Smart Infrastructure for the Mekong (SIM) Program

Laos Dam Safety Guidelines

Foreword

Dam safety is important through the entire life of a dam. Dam safety describes the efforts taken to ensure that dam failure (defined as an uncontrolled release of the reservoir) does not occur and that the safety of the public is maintained. While providing valuable benefits to society in the form of hydroelectric energy generation, navigation creation, water supply and flood mitigation benefits, dams can result in significant negative consequences if they fail. A robust dam safety program is necessary to continually evaluate and analyze dams to ensure that the risk of any potential dam failure is recognized, that appropriate design features are implemented and that appropriate remedial actions are taken as necessary.

Acronyms

CRB – Consultant Review Board
DDEM – District Department of Energy and Mines
DEB – Department of Energy Business
DEM- Department of Energy Management
DEPP –Department of Energy Policy and Planning
EAP – Emergency Action Plan
EDL – Electricite du Laos
EMA – Emergency Management Agency
EOC – Emergency Operations Center
IDF – Inflow Design Flood
IPP – Independent Power Producer
Lao PDR – Lao Peoples Democratic Republic
LEPTS – Laos Electric Power Technical Standards
MEM – Ministry of Energy and Mines

RAEPD – Responsible Agency for Electric Power Development
RCC – Roller Compacted Concrete
SOP – Standing Operating Procedures
TOF – Terms of Reference

1. Introduction

1.1 Background

Dams provide significant benefits in the form of control and storage of water for human or agricultural consumption, and hydropower generation. While the public benefits significantly from dam projects, they must also be protected from dam failure.

The control of water resources is very important to the government of the Lao Peoples Democratic Republic (Lao PDR). The government is responsible for creating the legal and regulatory frameworks, laws and regulations to control the development and operation of water resource projects within the Lao PDR.

Owners of dams have responsibilities and also assume liabilities. They must comply with governing laws and regulations and demonstrate their compliance. Dam ownership in Laos can shift during the life of the dam. For dams built under a concession agreement, the dam is owned by the developer for a period of 30 years (which is including construction period), after the dam is commissioned. At the end of the concession agreement, ownership of the dam is transferred to the Ministry of Energy and Mines (MEM). Some dams are owned throughout their life by the Electricite du Laos (EDL). These projects are developed by EDL and they are the original dam owners and maintain ownership throughout the life of the dam.

1.2 Objective of the Guidelines

The Laos Dam Safety Guidelines are guidelines rather than mandatory requirements. They do represent good dam engineering practice and they should not be dismissed because complying with them requires effort and some cost. If a dam owner intends to deviate from the guidelines, they should notify the MEM and provide the rationale for why the guidelines will not be followed. MEM should approve any deviations from the guidelines. The guidelines can be applied with some flexibility, if adequate justification is provided and approval is obtained.

to Independent Power Producers (IPP, investors of hydropower projects) as well as MEM, EDL and related agencies.

1.3 Key Principles for a Dam Safety Program

There are a number of key principles that form the basis of a good dam safety program. These principles should be kept in mind when conducting dam safety activities in Laos.

1.3.1 The public, infrastructure and the environment shall be protected from the effects of dam failure and the risks kept as low as reasonably practicable.

This should be the primary focus of a dam safety program. A key strategy for implementing this is to ensure that dams in Laos comply with the Laos Electric Power Technical Standards (LEPTS) but also to focus on the potential failure modes that are unique to each dam being evaluated. If the risks at a given dam are judged to be too high (based either on standards based criteria or based on a risk-informed approach) corrective actions should be considered to reduce the risk. A potential failure modes analysis also will be useful in establishing an effective monitoring program at a given dam, by focusing attention on the most likely potential faliure modes.

1.3.2 Dam safety is important throughout the life of a dam from design through operation and even decommissioning. The safety of a dam must be reevaluated throughout its life.

Dam safety should be considered throughout the life of a dam and evaluated at key phases in the life of a dam. These key phases include: planning, design, construction, first filling, times of flooding, routine operations and decommissioning. Dams have failed due to key items that were overlooked or unanticiapted at all phases throughout the life of a dam. Appropriate reviews and evaluations are needed at each phase to ensure that key issues are identified. Once a dam is in operation, periodic dam safety reviews of the safety of the dam (considering performance and risk) should be conducted at a regular interval. Changes in the predicted loads (including earthquakes and floods) for a given dam often occur during the life of the dam, and the dam should be reevaluated when revised loadings are indentified.

1.3.3 Thorough records of a dam should be developed and maintained throughout the life of the dam to provide a good history. This will be helpful in assessing the

dam foundation prior to placement of the dam and records of material composition and testing data are invaluable. If this information is not available later on, once the dam is in operation, it may be costly to collect and the information may be much more incomplete than what was available during construction. Photographic records of the dam at various points in the life of the dam, including throughout the entire construction process and good instrumentation records can also be used to establish baseline conditions and verify if conditions have changed at the dam. It is also very important to have an accurate record of the design assumptions that were utilized for the construction of the dam. This helps future evaluators better understand the specific loadings the dam was designed to resist.

