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	EXPIRES 30 June 2009 Engineering and Design INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY	
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CECW-CE

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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Engineering and Design
INTERIM RISK REDUCTION MEASURES FOR DAM SAFETY

1. Purpose. The purpose of this EC is to establish policy for developing, preparing and implementing, Interim Risk Reduction Measures (IRRM). The imperative objective is to reduce the probability and consequences of catastrophic failure to the maximum extent that is reasonably practicable while long term remedial measures are pursued.

All dams are unique and have specific vulnerabilities and potential failure modes that require expert judgment. Prevention of loss of life is paramount over all other social, economic, environmental, and political considerations. Loss of life shall be given preference in all decisions regarding the safety of a dam and in the formulation of prudent risk reduction strategies.

USACE dams have been classified through a risk assessment process into five Dam Safety Action Classes (DSAC), designated herein as Class I thru V. IRRM procedures have bee established for DSAC I, II or III dams which have been classified as Urgent and Compelling, Urgent, and High Priority. Elevated monitoring is typically required for DSAC IV dams. This EC provides specific guidance and procedures that are to be followed when implementing Interim Risk Reduction Measures.

2. Applicability. This EC is applicable to all USACE Commands having Civil Works responsibilities. Use of this document is mandatory for all dams assigned to DSAC I, II, or III.

3. References
ETL 1110-2-561*Relability Analysis and Risk Assessment for Seepage and Slope Stability Failures Modes for Embankment Dams*
EC 1110-2-6061 *Engineering and Design – Safety of Dams – Policy and Procedures*
EP 1130-2-500 *Partners and Support* (work Management Guidance and Procedures)

4. Distribution. Not Approved for Public release. Distribution is limited.

5. General. This Engineering Circular describes the procedures for implementing Interim Risk Reduction Measures for all DSAC I, II, and III dams based upon the USACE Dam Safety Action Classification Table 1 of Appendix A. The DSAC Table provides the characteristics and actions for each DSAC, including preparation of an Interim Risk Reduction Measures Plan (IRRMP), considerations for preparation of the plan, and example interim measures. Interim Risk Reduction Measures are a short-term approach to reduce Dam Safety risks while long-term solutions are being pursued. They are an important step in returning the project to a stable and safe condition. However, they should not (unless otherwise approved) take the place of long-term approaches. In establishing IRRM, the prevention of loss of life is the first and foremost objective, followed by prevention of catastrophic economic or environmental losses. The process of identifying and evaluating IRRM shall be conducted as expeditiously as possible, and collaboratively with the HQUSACE appointed Senior Oversight Group, and regional technical experts within the Corps. After initial assessment within the Corps, early involvement with the project stakeholders (e.g. project sponsors, project beneficiaries, local emergency response agencies, power marketing agencies, etc.) will be established with the goal of coordinating a proper risk assessment and support for the IRRM. The public trust must be established through frequent and early interaction and maintained through an effective Communication Plan.

6. Funding for IRRM. Funding for IRRMP preparation and implementation for DSAC I, DSAC II and DSAC III dams will be from the O&M account for the project unless Construction account funds are available. When IRRMP work is funded from the O&M account, the WCC will be 61130 for navigation, 61230 for flood damage reduction, and 61630 for joint activities. When using CG funds for study costs WCC will be 30AT. Codes for implementation costs with O&M will be the same WCC including structural measures. When using CG funds structural measures use CCS code 240, 540, or 640 based on the type project.

7. Interim Risk Reduction Measures Plan (IRRMP). Districts with DSAC I, II, and III dams shall develop and submit to the HQ USACE Dam Safety Officer (HQ DSO), through their MSC Dam Safety Officer (MS DSO), an IRRMP outlining the proposed risk reduction measures. IRRMP's for DSAC I dams shall be submitted to the HQ DSO within a 60-day period after being designated as DSAC I , or within 90 days after being designated as a DSAC II, or within 120 days after being designated as a DSAC III. Prior to submission of the IRRMP, the plan shall be subjected to an Independent Technical Review (ITR) by Regional Technical Specialists, or other appropriate specialists. See Appendix B. Stakeholders should also be engaged in developing the plan to the extent possible. Submission of the IRRMP shall include a formal briefing to the HQ DSO for DSAC I dams. Formal briefings for DSAC II and III dams are required if requested. The IRRMP should as a minimum include the following:

a. Overall project description and purposes.
b. Overview of identified potential failure modes.
c. General consequences associated with each identified potential failure mode.
d. Structural and nonstructural IRRM alternatives considered to reduce the probability of failure and/or consequences associated with the failure modes (reservoir pool restrictions and modification of reservoir regulation plan must always be included as an option that is addressed).
e. General discussion of predicted reduction in the probability of failure and associated consequences, impact on project purposes, environmental impacts, and economic impact to region associated with potential IRRM, both positive and negative.
f. Recommendations and risk based justification for IRRM to be implemented.
g. Schedules and costs to the USACE and others for implementation of IRRM recommendations.
h. If necessary, proposed cost and schedules for conducting a risk-based analysis to estimate the benefits and costs for incremental evaluation of IRRM.
i. ITR comments and comment resolutions.
j. Updated EAP which reflects site specific risks, and which includes emergency exercises for DSAC I, II, and III dams conducted in manners that are appropriate for the risk involved.
k. Communication Plan (Internal and External).

8. Decision Process for USACE Dam Safety Interim Risk Reduction Actions. The decision process associated with Dam Safety-related actions will depend on the nature of the action under consideration, the consequences of the action in both the short and long term, and the potential for national and international interest and attention. The decisions will be made based on life safety first, economic risk second, and other considerations last.

Fundamentally, decisions within USACE are the responsibility of the District Commander. Technical decisions related to Dam Safety are generally delegated to the District Dam Safety Officer (DSO). Occasionally decisions require MSC approval; some require HQ USACE concurrence; and there are certain USACE actions that are executed by warranted officials, such as procurement, that function outside the usual Commander's chain.

