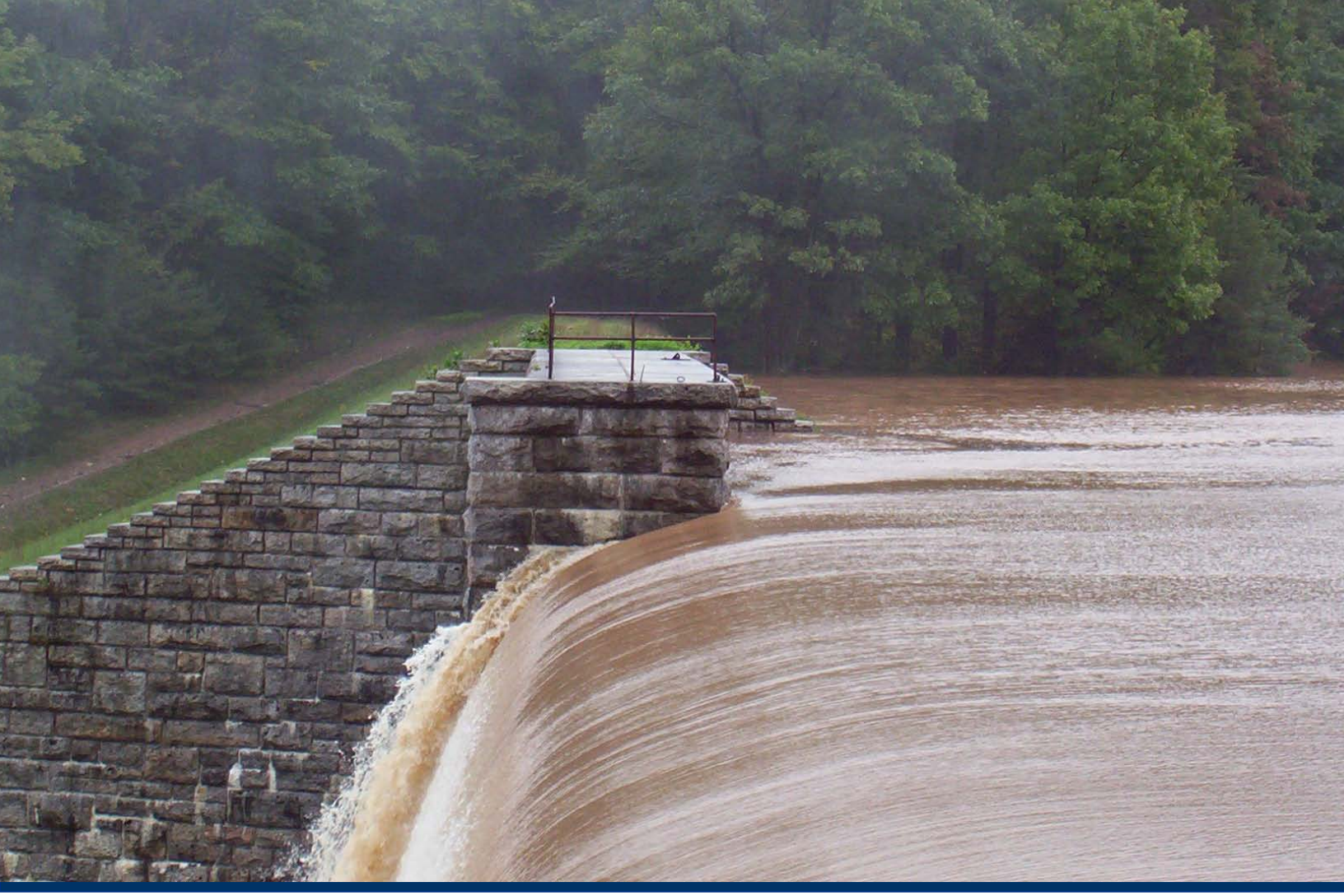

Summary of Existing Guidelines for Hydrologic Safety of Dams

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Preface

In September 2010, the Federal Emergency Management Agency's National Dam Safety Program sponsored development of this document under the supervision of James E. Demby, Jr., P.E. The primary authors of this document are Dr. Arthur Miller, P.E. (AECOM); and Paul Schweiger, P.E.; Amanda Hess, P.E.; Rod Holderbaum, P.E.; Bob Kline, P.E.; Don Roarabaugh, P.E.; and Gregory Richards, E.I.T. (Gannett Fleming).