1.3.4 The standard of care at a dam should be proportional to the potential consequences of dam failure.

The potential consequences of dam failure will vary, based on the setting of the dam. The most critical consequence is loss of human life but other consequences such as economic, environmental, cultural and societal can also be considered. Dams located in remote areas will likely have minimal consequences. Dams located upstream of cities or highly populated areas will likely have significant consequences. Hazard classification is a method of categorizing dams. Typically dams are classified as low, significant or high hazard, based on the potential for downstream consequences. Table 2 provides criteria that can be used to classify dams in one of these three categories. Low hazard dams should be inspected regularly and may include some instrumented monitoring but periodic dam safety reviews are not required as long as these dams remain in the low hazard category (the conditions at the dam should be reviewed at least every 2 years to determine if the low hazard category still applies). Dams with larger consequences are likely to be larger, more complex dams and as a result will typically have more instrumentation than smaller dams. There may be justification to inspect high hazard dams and record and review instrumentation data more frequently than significant hazard dams.

1.4 Hydropower Development in Laos

As of 2015, 36 hydropower projects had been completed in Lao PDR. The capacities of the powerplants range from 1 to 1075 MW. The dam types are primarily concrete dams, with some concrete-faced rockfill dams, one rockfill dam and one earthfill from 12 meters to 208 meters. Nine additional hydropower projects were being prepared for construction as of 2015. The capacities of these powerplants range from 45 to 260 MW. The dam types are a mix of concrete dams, RCC dams, concrete-faced rockfill dams, and earthfill embankment dams. The heights of the dams being prepared for construction range from 25 meters to 147 meters.

1.5 Existing Dam Safety Guidelines/Standards in Laos

There are a number of standards and guidelines in place relative to dam safety in the Lao PDR. These dam safety guidelines include the LEPTS, the Guideline on Operating and Managing LEPTS/Safety Rules for Operation and Maintenance, the MONRE document "Water Resources Law", Terms of Reference (TOR) Document for Feasibility Studies, Checklist for Feasibility Studies, Mekong River Commission (MRC) Guidelines. The Laos Dam Safety Guidelines are intended to supplement these other guidelines and not to supersede or replace the existing dam safety standards and guidelines already in place within the Lao PDR.

1.5.1 LEPTS, 2004

The LEPTS were developed in 2004 as a joint project between the Japanese Government and the Lao PDR Government. The goal of the standards is to establish the main principles governing the management of electricity activities such as generation, transmission, distribution and electricity services. The technical standards specify uniform, consistent and technically correct practices, with the goal of encouraging uniform practices in the industry. The LEPTS includes three chapters addressing:

Chapter 1: General Provisions
Chapter 2: Hydropower Civil Engineering Facilities
Chapter 3: Electrical Facilities

Chapter 1 and Chapter 2 are the governing chapters for dams and their associated waterways in Laos. Hydropower civil engineering facilities are defined as key facilities, such as dams, waterways, and powerhouses of the hydropower station. The General Provisions address: nomination of Chief Engineers during the design, construction and operation phases of the project; examination and inspection of the power facility;

requirements, performance requirements, monitoring and inspection requirements, material requirements, stability criteria, and design details.
The standards apply to new hydropower projects in Lao PDR and for exisiting facilities, the owner “shall try to do his utmost so that such power facilities conform to the fundamental requirements within the limits of possibility.”

1.5.2 Guideline on Operating and Managing LEPTS, 2006

The Guideline on Operating and Managing LEPTS was developed to operate and manage the LEPTS, specifically for hydropower civil engineering facilities and electrical facilities in hydropower stations in Lao PDR. The General Requirments Section of this document, details the process of initiating and developing a hydropower project in Lao PDR and the responsibilities of the Responsible Agency for Electric Power Development (RAEPD; which can consist of: the MEM, Department of Electricity (DOE); the Provincial Department of Energy and Mines (PDEM), the District Department of Energy and Mines (DDEM)) and the Owner).

Section 3 of the LEPTS document addresses Project Procedures, which outlines submittal requirements for various phases of the hydropower development and time frames for submittal of information by the owner and review of the submittals by the RAEPD. Forms to be used in the process are provided in an Appendix.

1.5.3 Water Resources Law

MONRE (Ministry of Natural Resources and Environment) is revising a final draft of “Water Resources Law”, which covers several articles of dam safety, watershed management and environment.

2. Dam Safety Management

2.1 Introduction

In order to effectively manage a dam safety program, policies, procedures and a dam safety organization (with well-defined staff responsibilities) must be in place. Ideally, a central group should have oversight on dam safety through all phases in the life cycle of a dam. This will provided consistency and continuity on dam safety issues. Without these things, dam safety may only be addressed in response to emergencies

- Good Records – Photographs, As-Built Drawings, Design Documentation, Inspection Reports (can be extremely valuable if issues develop later). Section 2.9 provides more discussion on this element.

- Thorough Review of Design at Key Milestones - These milestones should include the design at the feasibility level, at the completion of final design prior to initiating construction and during construction, if unexpected conditions require modifications of the design. Reviews should include a review by MEM at the feasibility design phase, and during the final design phase. The review should also include an independent review by a Consultant Review Board (CRB) of the design (provides unique perspective on interpretation of site conditions and analysis results, ensures key issues have not been overlooked). The CRB should consist of a small group of engineers/geologists with extensive experience in dam design and construction. The CRB members should be proposed by the dam owner and approved by MEM. CRB reviews should also be performed during major dam modifications. Section 2.2.2 provides more discussion on this element.

- Balancing Multi-Purpose Usage – This will involve setting priorities, evaluating impacts and resolving conflicting objectives. Multi purpose objectives may include: hydropower generation, flood mitigation, aquatic migration, temperature control and minimizing environmental impacts.