In the Dam Safety area, the principal team members involved in the decision process are the District Dam Safety Officer, the MSC Dam Safety Officer and Dam Safety Program Manager, and at the HQ USACE level, the Corps Dam Safety Officer, the Special Assistant for Dam Safety, and the Dam Safety Project Manager (DSPM). These principals inform and at times execute decisions on behalf of the Commanders in whom the decision authority is vested.

For non-controversial Dam Safety-related actions, following routine review within the local District, MSC, and Headquarters Dam Safety staff, the decision by the District Dam Safety Officer, acting on behalf of the Commander, would be expected. As the level of controversy and potential consequences and attention escalates, a more thorough review would progressively include Commanders at the District, MSC, and HQ USACE levels, perhaps informed by outside experts, and engaging Public Affairs officers. The decision may then be retained by the District Commander and in the case of highly significant dam safety problems, the MSC Commander. While the decision authority lies with the Commanders, the process leading to the final choice for action is informed by technical, policy, and management staff at the District, MSC, and HQ USACE levels.

The engineering profession has licensure and codes of ethics that address public safety. This is because a primary product of engineering work is physical infrastructure whose very existence has public safety implications. While most Federal engineers are not required to be licensed (states have the responsibility for consumer affairs where licensure rests), USACE adheres to the principle that public safety-related decisions will be executed by a licensed professional engineer. USACE Dam Safety Officers are required to be licensed professional engineers and thus are honor bound by their codes of ethics to place public safety as the fundamental canon in the execution of their responsibilities.

Table 1 depicts a summary of the principal participants in the decisions involving IRRMP formulating, informing and reviewing, and final solution selection and implementation.

Table 1
Decision Levels for Interim Risk Reduction Actions

DSAC	District	Division	HQ USACE
I and II	Formulate, recommend, and implement	Review and approve	Review and concur
III	Formulate, approve, and implement	Review and concur	Information provided

9. Interim Risk Reduction Measures (IRRM). Types of IRRM that should be considered include, but are not limited to, the items listed below. Practical options will vary from dam to dam, and therefore a creative effort may be needed to identify the options that exist for a specific project. The imperative objective is to reduce the probability of catastrophic failure and associated consequences of the maximum extent reasonably practicable while long-term remedial measures are pursued. IRRMP must be developed on an aggressive timeline to reduce the probability of failure once a potentially major dam safety deficiency is identified. IRRMPs are mandatory for DSAC I, II, and III dams. To date, seepage and internal erosion have been identified as the primary failure mode governing risk for the Corps' dam inventory. Seepage can be a lengthy failure continuum (progressive failure) which may lead to catastrophic loss of pool with little or no warning. An example of a seepage failure development continuum is shown in Figure 1 in Appendix C. As such, expert judgment is required to match IRRM with the identified potential failure modes, geology, dam design and loading, and determination of where the dam is on a failure line continuum.

IRRMP development timeline guidance outlining development, review, and implementation requirements is detailed in Tables 3 and 4 of Appendix B.

a. **Examples of non-structural Interim Risk Reduction Measures**:

1) Reservoir pool restrictions or water control action plans - modification of reservoir regulation plan to reduce operating pool levels and/or durations.
2) Pre-position emergency contracts for rapid supply of other needed items/equipment.
3) Stockpiling emergency materials, e.g., rock, sand, sand bags, emergency bulkheads, or other operating equipment, etc.
4) Use of other reservoirs in the system to mitigate the impact of operational changes.
5) Improved and/or increased inspection and monitoring to detect evidence of worsening conditions.
6) Update Emergency Action Plan and inundation mapping to include project-specific failure mode(s). The NWS must be included in the EAP to take advantage of their television/radio announcement and stream forecasting capabilities.
7) Explicit procedures, communications systems, and training of appropriately skilled team members for prompt and effective emergency response by the USACE in the event of the detection of worsening or catastrophic conditions.
8) Conduct appropriate emergency exercises that plan for a range of failure scenarios (including the combined effects of multiple failure modes and different timing of detection).
9) Coordination with local interests and federal and non-federal agencies, including the National Weather Service (NWS) and local Emergency Management Agencies (EMA), with a focus on the specific failure mode(s) and the effectiveness of response including appropriate response exercises.
10) Identify instrumentation/monitoring "trigger" or threshold pools that would initiate more urgent monitoring or emergency response. In addition, threshold values should be established for instrument readings where possible.
11) Installation of early warning systems.
12) Preventive maintenance and repairs such as cleaning drains and improving spillway gate reliability where non-functioning components would exacerbate the existing conditions in an emergency.

b. **Examples of structural Interim Risk Reduction Measures (some can be incorporated in long term remedial measures)**:

1) Isolate problem area (e.g., cofferdam around problem monolith(s) or other project feature).

2) Improve seepage collection system.
3) Lower the spillway crest to aid in prevention of failure.
4) Increase spillway capacity/construct another spillway.
5) Breach/lower saddle dams along the reservoir perimeter.
6) Strengthen weak areas (e.g., upstream or downstream blanket to cut off/slow seepage; install tie-backs/anchors; and install additional buttresses).
7) Construct a downstream dike to reduce head differential.
8) Construct downstream stability berm.
9) Increase dam height.
10) Modify outlet discharge capability such as by installing temporary siphon(s).
11) Increase erosion protection where necessary.
12) Protect downstream critical facilities (e.g., medical and emergency services).
13) Construct shallow cutoff trench to slow seepage.
14) Target grout program specifically for suspected problem area(s) to slow seepage.
15) Remove significant flow restrictions (downstream bridge conditions may restrict maximum discharge from the outlet works. Upstream bridges or small dams may restrict flow caused by debris buildup that could result in a large release).