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United States Bureau of Reclamation

The authors caution readers of this document that sound engineering judgment should always be applied when using technical references. This publication is intended solely for use by professional personnel who are competent to evaluate the significance and limitations of the information provided herein, and who will accept total responsibility for the application of this information. Anyone making use of this information assumes all liability from such use.

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Federal Emergency Management Agency

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Executive Summary

Background

There is a need for updated guidelines for evaluating the hydrologic safety of dams, and in particular, for determining the appropriate Inflow Design Flood (IDF) and freeboard requirements. The existing hydrologic guidelines of some states and federal agencies were written in the late 1970s. Since that time, significant technological and analytical advances have been made along with better watershed and rainfall information that improve the analysis of extreme floods and quantification of incremental dam failure consequences. Many existing dams that were constructed before dam safety rules existed still do not meet regulatory guidelines for safely passing the IDF. Existing guidelines often do not treat new and existing dams the same in recognition of the fact that upgrading older dams to pass the IDF can be difficult and expensive.

There continues to be much debate with the current criteria, both within the engineering profession and among dam owners and others involved with dam safety. Several states and federal agencies have recently updated their dam regulations, including the sections relating to hydrologic safety; however, there appears to be considerable inconsistencies and non-uniformity in the dam classification systems and spillway capacity criteria being specified.

The overriding purpose of this report is to document the available data and to present the state of the practice for evaluating the hydrologic safety of dams, including inventorying current practices used by state and federal agencies. This work included a review of hydrologic guidelines currently used in each state and federal agency that regulates dams, and was guided by an independent steering committee and reviewed by the Research Work Group. A subsequent publication will include new federal guidelines for the evaluation of the hydrologic safety of dams that could be applied nationwide.

United States Dam Inventory

The current National Inventory of Dams, developed and maintained by the U.S. Army Corps of Engineers (USACE), contains data on nearly 84,000 dams within the United States. Approximately 11,000 of these dams are considered High Hazard, another 11,000 dams are considered Significant Hazard, and the remaining are considered Low Hazard. Most of the dams (over 65,000) are regulated by the states and owned by a variety of private or municipal entities. Federal agencies own or regulate approximately 6 percent of dams [FEMA, 2010].

Evolution of Design Flood Selection for Spillways

An understanding of the timeframe of the development of the methodologies for selecting the Spillway Design Flood (SDF) in the United States is helpful to understanding the history of dam safety guidelines since each type of design flood selection methodology must first be introduced and evaluated by the dam safety community before it becomes accepted and included in the

guidelines. While laws related to the performance of dams have existed since before 1700 BC, dam designs during the early period of dam building in the United States were based solely on the judgment of the engineer. By about 1900, however, the field of surface water measurement had advanced enough to support the development of empirical equations to transpose maximum regional discharges to the drainage area of interest in order to predict peak flood discharges.

Systematic nationwide collection of surface water data began in earnest by the U.S. Geologic Survey in 1934 when the New Deal Federal Public Works Administration obtained funds to perform detailed studies of floods, rainfall, and runoff. The 1930s and 1940s saw many significant advances in hydrology including the innovation of the unit hydrograph which made it possible to estimate flood flows from storm rainfall.

The years following 1950 saw the development of elegant theoretical and mathematical approaches to solve hydrologic problems. This along with the advancement of computers to perform computationally demanding analyses led to greater use of watershed modeling using unit hydrographs and precipitation. During this period, engineers turned to meteorologists to establish limiting rates of precipitation for design purposes. Between 1963 and 1984, a series of Hydrometeorological Reports were subsequently developed to establish Probable Maximum Precipitation (PMP) estimates for the majority of the country.