- Potential Failure Modes Analysis – A potential failure modes analysis identifies the likely mechanisms by which a given dam can fail and is the key basis for focusing studies and ensuring adequacy of design, as well as establishing a monitoring program. Potential failure modes during constuction should also be idenfitied and evaluated in order to ensure stages of construction do not create unacceptable risk. Construction risks can imply different things, such as risks of escalating construction costs, risks to the contractor's equipment and completed work or life safety risks for people living downstream of the dam. In this document, the life safety risk to people downstream of the dam is the focus. Construction risks should consider potential failure modes that could initiate during construction of the dam, such as flood overtopping and breach of the partially completed dam, or erosion, head cutting and breach of the reservoir the consequences of dam failure (including loss of human life as well as economic, environmental, cultural and other consequences). Inundation maps should be considered and then developed for different failue scenarios, including failures from different loadings (static, seismic or flood) and failures initiating at different locations within the dam (or along appurtenant structure alignments) and for different reservoir water surface elevations. All of these considerations can affect the rate at which the dam breach develops and the ulitmate size of the breach, which will impact the flooding downstream. Inundation modelling and maps are not needed for every unique failure scenario, but enough scnearios should be modelled and mapped to cover the range of possible breach outflows. Section 2.7 provides more discussion on this element.

- Emergency Action Plan (EAP) – An EAP is needed to establish procedures and communication protocols in the event of an impending or in progress dam failure. Section 2.8 provides more discussion on this element.

- Operations and Maintenance (O&M) Manual – An O&M manual is needed to provide detailed instructions on how the dam is to be operated during normal and flood conditions and after an extreme loading event like an earthquake. The manual should detailed operating instuctions for all electrical and mechanical equipment at the dam, including detailed instructions on spillway gate operations for different reservoir water surface elevations and inflows (these instructions on flood operations can be incorporated into the O&M Manual or provided as a separate Water Control Manual document). Section 2.10 provides more discussion on this element.

- First Filling Criteria – First filling is a critical stage in life of dam, and numerous dams have failed during this initial loading. The first filling criteria should identify the maximum filling rate and requirements for inspecting and reading and evaluating instrumentation data during first filling. In order to adequately control the first filing rate, sufficient outlet works/diversion discharge capacity will need to be provided. Section 2.2.4. provides more discussion on this element.

- Monitoring Program – A monitoring program should be established for the dam to be implemented once the dam is in operation. The monitoring program should dams under similar loading conditions. Section 3.2 provides more discussion on this element.

- Regular Visual Inspections – Regular visual inspections are needed to identify: changed conditions at the dam, performance issues with the dam, and signs of a developing potential failure mode. Section 2.2.5 provides more discussion on this element.

- Periodic Dam Safety Reviews – Periodic dam safety reviews should be performed on a 10-year interval to allow for a thorough evaluation of the condition of the dam and its ability to withstand normal and more extreme loadings (floods and earthquakes). Section 3.3 provides more discussion on this element.

- Evaluation of Key Dam Safety Issues (Issue Evaluations) – Dam safety issues may develop once the dam is in operation. These issues may require investigations, analyses and/or studies to determine if additional dam safety actions are required. Section 3.4 provides more discussion on issue evaluations.

- Evaluation of Modification Alternatives – If an evaluation of a dam safety issue results in the conclusion that remedial actions are needed to mitigate the dam safety risk, modification alternatives should be developed and evaluated. Section 3.5 provides more discussion on this element.

- Decision Making Process – Dam safety decisions are required throughout the life of the dam. Decisions are needed at the conclusion of reviews to determine if modifications are needed to the design; decisions are needed during periodic dam safety reviews on whether the dam can continue to be operated without any additonal dam studies or evaluations; and decisions are needed when evaluating dam safety issues on whether or not dam safety actions are needed to mitigate the issue, and if so what the appropriate action should be. Section 2.6.3 provides more discussion on this element.

Table 1 provides a summary of the core elements of a dam safety program and when they should be implemented in a dam safety program.

Dam safety is important through the life cycle of a dam. The core elements of a dam

- Planning Phase – during this phase alternatives are investigated and the economic viabilty of the project is demonstrated.
- Design Phase – during this phase, detailed engineering studies and analyses are performed and design details are developed.
- Construction Phase – during this phase the dam is constructed and design changes may be necessary as a result of unanticipated condtions.
- First Filling – once construction of the dam is complete, reservoir storage commences and the dam is loaded for the first time.
- Operations – once storage commences, the dam is put into operation. Hydropower is generated and releases from the dam are made to meet downstream demands, to safely pass flood flows and provide flood mitigation and to satisfy environmental requirements.
- Decommissioning – some dams, at the end of their useful life are decomissioned. The dam is typically breached to prevent the storage of streamflows and restoration of the damsite and upstream and downstream areas is performed.

Each phase in the life of a dam is important and dam safety must be a consideration for each phase. The following describes more detailed dam safety considerations for each phase.

2.2.1 Planning Phase - Dam Safety Considerations

- Appropriate Location for Dam – The selected location and alignment of the dam will greatly influence issues related to the dam foundation stability and abutment stability. Care must be taken when selecting the location/alignment to minimize these potential issues. The location of the dam should consider the potential for future development of the areas upstream of the dam. Future development could impact the drainage characteristics of the upstream basin, which could increase the magnitude of floods.