10. Evaluation factors for IRRM. Some types of IRRM may significantly impact authorized project purposes (e.g., water supply, recreation, hydropower, etc), project beneficiaries, and others who depend indirectly on the project. Additionally, some IRRM may result in more frequent discharges from the dam and from lower pool elevations than originally designed, impacting stakeholder interests. Public safety must always be given a higher priority over all other project purposes and benefits. In evaluating and formulating IRRM, it must be kept in mind that each project has its own unique attributes that have to be addressed on a case by case basis using expert judgment. The following shall be considered and addressed:

a. Providing protection of life, property and the environment. Examples to consider are: Loss of life; increased sickness and disease; employment losses; business income losses; private property damage; infrastructure damage including roads and utilities; losses in social and cultural resources including community effects and historical resources; environmental losses including aquatic and riparian habitat, threatened and endangered species; and HTRW (such as flooding a Superfund site).
b. Reducing the probability of failure and consequences of uncontrolled pool releases.
c. Increasing the confidence that any changes associated with the dam that are related to development of a failure mode will be promptly detected.
d. Increasing the confidence that emergency management agencies will be notified promptly.
e. Increasing the warning time and effectiveness of evacuation of the populations at risk.
f. Reducing the probability of the initiating loading (critical pool levels).
g. Improving the organizational capability to implement IRRM (resources, time, funding, technology, etc.).
h. Preserving the public trust.
i. Addressing stakeholder issues and impacts.
j. Understanding the degree of confidence in the scope of the problem and effectiveness of the interim solution.
k. Capability for incorporating IRRM into the permanent solutions.
l. Impacting authorized project purposes or other project benefits.
m. Maximizing cost effectiveness.
n. Minimizing social disruption and environmental impacts.

11. Communications Plan. Early in the process of developing IRRM, the district shall develop a draft communication plan. The plan shall be coordinated through the appropriate PAO community in the MSC and HQ USACE. The plan shall specifically address communication with internal and external stakeholders and the public, and should encourage stakeholder participation in the IRRM.

12. Approval and Implementation of IRRMP. Approval of the IRRMP for DSAC I and II shall be by the MSC DSO with review and concurrence of the HQ DSO. Approval of the IRRMP for DSAC III shall be by the district DSO with review and concurrence of the MSC DSO with information copy furnished to HQ DSO. Within 30 days of approval of the IRRMP, the district shall develop a final communication plan that is coordinated through the appropriate Public Affairs offices in the MSC and HQ USACE. Changes to the IRRMP shall be submitted to the original approving official for review.

FOR THE COMMANDER:

STEVEN L. STOCKTON, P.E.
Corps Dam Safety Officer
Deputy Director, Civil Works
Directorate of Civil Works

Appendix A: Background Information on USACE Dam Safety Action Classification System
Appendix B: IRRMP Development Timeline Guidance
Appendix C: Seepage Failure Mode Continuum

Appendix A
Background Information on the USACE Dam Safety Action Classification System

A. INTRODUCTION

1. The Dam Safety Action Classification process is intended to provide consistent and systematic guidelines for appropriate actions to address the Dam Safety issues and deficiencies of USACE dams. USACE dams are placed into Dam Safety Action Classes (DSAC) based on their individual Dam Safety risk considered as probability of failure and potential failure consequences. Consequences of the dam failure considered are lives lost, economic, environmental, and other impacts. All dams will be evaluated in a screening analysis and classified according to the DSAC. Dams will be reclassified as new dam safety related information about the dam is developed through monitoring or studies. The intent is that the classification of a dam is dynamic, changing as project characteristics change or as more refined information becomes available.

2. The structure and make-up of the DSAC table resulted from the need to formally recognize different levels and urgencies of actions that are commensurate with the different safety status of USACE dams. These actions range from immediate recognition of an urgent and compelling situation requiring extraordinary action through to normal operations and Dam Safety activities for safe dams.

3. In the past, the USACE Dam Safety program essentially recognized two categories of actions: those for dams considered safe, which comprised routine Dam Safety activities, normal operation and maintenance; and those for dams that were considered in need of remediation, for which investigations, remediation funding justification documents, and design and construction of remediation measures were additional activities. However, these two categories do not provide formal recognition of an adequate range of actions and degrees of urgency, especially for dams with Dam Safety issues that are very high or extremely high risk, which warrant heightened actions that are not provided for in the current business-as-usual procedures. Three action classes are termed "unsafe" and two are termed "safe". The choice of three "unsafe" action classes is to provide adequate parsing in the range of levels of actions. It is expected that only a minority of USACE dams will be classified in the top two "unsafe" classes. These five action classes are now included in the USACE Dam Safety program and summarized in the DSAC table. At the top, DSAC I is for those dams considered to be critically near failure and for which urgent actions are needed to avoid catastrophe in the near-term. DSAC II is for dams with confirmed (unsafe) and unconfirmed (potentially unsafe) dam safety issues; failure could begin during normal operations or be initiated as the consequence of an event. The likelihood of failure from one of these occurrences, prior to remediation, is too high to assure public safety. DSAC III is for dams with confirmed and unconfirmed dam safety issues where the combination of life or economic consequences with probability of failure is moderate to high. DSAC IV is for dams that are not declared safe because they don't meet current guidelines, but which are not considered unsafe enough to warrant heightened attention and for which remediation is considered to be quite low priority, although investigations to confirm their DSAC classification should be given normal priority. At the bottom is DSAC V for dams that are determined to be safe. Examples of Dam Safety Action Classifications are given in Section C of Appendix A.

USACE Dam Safety Action Classification Table*

Dam Safety Action Class		Characteristics of this class	Actions for dams in this class
I URGENT AND COMPELLING (Unsafe)		**CRITICALLY NEAR FAILURE** Progression toward failure is confirmed to be taking place under normal operations. Almost certain to fail under normal operations from immediately to within a few years without intervention. **OR EXTREMELY HIGH RISK** Combination of life or economic consequences with probability of failure is extremely high.	Take immediate action to avoid failure. Validate classification through an external peer review. Implement interim risk reduction measures, including operational restrictions, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite investigations to support justification for remediation using all resources and funding necessary. Initiate intensive management and situation reports.
II URGENT (Unsafe or Potentially Unsafe)		**FAILURE INITIATION FORESEEN** For confirmed (unsafe) and unconfirmed (potentially unsafe) dam safety issues, failure could begin during normal operations or be initiated as the consequence of an event. The likelihood of failure from one of these occurrences, prior to remediation, is too high to assure public safety. **OR VERY HIGH RISK** The combination of life or economic consequences with probability of failure is very high.	Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current, and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite confirmation of classification. Give very high priority for investigations to support justification for remediation.
III HIGH PRIORITY (Conditionally Unsafe)		**SIGNIFICANTLY INADEQUATE OR MODERATE TO HIGH RISK** For confirmed and unconfirmed dam safety issues, the combination of life or economic consequences with probability of failure is moderate to high.	Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Prioritize for investigations to support justification for remediation considering consequences and other factors.
IV PRIORITY (Marginally Safe)		**INADEQUATE WITH LOW RISK** For confirmed and unconfirmed dam safety issues, the combination of life or economic consequences with probability of failure is low and may not meet all essential USACE guidelines.	Conduct elevated monitoring and evaluation. Give normal priority to investigations to validate classification, but no plan for risk reduction measures at this time.
V NORMAL (Safe)		**ADEQUATELY SAFE** Dam is considered safe, meeting all essential USACE guidelines with no unconfirmed dam safety issues. **AND RESIDUAL RISK IS CONSIDERED TOLERABLE.**	Continue routine dam safety activities, normal operation and maintenance.