While deterministic approaches to the hydrologic design of dams have been overwhelmingly supported over the past few decades, there has also been an increased interest in the application of risk analysis. The U.S. Bureau of Reclamation (Reclamation) appears to be the first agency to seriously apply risk-based decision making to dam safety. Beginning around 1995, Reclamation adopted the use of risk analysis as the primary support to their dam safety decision-making. In 1997, the USACE replaced the Probable Maximum Flood standard with an incremental procedure to provide a framework for evaluating the benefits of mitigating hazards presented by hydrologic deficiencies in high hazard situations.

Today, many professionals consider risk assessment to be a useful way to ensure dam safety as it requires dam owners to investigate failure modes in detail and understand where the greatest risks lie. However, the main drawback of this approach is that it is technically challenging, time consuming, and difficult to administer, and so the traditional standards based approach is generally still adopted by the states.

Origins of Dam Safety Design Guidelines

Thus far, the methodology used to determine spillway adequacy has been described without regard for the actual regulatory framework. Prior to 1950, regulatory guidelines and design standards for the hydrologic safety of dams were based mainly on judgment and experience. As of 1964, a fourth of the states exercised no supervision over dams at all, and a third exercised no responsibility over operation and maintenance of a dam once it was constructed. This same year, Franklin F. Snyder,

Hydraulic Engineer with the Office of the Chief of Engineers, published a dam classification and spillway design flood matrix that considered dam height, storage, and damage potential.

In the early 1970s a series of dam safety incidents occurred resulting in significant loss of life including the failure of Buffalo Creek Dam (West Virginia) in February 1972 and Canyon Lake Dam (South Dakota) in June 1972. Following these events, the Congress enacted the National Dam Inspection Act (PL 92-367) which became law on August 8, 1972. The Mine Safety and Health Administration (MSHA) also gained regulatory jurisdiction of coal refuse impoundments at this time. In the early 1970s, many states did not have laws regarding dam safety and often did not require a review of the dam design prior to construction or require construction inspection or post-construction inspection. It was also found that dam safety in most states was inadequate with a wide variation of practices, regulations and capabilities of all agencies supervising dam safety. There was also little or no overall coordination of dam safety efforts.

Dams subject to PL 92-367 were those having a height 25 feet or greater, or a maximum impounding capacity greater than 50-acre-feet. Dams less than six feet high or storing less than 15 acre-feet were excluded. Congress charged the USACE with implementing the provisions of the Act. In addition to carrying out a national program of inspection of dams for the purpose of protecting human life and property, the act also required: (1) an inventory of all dams located in the United States; (2) a review of each inspection made; and (3) recommendations for a comprehensive national program for the inspection and regulation of dams, and the respective responsibilities which should be assumed by Federal, State, and local governments and by public and private interests.

Because of the scale of the program, the USACE developed a classification system to screen the adequacy of spillway capacity. The selected classification system was quite similar to that proposed by Snyder in 1964 and closely resembles the current classification criteria used by many states.

In 1979, the Federal Emergency Management Agency (FEMA) and the *ad hoc* Interagency Committee on Dam Safety issued "Federal Guidelines for Dam Safety." This document provided the first guidelines for federal agency dam owners and dam owners regulated by federal agencies. For flood selection design or evaluation, the federal guidelines supported the use of risk analysis. The guidelines were clear, however, that the spillway design standard to be adopted for dams where loss of life or major property damage could be significant was the Probable Maximum Flood (PMF).

In 1986, FEMA published "Federal Guidelines for Selecting and Accommodating Inflow Design Floods for Dams" as a supplement to the "Federal Guidelines for Dam Safety." The primary purpose of the document was to provide general guidelines on procedures for selecting and accommodating inflow design floods for use by federal agencies in developing agency criteria and to ensure more nationwide uniformity in application.

