence of possible active faults.

(2) Deterioration and/or change in properties of foundation materials with time.

(3) Potential progressive erosion of rock at abutment contacts, spillways and intake-outlet areas.

(4) Identification of unusual distress in waterways (tunnels, stilling basins, etc.) that may be related to or explained by the geologic situation.

(5) Progressive instability of natural and cut slopes at abutment, inlet-outlet works, and spillways.

(6) The possibility that geological factors may explain unusual instrument readings or seepage quantities.

(7) Mineralogical deterioration of rock used for slope protection.

(8) Degree of hazard or risk from potential landslides as identified in the landslide surveillance program.

Considering the importance of items listed above the Committee believes that an engineering geologist from the Engineering and Research Center should be a member of each six-year dam inspection team. Geologists have not been used for these inspections in the past and this is viewed as a deficiency.

Although it was indicated that there is good communication between the geologists, who are located in the Division of Design, and other divisions such as Construction and Water Operation and Maintenance, the existence of any working

relationships would appear to depend entirely upon personal persuasion rather than by line authority. The Committee believes that the Bureau should accomplish such organizational changes as would improve and strengthen the role and responsibility of engineering geologists at the Center.

4.10 The Role of Risk Analysis

The Bureau of Reclamation has not adopted a probabilistic or risk analysis program founded on hazard potential and probability of failure of its major dams. However, the criteria used to determine priority in selecting dams to be investigated under the Examination of Existing Structures Program include many of the factors which could contribute to formalized risk analysis. In the landslide inventory, six hazard potential levels for landslides are used, but a total risk-based order of priority has not been established.

COMMENTS

Present practices in the Bureau's dam safety program do not focus on minimizing the consequences of dam failure, although reduction of risk is an obvious side benefit. Risk-reducing practices which the Bureau has not pursued systematically or with much urgency are the following:

(1) A program to train operating personnel in procedures to be followed in the event of an impending dam failure.

(2) Preparation of maps showing downstream areas exposed to the hazard of flooding in the event of dam failure.

(3) Installation of instrumentation for the purpose of providing timely warning of impending dam failures to affected populations and to dam operating personnel.

(4) Development of "action" thresholds for instruments which may give indications of impending failures; and finally,

(5) Categorization of dams according to their risk potential, thus providing clear priorities for investigations and upgrading.

The purpose of a dam safety program is to minimize dam failures and to reduce the consequent losses. Risk analysis could play an important role in the Bureau's dam safety programs by providing a more rational basis for determining priority, frequency, and intensity of inspections under the Periodic Review of Maintenance Program. Risk analysis also could help determine priorities for evaluation of structures under the Examination of Existing Structures Program, for correction of deficiencies which have been identified and for allocation of funds.

A recent review of risks associated with dams emphasized that dam failures are not uncommon and often can result in major disasters.²¹ Unfortunately, there currently is no systematic approach for evaluating risks for individual dams. The Committee believes this is a deficiency in the field of dam safety that should be corrected in the interest of minimizing the failure of existing dams and consequent losses.

Essentially, risk analysis involves the consideration of two basic elements: (1) the probability of failure, and (2) the consequences of failure (hazard potential or potential losses in the event of failure). The combination of these two elements in a rational manner produces a measure of risk. Such results can be used for the ranking of dams to establish priorities for pursuing safety measures and actions.

An assessment of the hazard potential would involve a determination of population and property classification within the downstream zone which would be inundated by dam failure. With that information, an estimate could be made of the probable loss of life, property damage and other socio-economic effects based upon expected characteristics of a possible failure and the resulting flood wave, and the expected mitigating effects of established emergency preparedness procedures.

A ranking of dams by only the hazard potential would be a significant advance in the priority listing of dams and by itself would be very helpful to dam engineering and regulatory organizations. In compiling the National Dam Inventory, the Corps of Engineers assigned tentative hazard potential classifications to about 75% of the 49,000 dams inventoried. Dams were assigned to one of three

broad classifications - low, significant, and high - depending only upon estimated levels of habitation and property importance downstream of the dams.