* At any time for specific events a dam, from any action class, can become an emergency requiring activation of the emergency plan

B. DAM SAFETY ACTION CLASSIFICATION DEFINITIONS

1. Adverse Consequences: The outcome of the failure of a dam or its appurtenances, including immediate, short and long-term, direct and indirect losses and effects. Loss may include human casualties, project benefits, monetary and economic damages, and environmental impact. (Adapted from USACE).
2. Conditionally unsafe: Assertion that the existence or occurrence of one thing or event (e.g., initiation of dam failure) depends on the existence or occurrence of another thing or event (e.g., extreme flood or extreme seismic event).
3. Confirmed (Unconfirmed): Through investigation or other means, Dam Safety issue is firmly established as of concern or not. Unconfirmed – not confirmed.
4. Critically near failure: Failure sequence has been initiated and continues under normal loading. Without intervention (e.g., interim risk reduction measures or remediation), dam is expected to fail.
5. Dam Safety issue: A potential deficiency that if and when confirmed, could result in failure of the dam.
6. Essential USACE guidelines: USACE Dam Safety-related policies are documented in regulations (e.g. ER's, EM's, EC's, EP's, ETL's and policy letters) that provide design, construction, and operation guidance. Essential guidelines are those specific requirements contained in these documents judged to be critical to the safety of the dam.
7. Failure: In the context of Dam Safety, failure is generally confined to issues of structural integrity, and in some contexts to the special case of uncontrolled release of the contents of a reservoir through collapse of the dam or some part of it. (ICOLD)
8. Interim risk reduction measures: Measures taken to reduce the probability of failure or the consequences of failure. Interim measures are a short term approach to managing Dam Safety risks while long-term solutions are under development.
9. Likelihood: Used as a qualitative description of probability and frequency. (ICOLD). A description of the occurrence chance of a particular event.
10. Marginally safe: Safe with reservations, barely within the lowest standards or limits of safety.
11. Normal Operations: Loading on the dam resulting from day-to-day pool operations to achieve authorized purposes. (For the purposes of a screening analysis for dry dams, or where pool elevations fluctuate widely and no historical normal pool elevation has been established, the normal loading is usually correlated to a 1 to 10 year return period.)
12. Operation restrictions: Changes to operating pool levels and durations, or reduced lockages, power generation, water supply, or conservation operations.
13. Peer review: Peer review is a form of deliberation involving an exchange of judgments about the appropriateness of methods and the strength of the author's inferences. Peer review involves the review of a draft product for quality by specialists in the field who were not involved in producing the draft.
14. Probability: A measure of the likelihood, chance, or degree of belief that a particular outcome or consequence will occur. A probability provides a quantitative description of the likelihood of occurrence of a particular event. This is expressed as a value between 0 and 1. (USACE)
15. Reliability: For gate and mechanical systems reliability is defined as the likelihood of successful performance of a given project element. It may be measured on an annualized basis or for some specified time period of interest or, for example, in the case of spillway gates, on a per demand basis. Mathematically, Reliability = 1 - Probability of unsatisfactory operation.
16. Remediation: Implementation of long-term structural and non-structural measures that resolve Dam Safety issues.
17. Residual risk: The remaining level of risk at any time before, during and after a program of risk mitigation measures has been taken.
18. Risk: Measure of the probability and severity of adverse consequences.
19. Safe (Unsafe): Involving little or no chance of dam failure. Meets all required USACE guidelines and criteria. Unsafe: Unacceptable chance of dam failure.

20. Tolerable Risk : A risk within a range that society can live with so as to secure the benefits provided by the dam. It is a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to keep under review and reduce it still further if and as we can.[HSE, 1999a].

C. DAM SAFETY ACTION CLASSES Five classes of action were selected to portray the range of actions District Dam Safety officers are to take in executing their Dam Safety responsibilities. The USACE dams are to be placed into Dam Safety Action Classes (DSAC) based on their individual Dam Safety risk considered as probability of failure and potential failure consequences.

DSAC I: URGENT AND COMPELLING (Unsafe)

Characteristics.
Dams in this class are CRITICALLY NEAR FAILURE OR EXTREMELY HIGH RISK under normal operations. These dams are ones where progression toward failure is confirmed to be taking place and are almost certain to fail under normal operations any time within a few years without intervention; or the dams have Extremely High Risk with a combination of life or economic consequences with high probability of failure.

Actions. A summary of the actions to be considered and pursued by the district for this class of dams are:

- Take immediate action to avoid failure.
- Validate classification through an external peer review.
- Implement interim risk reduction measures, including operational restrictions, and ensure that emergency action plan is current and functionally tested for initiating event.
- Conduct heightened monitoring and evaluation.
- Expedite investigations to support justification for remediation using all resources and funding necessary.
- Initiate intensive management and situation reports.

Examples of Critically Near Failure dams:

Dam A:

Dam A is experiencing foundation, abutment, and embankment piping or internal erosion due to seepage through these features under normal pool elevations. All of the seepage items may lead to the formation of piping, which can quickly progress to rapid breaching of the embankment. Loss of strength in the foundation or embankment may result in a slope stability failure which could result in dam overtopping though the lowered dam crest.