- Geologic Explorations – Thorough geologic explorations are needed to understand the site conditions and to avoid unknown conditions which can contribute to dam safety issues (such as localized weak foundation zones which can lead to foudation settlement and dam instability or cracking).

- Consideration of Downstream Populations and Future Development – Larger populations downstream of a dam will increase the consequences (loss of human life, economic, cultural and societal consequences) in the event of dam failure. The potential for downstream development in the future should be considered in the planning phase as this could eventually impact the risks at the dam. The ability to predict development very far into the future may be limited.

- Coordination with Other Dams on River System – Dams upstream and downstream of the planned dam should be considered as this can effect the hydrologic risk at a dam (considering both the impacts of inflows created by upstream dams and the impacts of releases from the planned dam on downstream dams). When this occurs, the dam should be designed considering the systematic effects of multiple dams influencing one another in terms of water management. Estimates of consequences (focusing primarily on the loss of human life) should also consider the potential failure of downstream dams due to breach releases from the failure of the planned dam.

- Advantages/disadvantages of Different Design Types – Depending on the site specific factors, there may be advantages and disadvantages of different design options. Costs and operational requirements will be significant considerations when selecting design options. The availability of materials may provide an economic advantage for either an RCC or a rockfill dam if both dams are being considered. When considering a selection between these two dam types, a rockfill dam may perform better under seismic loading, while the RCC dam will likely be better able to withstand overtopping during a large flood. When considering between a gated versus an uncontrolled spillway, there may also be tradeoffs between these two spillway types. A gated spillway may be more expensive initially and result in higher maintenance costs and it may create reliability concerns in future years; however, it offers much more flexibility for water management. An uncontrolled spillway may limit operational flexibility and the ability to manage flood releases. When selecting between design alternatives, all relevant factors should be considered and the selection should be based on the best combination of cost, operational considerations and dam safety considerations.

- Appropriate Analyses to Fully Design Dam and Ensure Adequate Structure – Appropriate analyses should be performed to ensure that the designed structure can withstand the anticipated loads, with appropriate safety factors. The appropriate level of analysis should be chosen. If the strucure is simple and three dimensional effects are minimal, a two dimensional analysis may be appropriate. For more complex structures, where three dimensional effects are significant, a three dimensional analysis may be justified. Studies are also needed to evaluate foundation stability and evaluate the potential for seepage and internal erosion through the dam and/or foundation.

- Defensive Design Measures/Redundancy – Defensive design measures and redundancy should be incorporated to improve the robustness of the design and to reduce the chance of dam failure should unexpected conditions occur. These measures could include adding backup power generators to provide a means of operating spillway gates should the main electric power source fail and providing foundation and formed drains for a concrete dam, even if stability factors can be met without drainage, or placement of an impervious blanket on the lower part of the upstream face of concrete faced rockfill dams to seal any potential cracks or joint openings, even if they are not expected.

- Evaluation of Potential Failure Modes – The evaluation of potential failure modes is important to ensure that critical potential failure modes (which may or may not be addressed by a standards based design) are considered and appropriate design measures and details are provided to mitigate these potential failure modes. A potential failure modes analysis is also valuable in focusing a monitoring program on the most critical aspects of the performance of the dam.

- Provisions for Long-Term Monitoring – monitoring needs and instrumenation installations need to be considered in the design phase. Monitoring should consider the key potential faliure modes identified for the dam.

- Good Documentation on Design – Good documentation is important to establish a detailed record of the assumptions and basis of the dam design. Key information, such as load cases, uplift assumptions, and assumptions on material properties should be highlighted. This information is invaluable in performing

- Consultant Review Boards – Consultant Review Boards (CRB) should be provided for all new dam designs and all significant dam modifications. The board members should be proposed by the IPP and approved by MEM and should be independent of the design firm. The CRB should be multidisciplinary, with the exact make-up of the board determined by the nature of the dam design. Boards should be composed of from 3 to 5 members and should have expertise in the following areas: engineering geology, geotechnical engineering, structural engineering, mechanical engineering, hydrology, and construction management. CRB members should have extensive expertise and experience in their discipline. The CRB should review the feasibility design, the final design and review construction progress at several key times during the dam construction. The CRB should prepare a report detailing their collective findings after each review. The design firm should prepare an accountability report that responds to the recommendations from each CRB report.

2.2.3 Construction Phase

- Evaluation of foundation conditions and preparation, including geologic mapping and photographs – Geologic mapping and photographs of the exposed foundation provide the basis for foundation approvals (verifying that the foundation meets the design intent and that the foundation conditions are well understood; there should be a formal process for documenting and having the designer sign off on the foundation approval). This information may also be valuable during future periodic assessments and if dam safety issues develop in the future related to the dam foundation.

- Preparation of Construction EAP – A construction Emergency Action Plan (EAP) should be prepared prior to the initiation of construction and should be implemented if needed during construction. The Construction EAP should follow the general EAP requirements (see Section 2.8) but should address the unique conditions that will exist and may develop during construction.

- Adapt design as necessary – The design of the dam often has to be adjusted or modified during construction as a result of encountering unexpected conditions or due to unforeseen events. Changes should be adopted if the design intent and in Italy), where design changes made hastily during construction ultimately contributed to failure of these dams. The design changes should also be well documented so that this information is available during future periodic dam safety reviews and if future dam safety issues develop.