Utilizing a listing of dams by hazard potential alone, however, for the purpose of assessing relative risks, would assume that all dams have the same probability of failure, which should be recognized as incorrect. Dams are located in different geological, seismological and hydrological situations and are of various types, sizes, ages and materials. These factors, together with information from past dam failures, could be inputs to an analysis of the probability of failure. Such analyses must rely heavily upon the engineering judgment and experience of professionals. The combination of these results with the hazard potential would produce an assessment of the total risk.

The Committee recognizes that the application of risk analysis, as discussed above, would be an innovation in dam engineering and surveillance procedures and that some research and study would be required for developing applicable methodology. However, such a development would be within present capability and should be pursued in the interest of dam safety. The type of methodology proposed is similar to that outlined by Vanmarcke²² for quantifying the benefits of dam inspection programs and dealing with the allocation of limited funds for inspecting many dams with different failure probabilities and hazard potentials.

V. RECOMMENDATIONS

5.1 DAM SAFETY OFFICE

The Bureau should establish an independent dam safety office, responsible directly to the Commissioner of Reclamation, to discharge the single function of dam and reservoir safety in the public interest. The safety office should be structured in accordance with the outline provided in Chapter III of this report entitled, "Elements of a Safety Program for Existing Dams."

5.2 MANPOWER AND FUNDING RESOURCES

Management should ensure that adequate funds and manpower are provided to accomplish all essential elements of dam safety within established time frames, including the correction of deficiencies.

5.3 UTILIZATION OF OUTSIDE ENGINEERING SERVICES

The Bureau should extend the recently adopted policy to use independent consultants on all future designs for major dams to encompass engineering evaluation for safety of existing dams. Consultants should be truly independent, and the Bureau should utilize a broad spectrum of the consulting engineering profession to obtain the greatest possible range of engineering experience and knowledge.

5.4 STANDING OPERATING PROCEDURES MANUALS

The Bureau should complete on a reasonable schedule manuals on Standing Operating Procedures for all of its major dams.

5.5 INSTRUMENTATION

(1) Field instrumentation to monitor the behavior of dam structures and to assist in evaluating safety should be a requirement for all major dams.

(2) The Bureau should instrument those major concrete and embankment dams presently lacking behavioral instrumentation.

(3) The Bureau should study the appropriateness and need at all major projects of instruments which would provide an alert or warning when the reservoir approaches critical level. Such devices could monitor lake level once it becomes critical, and measurements could be telemetered to the regional office or a central monitoring center.

(4) Strong motion seismographs should be located at all major damsites in earthquake zones 3 and 4.

5.6 REVIEW OF MAINTENANCE PROGRAM

(1) The Bureau should increase the scope of and participation in the 6-year examinations under the Review of Maintenance Program in order to obtain a comprehensive technical assessment of project features. Such examinations should include reviews of project data such as design criteria, subsurface profiles and logs, stability analyses, and construction and operating records; and all disciplines pertinent to dam engineering should participate.

(2) Responsibility for the total examination program, including the programming of remedial work, in all regions, should be centrally located so as to improve effectiveness.

(3) All pertinent project engineering data should be collected and permanently retained in a single repository, preferably at the project site whenever practicable. Such data should include design analyses, subsurface exploration results, laboratory reports, as-built drawings, and pertinent construction records.

(4) Special on-site inspections and evaluations of major dams should be made by qualified personnel during and/or immediately following unusual events such as floods creating reservoir pool levels and spillway discharges equal to or greater than those previously experienced.

5.7 LANDSLIDE SURVEILLANCE PROGRAM

To accomplish the objective of the Landslide Surveillance Program, the Bureau should:

(1) Complete the inventory by identifying all significant active, inactive and potential landslides at every reservoir and wherever the landscape may be affected by Bureau operations.

(2) Establish the degree of risk present in each landslide.

(3) Take the actions necessary to mitigate risk situations.

(4) Establish priorities for further instrumentation, geological investigations and analytical study where the risk of a landslide is high and where possible establish threshold values such as maximum credible earthquake, height of ground water, rate of drawdown, and lateral movement.

(5) Establish contingency plans in the event of failures of high-hazard slides.