Several other guidance documents relating to the hydrologic safety of dams were published in the decades that followed by agencies such as FEMA, the American Society of Civil Engineers (ASCE), and the National Research Council. These documents included numerous recommendations supporting both deterministic and risk-based approaches to spillway design. The guidance documents also identified several inconsistencies in the state-of-the-practice.

Pertinent International Guidelines

While the scope of this study specifically addresses guidelines for hydrologic safety of dams within the United States, there are several developments in the international arena that are particularly relevant to the study. Recently updated guidelines in Australia and Canada were reviewed and are summarized to provide a glimpse of how other countries' guidelines are changing. The Australian National Committee on Large Dams (ANCOLD) led the way internationally in the development of acceptable risk criteria in dam safety and published *Guidelines on Risk Assessment* in 1994. This was followed with *ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams* which was published in 2000 to provide more appropriate and consistent guidance within a risk process for dam safety evaluation under floods. These guidelines provided a basis for integrating risk assessment into dam safety. Guidelines published by the Canadian Dam Association (CDA) in 2007 include a dam classification system based on failure consequences and discuss both the traditional standards-based approach and the risk-based approach to dam safety decision making. Selecting the IDF using quantitative risk analyses is not discussed in CDA's guidelines and appears to be discouraged because of the inability to accurately assign a probability to extreme floods.

2011 Hydrologic Safety of Dams Survey and Summary of State and Federal Guidelines

In order to document the present state of the practice for evaluating the hydrologic safety of dams and inventory current practices used by state and federal agencies within the United States, a detailed questionnaire was prepared and distributed to all state dam safety agencies as well as any federal agencies which own, regulate, or assist in the design of dams. The questionnaire addressed many important issues related to the hydrologic safety of dams including dam classification criteria, determination of the spillway design flood, allowable methodologies and software, consideration of future development, incremental damage assessment, use of early warning systems, current practices related to risk analysis, and agencies' ability and receptiveness to perform risk analysis.

Surveys were completed by the appropriate dam safety agency from all 50 states as well as Puerto Rico with exception of Alabama and Florida. Of the federal agencies, respondents included the Bureau of Indian Affairs, Federal Energy Regulatory Commission (FERC), Mine Safety and Health Administration, Natural Resources Conservation Service, Tennessee Valley Authority (TVA), U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Forest Service, and the U.S. Fish and Wildlife Service. A comparison of survey results with past documented surveys allows the identification of trends and changes related to the hydrologic safety of dams over the past 40 years.

The Current State of the Practice

The existing hydrologic guidelines of many states and federal agencies were written in the 1970s or 1980s. Since that time, significant technological and analytical advances have been made along with better watershed and rainfall information that have improved the analysis of extreme floods and quantification of incremental dam failure consequences. Review of the published policy and guidelines for each state as well as the responses to the detailed survey completed as part of this study have revealed several important findings that can be used to define the current state of the practice regarding the hydrologic safety of dams.

In general, the guidelines for the hydrologic safety of dams are not consistent and vary widely from state-to-state and between federal agencies in many respects. Although some states and agencies have recently updated their guidelines, many states and agencies have not significantly changed their guidelines since their development. Some of those who have changed their guidelines have incorporated some form of risk-based analyses, but the requirements and methodology differ widely.

Some of the most notable inconsistencies in the existing guidelines relate to classification systems. From the most basic criteria for what defines a regulatory or a jurisdictional dam to whether the dam is classified by size, hazard, or not at all, there is no overwhelming majority of configuration for these classification systems. While size classification is used by many states and hazard classification is used by all states, the number of classifications and the distinctions between the classes vary. There is also no consensus on distinctions between new dams and existing dams.

In determining the magnitude of the SDF, most states follow a prescriptive approach in which the design flood is specified based upon the dam's classification (size, hazard, or both). Both probabilistic and deterministic (based on PMP or PMF estimates) criteria are used for the prescriptive approach by the states and agencies. Many of the criteria in prescriptive approaches are arbitrary with no apparent scientific rationale, and the prescribed SDFs for identical dams in different states have varying magnitudes.