Recent subsurface investigations have revealed significant degradation of the foundation and embankment soils. Extremely soft zones were found in multiple borings. Piezometers within the embankment downstream of the existing cutoff wall show significantly higher than expected pressures in reaction to the pool. Movement monuments have indicated continual and increasing settlement of portions of the embankment crest. A temperature survey of the piezometers shows cooler zones in the rock foundations which indicate direct seepage from the pool. Numerous and excessive wet areas persist in areas just downstream of the embankment. These wet areas have progressively increased over the years.

Dam B:

Dam B is experiencing foundation and abutment seepage and piping, and embankment piping along the conduit during all pool elevations. The conduit is founded on soil and constructed in soil materials. The periodic inspections indicated that a small amount of differential settlement has occurred at one of the conduit joints. It was constructed with seepage collars that likely prevented adequate compaction of the soil around the conduit and the seepage collars provide a seepage path along this interface that could lead to piping of the embankment. The left abutment is composed of granular glacial deposits and has experienced significant seepage during Normal pool events. The project has had several test fillings and subsequent seepage collection features were added after each test filling. The seepage is so severe that permanent operational restrictions have been imposed on the project to prevent high pools.

The most likely mode of failure for this project is seepage and piping of foundation or abutment materials which may rapidly progress to breaching of the dam.

An example of an Extremely High Risk Dam.

Dam C:

Items of concern include foundation and abutment seepage and piping under the embankment. The dam abuts highly karstic limestone formations. One documented cavity in the left rim is 77 feet deep and 15 feet wide. On the right rim, primary seepage pathways through the karst system have not been defined by previous subsurface investigations. In stream seepage measured downstream of the dam during zero releases have increased more than 40% from 90 cfs to 127 cfs in 15 years. Rim grouting has been performed twice previously with limited success. The seepage has potential to erode the earth embankment. There is a wet area downstream of the embankment that has appeared in the last 10 years.

Initial foundation treatment, which consisted of minimal excavation and a single line grout curtain, is inadequate. The initial grout curtain and a curtain installed later encountered large clay-filled, solution features in the limestone. There is a potential for erosion of this clay-filled material, which would jeopardize the integrity of the embankment. Piezometer levels are higher than expected; however, some have steadily increased or decreased over the last 20 years indicating erosion of the foundation materials.

There is a large metropolitan area (1,000,000 people) with high potential life loss and less than one hour of warning time for the flood wave. This project is considered to have extremely high risk.

DSAC II: Urgent

Characteristics. Dams in this class are considered to have Failure Initiation Foreseen in that, for confirmed (unsafe) and unconfirmed (potentially unsafe) dam safety issues, failure could be initiated during normal operations or from a hydrologic or seismic event. The likelihood of failure from one of these occurrences, prior to remediation, is too high to assure public safety. Or, dams in this class have Very High Risk in that the combination of life or economic consequences with probability of failure is very high.

Actions. A summary of the actions to be considered and pursued by the district for this class of dams are:

- Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current and functionally tested for initiating event.
- Conduct heightened monitoring and evaluation.
- Expedite confirmation of classification.
- Give very high priority for investigations to support justification for remediation.

An example of a Failure Initiation Foreseen condition:

Dam D:

The most likely mode of failure for this project is breaching of the dam by erosion or piping through cracks in the core caused by significant displacements of the upstream shell during an Operating Basis Earthquake (OBE) or greater earthquake. Foundation seepage may lead to the formation of piping, which can quickly progress to rapid breaching of the embankment.

Detailed evaluation of the dam foundations indicates that a loose layer of alluvial materials will liquefy during an OBE earthquake or greater earthquake. The predicted large displacements during the earthquake will cause significant cracking or loss of the integrity of the dams' core section. The displacements are large enough to result in complete failure of the upstream shell of the dam. This will result in piping of the remaining dam embankment and will quickly progress to breach. The intake tower is located in the central part of the embankment just upstream of the core. Large displacement of the upstream shell will likely cause damage to the intake tower.

The population at risk is located less than one hour travel time of the flood wave at the mouth of a narrow canyon. Loss of life is expected to be very high if the dam were to fail from an earthquake.

Dam E:

The most likely failure mode is embankment, abutment, and foundation seepage and piping. Deficiencies in the design and construction techniques contribute to a condition of active piping at moderately high pools – 0.05 to 0.01 pool frequency. Most of the embankment is founded on alluvial and glacial soils without any seepage cutoff. Additionally, the rock below the foundation soils was not inspected or treated and has a history of solutioning. The grout curtain installed on the remainder of the foundation does not meet current standards. There is a history of seepage on the downstream embankment slope, the toe of the downstream embankment, zones downstream of the toe, and along the abutment contacts with the higher pool levels. Piezometric data show a 10 foot rise in the phreatic line over the last 20 years. There has been a continual and steady settlement of the dam crest to the left of the concrete section since at least 1978. It is likely that the settlement is the result of internal erosion caused by seepage. It is possible that seepage through the lift joints in the concrete section may be entering embankment materials.

An example of a Very High Risk condition:

Dam G:

Dam is overtopped by several feet at 80% of the probable maximum flood (PMF) and also has potential for foundation seepage creating a piping failure at pool levels for infrequent events. The very large population immediately downstream and a major downtown urban area within 10 miles of the dam has the potential for very high consequences and thus the risk for this project is considered to be very high even through the failure mode is driven by a near PMF event.

DSAC III: HIGH PRIORITY (Conditionally unsafe)

Characteristics. Dams in this class, for confirmed and unconfirmed Dam Safety issues, are considered to be Significantly Inadequate or have Moderate to High Risk in that the combination of life or economic consequences with probability of failure is moderate to high.

Actions. A summary of the actions to be considered and pursued by the district for this class of dams are:

- Implement interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current and functionally tested for initiating event.
- Conduct heightened monitoring and evaluation.
- Prioritize for investigations to support justification for remediation considering consequences and other factors.