5.8 EXAMINATION OF EXISTING STRUCTURES PROGRAM

(1) The Bureau should give higher priority to the Examination of Existing Structures Program, particularly for evaluation of those dams in high-hazard areas. The Program should be expanded to encompass a comprehensive review of safety examination of each structure taking into account all aspects bearing on safety as well as the hydrological and seismological concerns currently under study.

(2) The Bureau should give higher priority to the examination and evaluation of the safety of all dams located upstream of Bureau dams whose failure would adversely affect Bureau's dams. For this purpose, the Bureau should seek the necessary authority and funding.

(3) The Bureau should establish formal, routine procedures for funding the remedial works identified by this Program. Authorization for such funds should be sought by lump sum, line item in the yearly budget request rather than on an ad hoc, project by project basis.

5.9 HYDROLOGY

(1) The Bureau should become more aggressive in the development, acquisition, testing and, where appropriate, application of mathematical watershed models and should establish closer ties and cooperative ventures with government organizations such as the Corps of Engineers' Hydrologic Engineering Center and private firms that have expertise in this field.

(2) The spillway design flood methodology should be modified such that a spectrum of possible design hydrographs is computed representing various likely combinations of design assumptions and parameter values. The rationale for

selection of a particular hydrograph for design purposes should then be documented in an explicit manner.

(3) Further development of state-of-the-art methods should be encouraged in order to establish computational procedures which can facilitate the development of inundation maps.

5.10 SEISMOLOGY

(1) The Bureau should make a more complete geologic and seismologic analysis for existing dams in order to estimate maximum credible earthquakes in regions of high to moderate seismicity or from active faults.

(2) The Bureau should accelerate the present slow rate of geologic and seismologic review of existing structures in order to achieve completion of the program in a reasonable period of time.

(3) The Bureau should develop, with other concerned federal agencies, standard, but flexible, state-of-the-art guidelines for the assessment of active faults and establishment of near and far field maximum credible earthquakes.

5.11 EMERGENCY PREPAREDNESS

The Bureau should establish a more effective and comprehensive emergency preparedness program. Significant elements of that program should include:

(1) Extensive training of project operating personnel, stressing procedures to be followed in the event of dam failure or other serious flooding.

(2) Coordination, education, and training of Bureau and user personnel, civil defense authorities, and community leaders downstream of the dam regarding warning and evacuation procedures in the event of dam failure.

(3) Preparation of inundation maps for all dams whose failure would endanger the lives of the public or cause substantial property damage. Such maps should be prepared on the basis of failure with full, medium, and low reservoir levels and should consider the effects of an upstream dam failure upon downstream dams on the same river course. These maps should be filed with appropriate downstream public officials for their use in developing warning and evacuation procedures.

(4) Installation of suitable audible warning systems where appropriate to alert those in the immediate downstream area of impending failure or of increased discharges which cause rapid rises in tailwater levels.

5.12 ENGINEERING GEOLOGY

In view of the fact that a high percentage of dam failures are caused by geologic and geotechnical factors primarily in the foundations of dams, the Bureau should consider such Engineering and Research Center organizational changes as would be required to strengthen the role and responsibility of engineering geologists and geotechnical engineers at the Center.

5.13 RISK-BASED ANALYSES

The Bureau and the profession should give consideration to the preparation and implementation of a probabilistic or risk analysis program for the purpose of ranking major dams in accordance with the hazard potential and probability of a failure or partial failure of the structure. Subsequently, the Bureau should initiate a program to inform the public that while all of its dams are considered safe, they nevertheless pose very small but varying degrees of risk of failure.

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APPENDIX A

POST-TETON DAM FAILURE REVIEWS AND SAFETY ACTIVITIES

This Appendix briefly reviews the investigation, studies and other dam safety activities resulting from the Teton disaster. These activities include Congressional and engineering investigations into the failure of Teton Dam, reviews of Bureau of Reclamation procedures, both technical and non-technical, and the initiation of government-wide programs for ensuring the safety of all federal dams.