Historically, a few important federal agencies have led the way in the development of dam safety regulations and design standards, and the trend among these agencies is toward incorporating a risk-based approach rather than the prescriptive approach. The USACE is currently partnering with Reclamation, FERC, and TVA to achieve a common risk management framework and guidelines. This trend toward risk-based design is also apparent in the international practice.

The transition to risk-based analyses in some states has also begun. The methodologies developed by California, Washington, and Montana reflect an initial movement to make site-specific, cost-effective, and risk-based designs. They also demonstrate how the complexities of risk analysis can be applied in a simplified, standard-based system. Comparison of these three recently developed, risk-based approaches indicates a lack of consistency regarding the criteria used among the systems, the weights assigned to the criteria, and the resultant risk tolerances.

Although the trend appears to be the incorporation of risk-based approaches into guidelines for the hydrologic safety of dams, there are many obstacles to widespread acceptance by state regulatory agencies. The budgets, staff availability, and technical ability of many dam safety state agencies are very limited. Many respondents indicated that they have concerns regarding risk-based analyses to determine spillway capacity requirements due to review requirements and the lack of widely acceptable and defensible guidelines.

It should also be noted that the federal agencies who have led the way in developing risk analysis procedures and tolerances are owners of a significant number of dams. These agencies have been able to utilize the prioritization and ranking aspects of risk analysis to manage their respective portfolios in addition to using quantitative risk analysis in design. The administrative processes and reviews of regulatory agencies, such as FERC, MSHA, and most of the states, differ significantly from that of dam owners like USACE and Reclamation. The application of quantitative risk analysis for dam design in regulatory agencies may be burdensome or even unnecessary. The state dam regulatory agencies of California, Washington and Montana have recently developed risk-based indices to determine acceptable flood capacity; however, none of the states use quantitative risk assessment.

There are many differing opinions regarding the need for uniformity of design criteria between states and federal agencies. It is generally recognized that the implementation of strictly uniform criteria is not a possibility. Instead, a flexible framework of criteria may be required to provide for the specific requirements, budget, and technical ability of each state. While leading federal agencies and a few states have recently transitioned from strictly prescriptive to risk-based criteria, it is evident that a large portion of the dam safety community has significant reservations concerning the validity and practicality of risk analysis. Having one set of federal dam safety standards for risk determination may help to promote the use of risk-based analysis by states and potentially encourage increased uniformity of state guidelines.

The survey responses also indicate that a significant portion of the dam safety community is unaware of current and even long-standing landmark publications regarding guidelines for the hydrologic safety of dams. A quarter of respondents were unaware of FEMA's 2004 federal guidelines for "Selecting and Accommodating Inflow Design Floods for Dams," and approximately half were not familiar with the most recently published USACE, Reclamation, and ASCE inflow design and dam safety guidelines. It is therefore apparent that any attempt to encourage the adoption of more uniform guidelines and consideration of adopting risk-based criteria will require a more effective outreach and educational effort.

Although the literature search identified several studies that provided information on state practices related to selecting inflow design floods for dams, none of the studies provided a comprehensive compilation of this data. In addition to providing background information for developing new federal guidelines for the hydrologic safety of dams, this report and the associated database provide a comprehensive compilation of current federal and state guidelines that can be used by individual

states to evaluate and compare their current guidelines with those of other agencies. As individual states revise their guidelines, this information will provide them with important information that will help them to make informed decisions that should result in more uniformity.