- Photographic/video record of construction – A good photographic and video record of the dam construction should be developed and kept in the files for the dam. This information can be very useful in addressing questions that develop during future dam safety reviews and issue evaluations.

- Materials testing – Materials testing should be performed during construction to verify that materials meet the specification requirements and also to establish data that can be used in future studies and analyses.

- As-built drawings – This information is critical to establishing the completed condition, geometries and dimensions of the constructed dam. If this information is not provided it creates uncertainties and confusion as to the actual condition, geometries and dimensions of the dam during future evaluations.

- Document and provide complete baseline information – This should include all the information described above but also include – unusual conditions encountered during construction of the dam and daily, weekly and monthly construction inspection summaries.

2.2.4 First Filling

- Critical Time in Life of Dam – First filling of a dam is a critical event in the life of a dam. A number of dams have failed during first filling (including Teton Dam in the United States and Malpasset Dam in France) . The first filling of a dam is the first time that the dam will be loaded and if there are issues related to seepage, dam stability or foundation stability they will often become apparent during first filling.

- First Filling Program – A formal program should be established for the first filling of a dam. The program should include the following:

    - Filling Rate – A filling rate is important to ensure that the dam is not filled dam and foundation are responding to the reservoir imposed loads in a reasonable and satisfactory manner.

- Monitoring Program – A monitoring program should be established for the period of first filling. Twenty-four hour surveillance of the dam is typically required and instrumentation readings are taken on at least a daily basis. Detailed inspections of the dam should occur at least twice a day. Routine monitoring of instrumentation data and inspections should commence once first filling is complete.

- Provisions for Nighttime Surveillance – In order to perform 24-hour surveillance, provisions for nighttime observations and inspections will be needed. This will likely involve lighting at critical areas of the dam and the foundation.

- Staffing Requirements – Staffing will need to be arranged for 24-hour surveillance of the dam.

- Expected Performance – Expected performance of the dam should be identified and documented prior to the start of first filling. Typically expected performance is obtained from analyses and studies that are performed during the design phase. Predicted dam deformations, piezometric levels, uplift pressures and seepage volumes can be obtained from the analyses and studies. For installed instruments, a range of expected or normal readings should be provided, with the intent that if readings are outside the expected range, additional evaluations and/or monitoring will be required. For visual inspections, a checklist of items to observe should be provided, along with a list of conditions that would generate concern and trigger more in depth evaluations.

- Emergency Action Plan – An Emergency Action Plan (EAP) should be developed and finalized prior to first filling. The EAP should identify what conditions would indicate the initiation of dam failure and the responses that are required for different escalating conditions. See Section 2.8 for more details on an EAP.

- Monitoring Program – A monitoring program is initiated once the dam is in operation. The monitoring program consists of obtaining instrumentation readings on a defined schedule and visual inspections of the dam (discussed below). The purpose of the monitoring program is to verify that the dam is performing as expected. If readings are outside of the defined expected range (which can be developed from the results of analyses and studies performed during the design phase and then expanded into a range to account for the uncertainty in the analyses/studies), additional evaluations and investigations should be conducted and the reading frequency may be increased during the evaluation period. More discussion is provided in Section 3.2.

- Visual Inspections – Visual inspections should be performed on a regular basis. Formal visual inspections should be conducted at least once a month, with a checklist used to document that all key features of the dam have been observed and with notes made if changing conditions are identified. Appendix B contains two examples of Ongoing Visual Inspection Checklists – one for a concrete dam and one for an embankment dam. More thorough inspections of a dam should be conducted annually, during the periodic dam safety reviews and during special inspections. During the periodic dam safety review, the inspection should be documented with an inspection report, including a written narrative and a good photographic record of key features of the dam and associated structures. Outside of these scheduled inspections, dam operations personnel should be trained to observe changing conditions of the dam (such as: increased seepage or seepage at new locations; deformation of the dam; and, concrete deterioration in the spillway).

- Special Inspections – Special inspections of the dam should be carried out when the reservoir reaches historic reservoir levels, after an earthquake in the area or if unexpected performance occurs.

- Periodic Dam Safety Reviews – Periodic dam safety reviews should be performed on a 10 year schedule for significant and high hazard dams. Typically periodic dam safety reviews are not performed on low hazard dams, but inspections of these dams should be conducted on an annual basis and every two years a re-evaluation of whether the low hazard classification still applies should be routine inspections and monitoring of the dam). More information on periodic dam safety reviews is provided in Section 3.3.

- Emergency Action Plans – Emergency action plans (EAPs) should be in place for all dams in operation. EAPs document procedures that should be implemented if unexpected conditions related to dam performance develop at the dam. For more details on EAPs, see Section 2.8.

2.3 Dam Safety Evaluation Process for Existing Dam

Dam safety activities shown in Table 1 are needed to help in identifying potential dam safety issues at a dam. If potential dam safety issues are identified, either as a result of changing conditions discovered during an inspection, from instrumentation readings, from a change in loading conditions or consequences or from a periodic assessment, a process is needed to evaluate these issues. The process shown in Figure 1 should be used if dam safety issues are identified. If the issue is resolved as the result of studies and analyses, corrective actions will not be required. If the issue is confirmed, a corrective action study should be initiated and a preferred corrective action should be selected. Section 3 provides a more detailed discussion of Issue Evaluations and Corrective Action Studies.