1 CONGRESSIONAL INVESTIGATIONS

1.1 House of Representatives Investigation

Following the Teton Dam failure, the Subcommittee on Conservation, Energy and Natural Resources of the House of Representatives Committee on Government Operations launched an investigation into the facts and circumstances which led to the disaster. The Subcommittee conducted public hearings, interviewed witnesses, and reviewed numerous pertinent documents. The Committee recommended a number of reviews and studies pertaining to the Bureau of Reclamation practices and procedures.¹ The Committee requested the General Accounting Office (GAO) to examine the site selection process for Teton Dam and other selected dams, and to provide a comparative analysis of the adequacy of the methods and procedures used by the Bureau of Reclamation and the Corps of Engineers. The Committee also asked the GAO to review the adequacy of procedures followed when potential problems are identified during site selection and construction.

1.2 Senate Investigation

The Subcommittee on Energy, Research and Development of the Senate Committee on Energy and Natural Resources initiated an investigation to discover the cause of the Teton Dam failure and, in addition, to establish a set of recommendations that might help avert any future similar disasters. The Subcommittee concluded² that the failure

resulted from circumstances which could have been foreseen and accounted for and that, therefore, the failure must be attributed to inadequacies in the design of key components of the structure. The Subcommittee recommended the establishment of an independent Federal Board for Dam Safety. This Board would establish procedures for safety reviews and standards for federal dams and determine the adequacy of sites and designs for all proposed large federal dams. It would accomplish several studies dealing with Bureau of Reclamation organizational and procedural structures, the use of the U.S. Geological Survey for evaluating the suitability of each new dam site, the possible consolidation of functions of the major federal dam building agencies, and the relative merits of designing large dams by federal agencies versus contracting all or part of their work to private-sector engineering firms. The Subcommittee also recommended certain modifications in Bureau of Reclamation procedures to encourage the discovery of any information that might bear on the safety of any existing or proposed dam or any dam under construction, to take steps to upgrade the competency of the professional staff, and to establish a policy of regular site visits by designers.

1.3 Review by the General Accounting Office (GAO)

At the request of the Subcommittee on Environment, Energy, and Natural Resources of the House of Representatives Committee on Government Operations (see paragraph 1.1), the GAO reviewed the dam building procedures and practices used by the Bureau of Reclamation and by the Corps of Engineers to determine whether changes are needed relating to the safety of dams being built. The GAO concluded³ that: an independent review for all storage dams should be made part of the Bureau's instructions; an independent review of the Bureau's technical procedures should specifically address the questionable design practices identified by the independent Panel investigating the Teton dam failure; the Bureau should develop instructions and drawings that more clearly reflect the intent of its designers; Bureau designers should visit the site frequently to be as sure as possible that the design intent is achieved; and the Bureau should establish improved policies and procedures regarding (1) requirements for the amount and use of instrumentation for monitoring changing conditions inside the dam and the abutments, (2) requirements for visual inspections during reservoir filling, (3) availability and capacity of outlet drains, and (4) appropriate reservoir filling criteria.

In regard to emergency preparedness plans and procedures, the GAO recommended that the Bureau revise

guidelines and procedures to establish a stronger emergency preparedness program and develop emergency preparedness plans for all major dams before reservoirs are filled. Such plans should contain a definition of emergency situations that require immediate notification of local officials and should include maps which show lands that would be flooded if a failure occurs. The GAO also suggested that the Bureau evaluate the availability and use of radio systems between dam sites and civil defense or other emergency offices as an alternative means of communication in case telephones are busy or inoperable during emergencies, and that the Bureau study the feasibility of using horns or other publicized alarm systems during emergencies to warn people that may be downstream near the dam.

2 INVESTIGATION OF THE TETON FAILURE BY AN INDEPENDENT PANEL

Immediately following the failure of Teton Dam, the Governor of the State of Idaho and the Secretary of the Interior jointly appointed an independent panel of experts to conduct an engineering and geological review of the cause of the failure. The Panel completed its investigation in December 1976, and its report⁴ attributed the failure to an unfortunate choice of design together with less than conventional precautions to ensure adequate functioning of the dam. The design did not adequately take into account the foundation conditions.