1. Introduction

1.1. Authorization

There is a need for updated guidelines for evaluating the hydrologic safety of dams, and in particular, for determining the appropriate Inflow Design Flood (also referred to as Spillway Design Flood) and freeboard requirements. The existing hydrologic guidelines of many states and federal agencies were written in the late 1970s. Since that time, significant technological and analytical advances have been made along with better watershed and rainfall information that improve the analysis of extreme floods and quantification of incremental dam failure consequences. Many existing dams that were constructed before dam safety rules existed still do not meet regulatory guidelines for safely passing the Inflow Design Flood (IDF). Existing guidelines often do not treat new dams and existing dams the same in recognition of the fact that upgrading older dams to pass the IDF can be difficult and expensive.

There continues to be much debate with the current criteria, both within the engineering profession and among dam owners and others involved with dam safety. Several states and federal agencies have recently updated their dam regulations, including the sections relating to hydrologic safety, however, there appears to be considerable inconsistencies and non-uniformity in the dam classification systems and spillway capacity criteria being specified.

In September 2010, the Federal Emergency Management Agency (FEMA) authorized a new study titled: "*Development of Guidelines for the Evaluation of Risk-Based Hydrologic Safety of Dams.*" The objective of this study is to develop and publish a guidance document for the evaluation of the hydrologic safety of dams, including guidelines for determining the IDF for new and existing dams that could be applied nationwide. This project is being completed under the direction of Dr. Art Miller with management and execution of the project by the BakerAECOM Risk MAP Professional Technical Services (PTS) Team comprised of Gannett Fleming, AECOM, Michael Baker, Jr., Inc., and Taylor Engineering. The project team includes an Independent Steering Committee comprised of Dan Mahoney (FERC), John Moyle (NJ), Brian Long (WV), Jim Gallagher (NH), and Lawrence Siroky (MT).

1.2. Purpose

Prior to developing the guidance document for the risk-based evaluation of the hydrologic safety of dams, the study team was tasked with reviewing and documenting the hydrologic guidelines currently used by each state and federal agency that regulates dams. Previous publications and technical papers that contain hydrologic safety guidelines for dams were reviewed. Organizations dealing with dam safety were contacted to determine what guidelines and support materials exist, including the Australian National Committee on Large Dams (ANCOLD), the American Society of Civil Engineers (ASCE), the Association of State Dam Safety Officials (ASDSO), the Canadian

Dam Association (CDA), FEMA, the Interagency Committee on Dam Safety (ICODS), the National Research Council (NRC), U.S. Society on Dams (USSD), and others. This initial task also included conducting a survey to gather information from every state dam safety program and federal agency that owns or regulates dams.

The overriding purpose of this report is to document the available data and to present the state of the practice for evaluating the hydrologic safety of dams, including inventorying current practices used by state and federal agencies.

1.3. Scope of Work

The scope of work for developing the guidelines for the hydrologic safety of dams was divided into five tasks. Tasks 1 and 2 relate to the current document which summarizes the existing guidelines while Tasks 3 and 4 relate to preparing the new guidance document. Task 5 relates to monthly reporting. The scope of work for the first two tasks, covering the primary purpose and scope of this reports' effort, is as follows:

> *"Task 1: Data Search – The contractor will review and gather the hydrologic guidelines currently used in each state and federal agency that regulate dams. The contractor shall also review the ASCE publication titled, 'Evaluation Procedures for Hydrologic Safety of Dams,' as well as identifying and reviewing other publications that may contain hydrologic safety guidelines. The contractor shall also contact organizations dealing with dam safety to determine what existing guidelines may exist, such as ICODS, ASDSO and its 'Model State Dam Safety Program,' and FEMA's 'Selecting and Accommodating Inflow Design Floods for Dams.'*
>
> *"Task 2: Compile Data – Within 6 months of contract start-up, the contractor will compile available data and present a draft report which incorporates findings from Task 1. The draft report should include a state of the practice of evaluating the hydrologic safety of dams. The draft report will be submitted to the Research Work Group and an independent steering committee recommended by the contractor and approved by the Research Work Group for review. The Research Work Group and steering committee will provide comments on the draft report within 30 days of submission. The contractor will submit a revised Report incorporating the comments within 30 days of receipt of comments."*