An example of a Significantly Inadequate Dam:

Dam H:

Two failure modes have been identified for this dam - overtopping and piping. The most probable is a piping failure of the foundation overburden materials, initiating at the left cut slope of the outlet channel. A pervious sand and gravel deposit overlying the bedrock is exposed in the outlet channel and does not have adequate seepage control filters. Dam is estimated to be overtopped by several feet by the probable maximum flood and the embankment is breached by erosion.

During pools up to the record event, seepage has been observed downstream of the toe of the dam in the cut slopes on both sides of the outlet works stilling basin. Construction of remedial seepage control filters and relief wells were constructed several years after the dam was completed but appear to be insufficient to reduce the seepage to acceptable levels based on piezometer response. Seepage on the left cut slope is still occurring and is anticipated to increase in severity under higher pool levels. The seepage being experienced along the outlet channel is occurring through a sand and gravel layer located immediately above the bedrock surface.

An example of a Moderate to High Risk Dam.

Dam I:

Dam has a long term history of downstream movement in the clay shale foundation. The piezometric data indicate high uplift in the foundation clays that are the result of the original loading by the embankment during construction. The available inclinometer data show distinct zones of movement at high pool levels as well as a very slow creep over time. Analysis shows the factors of safety for the more extreme pool elevations approach 1.0. The dam has been loaded to top of spillway gates for a pool of record, but there is still an additional 30 feet of storage above that elevation, thus the pool elevation of concern is a rare event. There is significant data to indicate a conditionally unsafe project (potential for failure only when the pool is very high) and the very large volume of water behind this dam at the higher pool elevations would create very high economic and environmental consequences with low to moderate loss of life consequences.

DSAC IV: PRIORITY (Marginally Safe)

Characteristics. Dams in this class are considered to be Inadequate with Low Risk.
For confirmed and unconfirmed Dam Safety issues, the combination of life or economic consequences with probability of failure is low and may not meet all essential USACE guidelines.

Actions. A summary of the actions to be considered and pursued by the district for this class of dams are:

- Conduct elevated monitoring and evaluation.
- Give normal priority to investigations to validate classification, but no plan for interim risk reduction measures at this time.

Examples of Inadequate with Low Risk condition Dams:

Dam J:

The embankment has a potentially preferential seepage path along the top of the outlet conduit and may result in piping of embankment materials during extreme hydrologic events. The dam does not have a foundation seepage cutoff system. Seepage has been apparent at the toe of the dam since the initial filling. High foundation seepage pressures are anticipated for the Extreme events. With the relief well system functional, it is estimated that the seepage pressure would be 2 feet above the ground surface at the toe during an Extreme event. It is likely that the high seepage pressures may cause some piping in the form of sand boils potentially causing embankment instability due to loss of foundation material.

After the pool of record it was found that significant scouring occurred just below the outlet apron. There is currently a 140 foot long, 120 foot wide, and 13 foot (maximum) deep scour hole downstream of the outlet apron. There is potential for additional scouring and undermining of the outlet apron and wing walls under Extreme conditions.

The population centers downstream are all located on the elevated floodplain of a wide valley and the potential for economic consequences is low to moderate. The overall risk is considered low and some essential guidelines are met by this dam.

Dam K:

An overtopping failure mode may result from inadequate freeboard based on existing routings. The resultant consequences are low because of a wide downstream valley, low population density, and ample warning time. Thus the risk is low.

DSAC V: NORMAL (Safe)

Characteristics. Dams in this class are considered to be adequately safe, meeting all essential USACE guidelines with no unconfirmed Dam Safety issues such that the residual risk is considered tolerable.

Actions. Continue routine Dam Safety activities, normal operation and maintenance.

Example of an Adequately Safe Dam.

Dam L:

Dam meets the requirements for hydrologic capacity to pass the most current inflow design flood (IDF), there is no known seepage and piping issue and seepage control features meet current standards, the seismic capacity and performance of all the features of the project are appropriate for the current seismic loads, and there are no operations and maintenance issues that impact the operations of the project for all pool and loading conditions. The project staff and water management staff are appropriately trained and qualified to deal with project operations under emergency and flood conditions. With this high level of readiness and low probability of unsatisfactory project performance a review of the project's residual risk indicates that the risk is tolerable for all design loads and the dam is "safe."

Normal operations require due diligence by a district to perform the requisite monitoring, evaluation, maintenance, and training to actively manage the inherent residual risk associated with any dam with the goal to keep the residual risk at or below the that which is considered tolerable for the respective dam.

D. ACTIONS

The actions listed are an executive summary of the actions that a district Dam Safety officer should pursue based on the action classification assigned to each dam. **The basic concept is that dams in classes I, II, and III shall be treated as unsafe until confirmed safe.**

E. DOCUMENTATION

It is recommended that a district document their decision for assigning a class to a given dam using a short fact sheet that addresses the available information in summary form to include the failure modes of concern, the loading conditions of concern, the probability of failure, the consequences, and DSAC assignment.

Appendix B
IRRMP Development Timeline Guidance

IRRMP must be developed in an aggressive timeline to minimize the probability of failure once a potentially major dam safety deficiency is identified. IRRMPs are mandatory for DSAC I, II, and III Dams. The following tables describe the timeline for IRRM development.