Table 1 - Dam Safety Activities During the Life Cycle of a Dam						
	Planning/Design	**Construction**	**First Filling**	**Operations**	**Modifications**	**Decommissioning**
Record Keeping	Yes	Yes	Yes	Yes	Yes	Yes
Design Review	Yes	Yes	No	No	Yes	Yes
Potential Failure Modes Analysis	Develop	Yes	No	Update	Update	No
Inundation Studies	Develop	No	No	Update	Update	No
EAP	Develop	Implement*	Implement*	Implement*	Implement*	Implement*
O&M Manual	Develop	Use	Use	Use	Use	Use
First Filling Criteria	n/a	Yes	Yes	Possibly	Yes	No
Monitoring	n/a	Yes	Yes	Yes	Yes	No
Routine Inspections	n/a	Yes	Yes	Yes	Yes	Yes
Special Inspections	n/a	Yes	Yes	Yes	Yes	Yes
Periodic Dam Safety Reviews	n/a	n/a	n/a	Yes	No	No
Dam Safety Issue Evaluations	n/a	Perform*	Perform*	Perform*	No	No
Modification Alternative Evaluations	No	Possibly	No	Possibly	Yes	Yes
Decision Making Process	Yes	Yes	Yes	Yes	Yes	Yes

*** as needed**

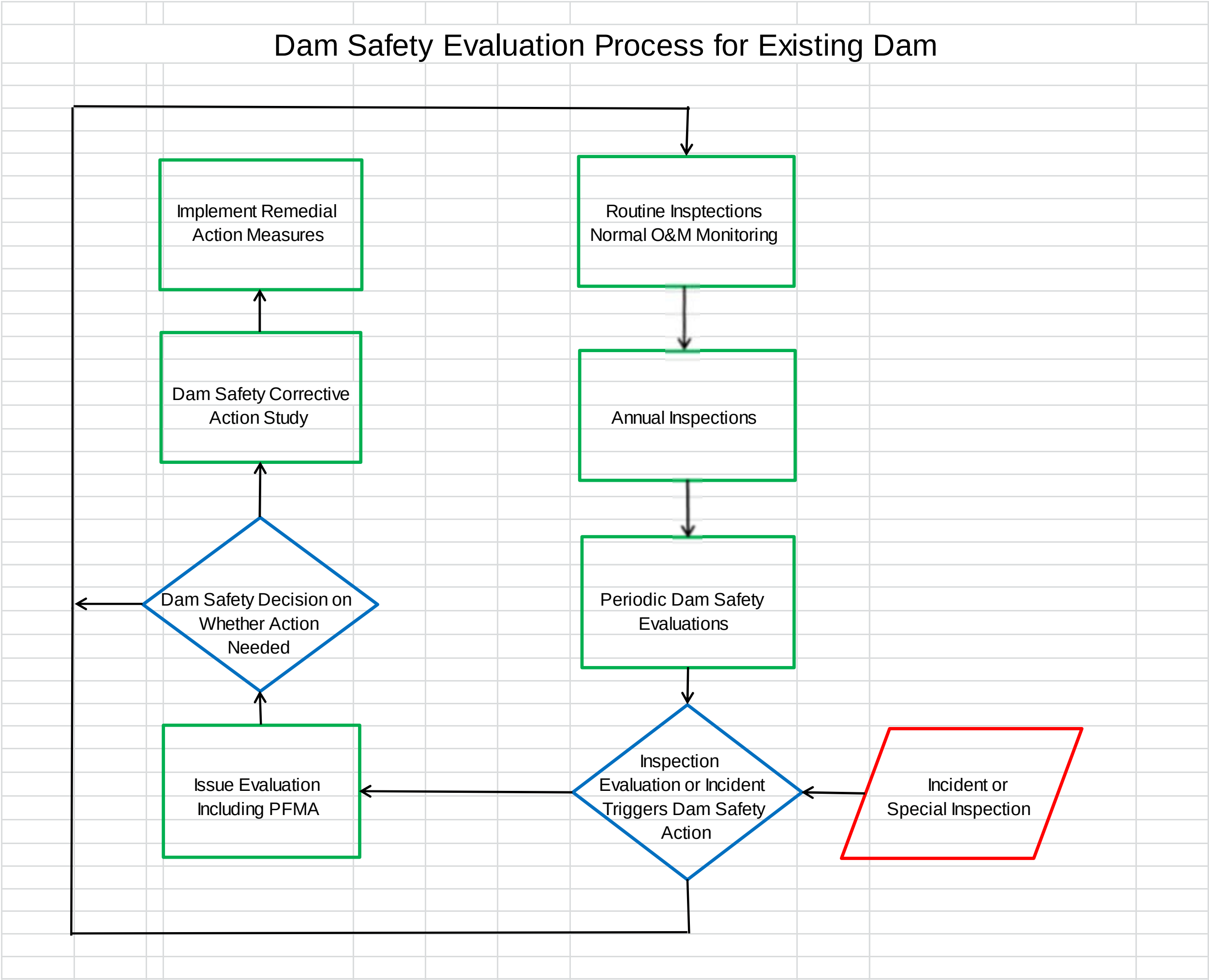

Figure 1 – Dam Safety Evaluation Process for Existing Dam

2.4 Potential Failure Modes Analysis

A potential failure modes analysis should be conducted at the feasibility design phase and updated during final designs and then reviewed and updated during periodic dam safety reviews once the dam is in operation. Potential failure modes are mechanisms that can result in an uncontrolled release of the reservoir. A potential failure modes analysis is a critical first step in conducting a qualitative risk analysis. For a dam in the hydrologic and seismic potential failure modes. For an existing dam, the perspective of local office personnel, including dam operators, inspectors, and dam tenders, is invaluable. The goal of a potential failure modes analysis is to: (1) identify the site-specific credible potential failure modes for a given dam; (2) provide complete descriptions of the potential failure modes, including the initiating event and the progression of steps leading to an uncontrolled release of the reservoir; and (3) provide a general description of the magnitude of the breach, including identifying and recording the factors that make the potential failure more likely and less likely and the consequences more severe or less severe. It is important that the potential failure modes analysis be thorough and considers the unique characteristics of the dam and the damsite. If critical potential failure modes are overlooked, a critical vulnerability at the dam may allow a potential failure mode to initiate.

It is recognized that large controlled flood releases may result in significant downstream consequences, including loss of life, but these events have typically not been included as potential failure modes because they result from intended operation of the dam. Large controlled releases that may result in serious downstream consequences are typically made to prevent even greater consequences that would occur from dam failure. The MEM may elect to consider the risk from large controlled releases.

Identifying potential failure modes is done in a team setting, with a diverse group of qualified people. It is important to take a fresh look at the potential failure modes, and not just default to those that may have been previously identified. A facilitator leads the group and elicits “candidate” potential failure modes from the team members, based on their understanding of the vulnerabilities of the dam and project from the data review and field conditions. It is often useful to “brainstorm” potential failure modes, then go back and evaluate each one. It is the facilitator’s role to ensure the potential failure modes are completely described.

The facilitator must be a senior level engineer with many years’ experience in dam design, analysis and construction. The facilitator must have participated in several potential failure mode sessions (at least three) before facilitating a session.

It is important to put scale drawings or sketches of the dam and critical appurtenant structures up on the wall, and sketch the potential failure modes during the discussions. The potential failure modes must be described fully, from initiation to breach and

- **Failure progression.** This includes the step-by-step mechanisms that lead to the breach or uncontrolled release of the reservoir. The location where the failure is most likely to occur should be also be highlighted. For example, this might include the path through which materials will be transported in an internal erosion situation, the location of overtopping in a flood, or anticipated failure surfaces in a sliding situation.