3 INVESTIGATION OF THE TETON FAILURE BY THE U.S. DEPARTMENT OF THE INTERIOR REVIEW GROUP

Concurrent with the Independent Panel's investigation, a Department of the Interior Review Group, consisting of representatives of several federal agencies, conducted an investigation of the Teton failure. On June 8, 1976, the Under Secretary of the Interior requested that the Group examine the causes of failure and make recommendations to prevent the recurrence of such failures. The Group's findings⁵ agreed with the Independent Panel with respect to placing blame on inadequate design. The Group developed several recommendations regarding the prevention of the recurrence of such failures which included use of an independent board of review for every major dam during design and construction, and that design personnel remain actively involved with a project during construction. The Group also recommended that major dams and their foundations include instrumentation to monitor construction and post construction behavior, and that the data be promptly interpreted and evaluated.

Supplementing its report, the Review Group wrote⁶ to the Secretary of the Interior in May, 1977, and listed additional recommendations which pertain to organization and procedures. The Group noted that construction engineers are administratively responsible to the regional director and technically responsible to the Director of Design and Construction, and concluded that this division of management responsibility has created serious problems and should be corrected. The Group also noted problems with coordination and control related to the present organization in the Engineering and Research Center and recommended that all research, planning, design, construction, operation, and maintenance activities for major dams be placed under a Chief Engineer in the Engineering and Research Center. Other recommendations of the Group pertain to division in responsibility for pre-construction activities, the involvement of field geologists in decision making relative to foundation treatment, and the documentation of design concepts and intent prior to construction as well as any design modifications found necessary during construction.

4 REVIEWS OF BUREAU OF RECLAMATION'S DAM BUILDING PROCEDURES

4.1 Review of Bureau Non-Technical Procedures

In December 1976, an in-house study team completed a review of the Bureau's management procedures that affect dam safety.⁷ The study team developed a comprehensive set of flow charts defining procedures followed during the planning, design, research, construction, and operation and maintenance phases of large dams. The team also interviewed key officials of the Bureau of Reclamation to uncover any organizational problems related to the procedures. This effort included a comparison of Bureau procedures with those of the Corps of Engineers and the Tennessee Valley Authority. The study team concluded that nothing in Bureau dam procedures, as presently operated, indicates the need for immediate change, and that the organizational structure does not hamper communication either across or up and down organizational lines. In this regard, a difference exists with the views of the Interior group which reviewed the Teton failure (see paragraph 3). The study team acknowledged one important difference between Bureau practice and those of the Corps and TVA in that the Bureau makes only little use of outside consultants during the dam building process. Both the Corps and TVA use consultants more extensively to accomplish specific work, to advise on specific problems, and to serve on review boards.

4.2 Review of Seven Recently Completed Dams

The U.S. Department of the Interior engaged the firm of W.A. Wahler and Associates, Palo Alto, California, to study seven recently completed dams whose reservoirs are currently being filled. These studies⁸⁻¹⁴ encompassed a field inspection and a critical review of available data on the site and material investigations, design, construction, and operation of the dams and important appurtenant structures to ascertain any apparent risks of serious disasters or failure in filling the reservoirs or in operating the projects.

Dams covered by this review were Soldier Creek Dam in Utah, Pueblo Dam in Colorado, Crystal Dam in Colorado, Ririe Dam in Idaho (designed and constructed by the Corps of Engineers), Nambe Falls Dam in New Mexico, Mountain Park Dam in Oklahoma, and Mt. Elbert Forebay Dam in Colorado.

The Wahler firm raised major safety concerns in the cases of Pueblo, Soldier Creek, and Mt. Elbert dams. For Pueblo,⁹ based on the lack of data which would confirm the adequacy and stability of the earth embankments, W.A. Wahler and Associates recommended that the pool not be permitted to rise significantly above the present level until certain supplementary investigations are completed. The firm concluded⁸ that serious risk could be involved in filling the pool behind Soldier Creek Dam and recommended the completion of further explorations, testing, instrumentation, and certain remedial work. The remedial work would serve to control piping and to facilitate the safe discharge of any seepage water that may reach the downstream portion of the embankment, foundation, and abutments. At Mt. Elbert Forebay Dam, the review engineer recommended¹⁴ that the initial filling of the reservoir be delayed pending completion of certain engineering studies, reservoir blanket repairs, modifications to the penstock gate control system, and installation of additional instrumentation.