Table 3. DSAC I Dams Interim Risk Reduction Measures Timeline

Item	Process for Action Classification DSAC I Only Interim Risk Reduction Measures Action Item	Notes	Day
1	Designate dam safety problem as DSAC I	One time screening and thorough / routine Periodic Assessment	0
2	Alert MSC DSO, OPs Chief, EOC, and local PAO		0
3	Assemble peer review team concurrent with IRRMP development. Use emergency contracting procedures if necessary.		3
4	District begins to pre-position contracts and materials and informs major stakeholders if appropriate.		7
5	Obtain initial O&M funding from district to develop Interim Risk Reduction Measures Plan (IRRMP)	District funds are used for initial activities until wedge funding is secured.	7
6	Obtain remaining funding for IRRMP from HQ DSO Wedge Funds	Wedge funds will be available to complete the IRRMP	21
7	District completes IRRMP		49
8	District begins NEPA actions if necessary		51
9	Public Coordination/Communication	Begin development of IRRM Communications Plan	55
10	ITR of IRRMP by Regional Technical Specialists and peer review	Includes Senior Oversight Group and concurrent RTS and peer reviews throughout development	56
11	Seek approval of IRRMP from MSC DSO in coordination with HQ USACE. Request initial Wedge Funding for PED to implement the IRRMP	Includes formal brief of IRRMP to MSC and HQ DSO	60
12	Approval of IRRMP by MSC DSO		70
13	Complete development of IRRM Communication Plan		90
14	Public Coordination/Communication	Begin coordination	92
15	NEPA actions complete for IRRM		99
16	District implements non-structural IRRM and begins plans, specs, and cost estimate for structural IRRM activities	Pool restrictions, etc. per ETL	100
17	District develops plans, specs and cost estimate for structural IRRMP activities	Completion	121
18	Approval of structural IRRM P&S by MSC DSO in coordination with HQ DSO		145
19	District issues emergency contracts for structural IRRM		175

Table 4. DSAC II Dams Interim Risk Reduction Measures Timeline

Item	Process for Action Classification DSAC II Only - Interim Risk Reduction Measures Action Item	Notes	Day
1	Designate dam safety problem as DSAC II	One time screening and thorough / routine Periodic Assessment	0
2	Alert MSC DSO, OPs Chief, and PAO		0
3	District begins to pre-position contracts and materials, if appropriate, and informs major stakeholders		15
4	Obtain initial O&M funding from district to develop Interim Risk Reduction Measures Plan and start development of IRRMP with a seamless ITR/Peer Review process	For initial district effort	15
5	Request funding for remaining IRRMP from HQ DSO Wedge Funds	Wedge Funding may not be available for all activities in DSAC II	25
6	District completes IRRMP and initiates ITR		45
7	District begins NEPA actions if necessary		75
8	Public Coordination/Communication	Begin development of IRRM Communications Plan	80
9	ITR of IRRMP to be completed by Regional Technical Specialists. Peer Review process is initiated	Includes Senior Oversight Group and concurrent RTS and peer reviews throughout development	80
10	Seek Approval of IRRMP from Division and MSC. Request Initial Wedge Funding for PED	Includes Formal Brief HQ DSO IRRMP	90
11	Approval of IRRMP by MSC DSO in coordination with HQ DSO		105
12	Complete development of IRRM Communication Plan		135
13	NEPA actions complete for IRRM		150
14	District implements non-structural IRRM and begins plans, specs and cost estimate for structural IRRM activities	Pool Restrictions, etc. per ETL	180
15	District completes plans, specs and cost estimate for structural IRRMP activities		210
16	Approval of structural IRRM P&S by MSC DSO		240
17	District issues Contracts for Structural IRRM in coordination with HQ DSO		310

Schedule for DSAC III dams is the same as shown above through completion of the IRRM Plan (90 days). The remaining DSAC III activities through issuing a contract should be completed within 365 days. A formal IRRMP is not required for DSAC IV dams, and remedial actions may follow more routine processes. While DSAC IV dams have a lower risk, a plan must be developed to move DSAC IV dams to DSAC V level.

Appendix C
Seepage Failure Mode Continuum

Figure 1 was developed to illustrate the progressive nature for seepage\internal erosion failure of a dam. The failure continuum illustrates two relative and interdependent scales:

1. Stages of a seepage erosion/piping failure development, and
2. Corresponding risk reduction strategies that can be considered for implementation as the failure mode is progressing toward breach formation.

The stages of a seepage erosion/piping failure mode development as presented are generally consistent with the stages described by Foster and Fell (1999), and the US Bureau of Reclamation (2000). The stages include initiation, continuation, progression, and breach formation. The literature describing these stages is somewhat ambiguous with regard to the transition between the continuation and progression phases. It is not uncommon for these terms to be used interchangeably depending on various nuances associated with a material transport (erosion and piping) failure of an embankment dam. However, the continuum developed in Figure 1 illustrates these as two distinct and separate stages in the development of the failure mode as described further below.

Initiation: Initiation begins at the onset of a loading condition that leads to the development of a concentrated leak (e.g. raising the pool, development of a crack due to an earthquake, differential settlement, and hydraulic fracture). Initiation can also occur when seepage begins to exit a free (unfiltered) discharge face with sufficient gradient, quantity and velocity of flow so that soil particles begin to move. Initiation may occur in the embankment, in the foundation/abutment, or at the interface between the embankment and foundation materials.

Continuation: Following initiation is the continuation stage. During continuation, the pipe or erosion front moves up gradient toward the source of water and is not arrested due to the presence of a filter, cutoff, restriction or stoppage by material at the upstream end, caving because a roof does not form, or other intervention activity. The piping or erosion typically continues towards the source of water at an accelerating rate due to increasing gradients and flow quantities.

Progression: The progression phase occurs when the piping/erosion feature(s) widen and/or deepen as flows increase in the feature. Progression is enhanced when a roof continues to form and there are no other restraints to growth. The amount of flow continues to increase causing in most, if not all, cases the piping/erosion feature to grow rapidly. The progression phase follows the continuation phase and begins when there is a significant increase in the volume and velocity of flow in the erosion/pipe feature to cause it to enlarge. For example, the progression phase would begin when a piping feature breaks through the upstream slope of the core (for a dam having highly permeable shells) or the upstream shell (for more homogeneous or low permeability shell materials) of an embankment, or through foundation materials and into the reservoir. The formation of the sinkhole through the upstream slope of the dam signifies the completion of the continuation phase and the start of the progression phase of failure mode development. In some instances where overlying foundation and/or embankment materials are very stiff or well compacted, the progression stage may not manifest itself in the form of sinkhole development until significant progression has occurred.

Breach Formation: As progression continues, flow through the erosion/piping feature and the corresponding erosion of material is not arrested. Typically, the dam crest will begin to settle due to sinkhole development, localized slope instability or unraveling of the downstream slope to the point where overtopping from the reservoir begins to occur. During breach formation, the materials in the dam are eroded, widening and deepening the opening in the dam until the full contents of the reservoir are lost.