- **The resulting impacts.** The method and expected magnitude of the breach or uncontrolled release of the reservoir is also part of the description. This would include how rapid and how large the expected breach would be, and the breach mechanism. For example, the ultimate breach from an internal erosion failure mechanism adjacent to an outlet conduit might result from progressive sloughing and unraveling of the downstream slope as a result of flows undercutting and eroding the toe of the dam, until the reservoir is breached at which point rapid erosion of the embankment remnant ensues, cutting a breach to the base of the conduit.

There are several benefits to performing a potential failure modes analysis. It identifies the key vulnerabilities at a given dam and this should be used to focus monitoring and inspection efforts at the dam. It should also be used to guide the development of inundation studies and the preparation of Emergency Action Plans (see Section 2.8). Potential failure mode analyses should be updated during the periodic dam safety reviews as well as during Issue Evaluations.

Once a potential failure modes analysis is completed, an additional step can be to perform a qualitative risk analysis. This procedure is outlined in Appendix A and involves assigning a failure likelihood category and consequence category for each identified potential failure mode. These categories are set up on a progressive scale and descriptions are provided for each category to aid in the assignments. The qualitative risk for each potential failure mode can be portrayed by plotting each potential failure mode in the matrix provided in Appendix A. Potential failure modes plotting in the lower left hand corner of the matrix have the lowest risk (low likelihood of failure combined with low expected consequences) and potential failure modes plotting in the upper right hand corner of the matrix have the highest risk (high likelihood of failure combined with high expected consequences). This qualitative risk approach can provide several benefits. It can help guide decision-makers on whether or not dam within an inventory of dams. Potential failure modes could be ranked based on their combined failure likelihood category and consequence category.

2.5 Risk Integrated into Dam Safety Program

Risk as related to dam safety (using a quantitative approach) involves two components – annualized failure probability and annualized life loss. Annualized failure probability is the probability of dam failure (or the failure of a waterway at a dam) occurring in any given year. Dam failure is defined as an event the leads to an uncontrolled release of the reservoir. Annualized failure probability is the product of the probability of the load (either static, hydrologic or seismic) and the probability of dam failure given the load. Annualized life loss is the product of the annualized failure probability and the estimated life loss if dam failure occurs. A quantitative risk analysis approach is not recommended at this time for dams in Laos, but a qualitative approach is presented as something that could be considered for some dams (see Appendix A). In a qualitative approach, the likelihood of failure and the level of consequences are considered for potential failure modes, and these parameters are more general portrayals of annualized failure probability and annualized life loss.

A risk informed approach can be valuable in managing and structuring a dam safety program. The following steps can be used to implement a risk-informed approach:

- Learn as much as possible about the dam from any available sources.
- Based on that knowledge, perform a potential failure modes analysis (essentially identifying potential weaknesses or vulnerabilities at the dam). This is discussed in more detail in Section 2.4.
- Estimate the risks using a qualitative approach (see Appendix A)
- Evaluate the potential risks posed by the various failure modes to determine if additional actions are required to better understand the risks or to mitigate the risks.
- Develop a monitoring program based on identification of potential abnormal behavior related to the failure modes and develop expected responses to unusual behavior.

based on the critical potential failure modes identified in the potential failure modes analysis.