Based upon the Wahler findings, on August 9, 1977, the Department of the Interior announced¹⁵ the suspension of pool filling in the cases of the Pueblo, Mt. Elbert Forebay, and Soldier Creek Dams.

4.3 General In-House Review of Technical Procedures

On April 23, 1977, the President directed¹⁶ that 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 immediately undertake a

thorough review of practices which could affect the safety and integrity of dam structures. Specifically mentioned to be investigated were reviews for including new technology 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; and the involvement of local communities in identifying, analyzing, and solving dam safety questions. The Commissioner established a Bureau of Reclamation team for accomplishing this effort in May 1977, and the team was scheduled to submit its report to the Commissioner in mid-August 1977.

4.4 In-Depth Review of Technical Procedures by Independent Firm

The Secretary of the Interior has directed that an in-depth review of the Bureau of Reclamation dams program for technical capabilities, safety procedures, and design analysis procedures be conducted by an outside engineering firm. The objective of this review is to determine whether the Bureau of Reclamation technical procedures used in planning, design, research, construction, operation, and maintenance of water storage dams follow reasonable safety standards within the limits of existing technology. The technical adequacy of procedures for maintaining structures during operation will be a part of this effort. Proposals for the work have been solicited and received, but a contract has not been awarded by August 12, 1977, when the Committee on the Safety of Dams terminated its review. An effort of about 10-months duration is contemplated and results will not be available prior to late 1978.

4.5 Review of Activities Related to the Safety of Existing Dams by the NRC Committee on the Safety of Dams

In July and August, 1977, at the request of the U.S. Department of the Interior, the Committee on Dam Safety of the National Research Council reviewed and critiqued those activities of the Bureau of Reclamation related to the safety of existing dams. The report of which this Appendix is a part resulted from that effort. In the report, the Committee presents a set of recommendations to improve dam safety in the Bureau of Reclamation in the public interest.

The principal recommendations of the NRC Committee on the Safety of Dams include: (1) the establishment of an independent dam safety office within the Bureau; (2) the implementation of risk analysis based programs for the purpose of ranking major Bureau dams; (3) the use of independent consultants for performing engineering evaluations of the safety of existing dams; (4) the establishment of a more effective and comprehensive emergency preparedness programs; (5) improving the field instrumentation program for safety evaluation purpose; 6) increasing the scope of and participation in the 6-year dam examinations; (7) the expansion and acceleration of activities performed under the Bureau's Examination of Existing Structures Program and the Landslide Surveillance Program; (8) the implementation of steps to strengthen the role and responsibility of Bureau engineering geologists and geotechnical engineers; (9) the preparation of inundation maps for dams whose failure would endanger human life or cause substantial property damage; and (10) the implementation of certain improvements in the methodologies used for performing hydrologic and seismologic studies.

5 OTHER EFFORTS PERTAINING TO FEDERAL DAM BUILDING PROCEDURES

5.1 Effort of the FCCSET

The President's April 23, 1977, directive¹⁶ (paragraph 4.3) instructed the Chairman of the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) to convene an ad hoc interagency committee to coordinate federal 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 directed by that memorandum are to be provided to the FCCSET to form the basis for the interagency analysis by FCCSET which is to be completed by October 1, 1977. This effort by FCCSET includes the preparation of proposed federal dam safety guidelines for management procedures to ensure dam safety.

5.2 Independent Review Panel

The President also requested¹⁶ the Director of the Office of Science and Technology Policy to arrange for a review of federal agency regulations, procedures and practices, and of the proposed federal dam safety guidelines by a panel of recognized experts. The purpose of the panel is to advise the President as to the adequacy of procedures and regulations throughout the federal government to ensure

the safety of dams which are in any way affected by a federal role.

APPENDIX REFERENCES

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14. W.A. Wahler and Associates (1977). Review of Design, Construction, and Operation of Mt. Elbert Forebay Dam and Reservoir Project, Colorado, U.S. Department of the Interior, Washington, D.C.
15. U.S. Department of the Interior, Press Release (August 9, 1977) concerning the Pueblo, Mt. Elbert and Soldier Creek Dams.
16. President Jimmy Carter (1977). Memorandum to all principal dam safety agencies within the government.