The corresponding risk reduction strategies shown on the continuum diagram have been grouped into three overall categories that generally reflect the timeframe available for intervention: long-term, short-term, and heroic (i.e., crisis management).

Long-term: The timeframe for implementation of long-term risk reduction strategies would be in the range of 1 to 5 years. Corrective actions accomplished during this timeframe would not only stop a piping/erosion failure mode development, but in general would provide sufficient safeguards that would prevent any future failure mode initiation. **Embankment dams on Karst foundations are a special consideration and long-term solutions that prevent future failure mode initiation may not be possible. In this case, long-term solutions such as cutoff walls that do not fully penetrate the formation with Karst may provide only a limited design life.**

Short-term: The timeframe for the implementation of short-term risk reduction strategies would be in the range of 1 to 3 months. In some circumstances, depending on how far along are the continuation stage and the rate of failure mode development, short-term risk reduction strategies such as grouting or construction of filters/drains and cutoffs may occur over slightly longer periods of time. Corrective actions accomplished during this timeframe are generally aimed at preventing the failure mode from reaching the progression phase and failure of the dam. Short-term strategies usually involve some form of reservoir drawdown or modified reservoir operations under reduced storage levels.

Heroic: Heroic risk reduction (crisis management) strategies are typically those that must be implemented in the range of a few hours to a few days or weeks. **Heroic actions are typically required when a piping/erosion failure mode has reached an advanced continuation stage.** The actions taken are aggressive and implementable in order to prevent entry to the progression stage, or to arrest the progression stage in its earliest period of development and usually involves a rapid lowering of the reservoir level. Corrective actions accomplished during this timeframe would stop a piping/erosion failure mode development, and provide enough time for planning, design and construction of short- and long-term risk reduction measures leading to a permanent solution that will prevent any future failure mode initiation. It should be noted that each dam is unique and the actions taken at each site will need to be tailored to the attributes of the dam and the nature of the failure mode that is developing.

Reference

Foster, M., and R. Fell, A Framework for Estimating the Probability of Failure of Embankment Dams by Piping Using Event Tree Methods, UNICIV Report (Draft), April 1999.

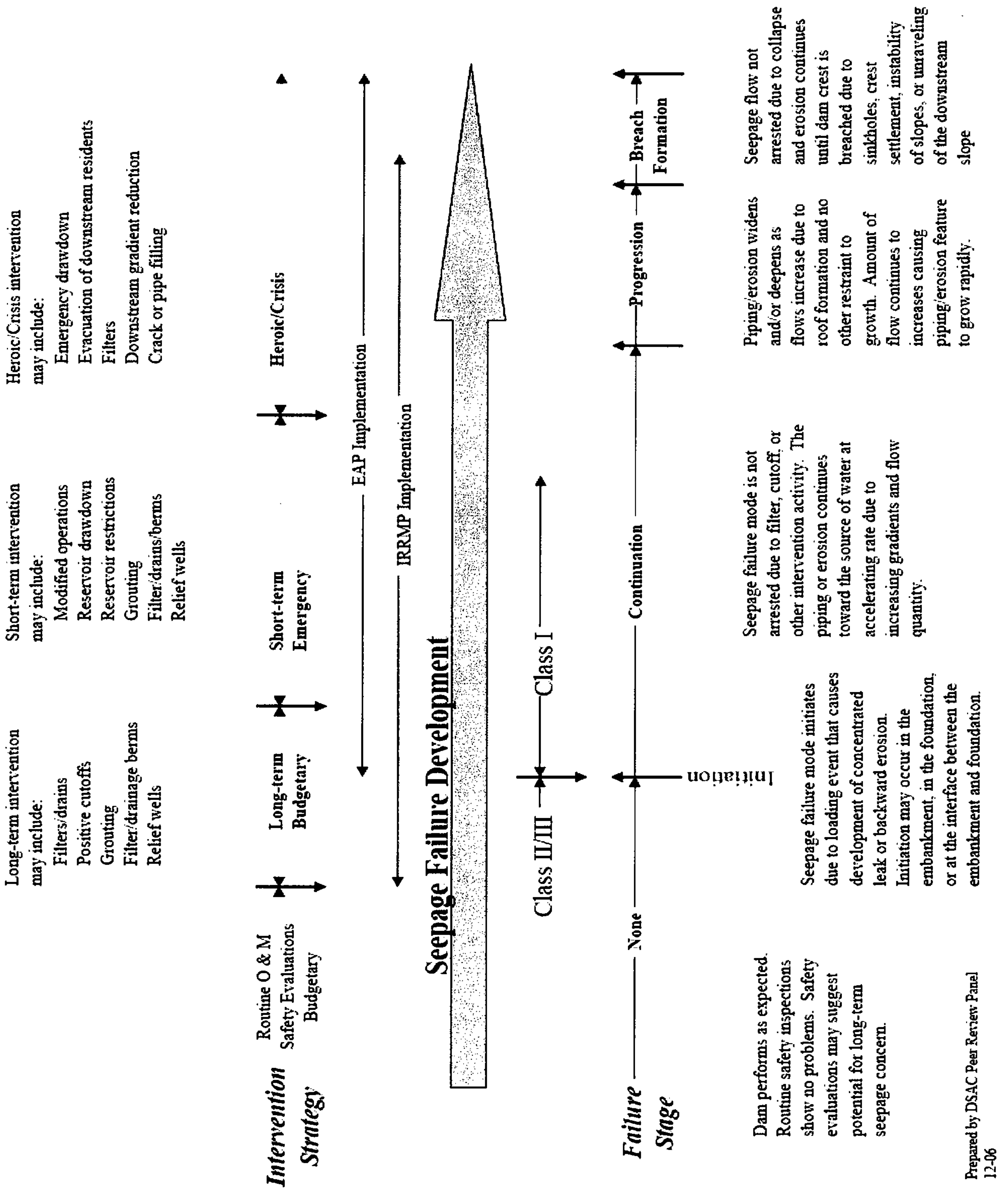

Figure 1
Seepage Failure Mode Development Continuum
DSAC Peer Review Panel
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