2.6 Program Management

2.6.1 Introduction

The effective management of a dam safety program requires that roles and responsibilities are well understood. The following section defines roles and responsibilities in the Lao PDR.

2.6.2 Roles and Responsibilities

Role/responsibilities of project developer – The project developer is responsible for providing the funding for the project; for selecting the designer and contractor for the project; and for ensuring that all dam safety requirements during the planning, design, construction and operations are met. The project developer is also responsible for funding and ensuring the dam safety activities are conducted during the concession agreement and that thorough records are developed and maintained during the concession agreement.

Role/responsibilities of dam designer – The dam designer has the overall technical responsibility for the design of the dam, the hydroelectric powerplant and all the associated structures. The dam designer is responsible for conducting the appropriate studies and analyses to verify that the design meets all the dam safety requirements of the Lao PDR guidelines and standards and the accepted current dam engineering practice. The dam designer is responsible for ensuring that qualified technical staff perform, check and review the studies, analyses and designs. The dam designer develops thorough design documentation that incorporates all the studies, analyses and designs.

Role/responsibilities of MEM – The MEM is responsible for reviewing hydroelectric projects during the feasibility, final design, construction and first filling phases. They review designs and ensure that the requirements of the Lao PDR are met. They are responsible for ensuring that the project developer complies with all the requirements in these guidelines during the concession agreement. They are also responsible for maintaining a complete set of records during the life of each dam in Laos.

2.6.3 Decision-Making

Managing dam safety at a given dam and within a dam safety program requires a number of decisions. During the feasibility design phase, a decision is required at the end of the review process as to whether all the requirements have been met. At the end of final designs a similar decision is needed. During construction, unexpected conditions may arise and decisions will be needed on what actions are appropriate to maintain the design intent. Once a dam is in operation, decisions are needed at the end of any dam safety evaluations on whether conditions are acceptable, whether additional investigations or studies/analyses are needed or whether corrective actions should be initiated. During operations, decisions are also needed under normal operating conditions (deciding on what releases to make from the dam) and decisions are needed under unusual or emergency conditions (including releases that will be made but may also include decisions on how to respond to unexpected performance of the dam).

The appropriate decision makers should be identified within MEM for all of these decisions. It is helpful to have a small consistent group of decision makers, for all dam safety decisions across the various phases in the life cycle of a dam. Having a group provides different perspectives and opinions which can promote good decision making and having a consistent group ensures that all dams and the downstream populations are treated equitably.

2.6.4 Communication

Communication is important in all aspects of dam safety within an organization, with the public, and with the specific owners or stakeholders of a project. This communication can help create an awareness of potential dam safety issues and help all parties gain a greater understanding. Creating an understanding of dam safety issues is important for those who have varying degrees of connections to the dam and the associated potential impacts. These diverse groups have a variety of backgrounds, experience, and sophistication. Communication is important between a number of organizations and groups, including:

- Internal to the MEM
- Between MEM and IPP organizations
- Between MEM and the Public
- Between MEM and Organizations from Other Countries

- Between the various groups within MEM when dam safety responsibilities are being transferred (from the feasibility design phase (DEPP is responsible for the planning and feasibility study stage) to final design (DEM is responsible for the basic design and final design) and then on to construction (DEM is also responsible for the construction and operational stage; DEB is responsible for the concession, commercial and beneficial issues of the project development).
- Between the office overseeing construction of a new dam (DEM) and the main MEM office in Vientiane during construction.
- Between the local (district) offices and dam operators and the main MEM office in Vientiane during operations.

Internal communication within the MEM should include the DEPP for dam planning; the DEM for dam design, construction and operation; and the DEB for concession agreements. There should be communication and exchange of information between these groups.

2.6.4.2 Between MEM and IPP organizations

This communication will occur during feasibility studies between the DEPP of MEM and IPP organizations. The communication will focus on the feasibility designs. The DEPP should clearly communicate any concerns regarding the feasibility design and the IPP organization should effectively respond to questions and concerns regarding the design.

2.6.4.3 Between MEM and the Public

Communications should also be provided proactively for organizations and the public that will be, could be, or consider themselves impacted by a dam failure or by dam safety actions that will restrict or modify the operations at the dam. These communications should be initiated at the planning or investigation stage to prevent erroneous information and rumors from developing. Such presentations need to be appropriately technical, conveying the technical information in a manner that conveys the key issues and concerns at the dam, the potential impacts of a dam failure, the proposed actions to address the issues/concerns, and the impacts of these actions on organizations and the public. In addition, the presentation needs to convey the schedule for the dam safety actions.

A number of principles apply to dam safety communication. These principles are discussed below.

Emergency Action Plans identify emergency situations that may develop at a given dam and establish protocols for reacting to the emergency. The advance planning inherent in these plans, and the familiarity of local officials and the public with the plans, will save valuable time during an emergency. Emergency Action Plans and communication with the public are important and integral aspects of reducing risk to life.

Communications with the public should include all key information. This will help instill confidence in the organization and better prepare the organization and the public for responding to an emergency.

Dams present both a benefit and a risk to the public. When dam safety risks are presented, the public may focus on the negative aspects of the dam and not realize the offsetting benefits that the dam provides. When describing dam safety issues at a given dam, the presenter should focus on the benefits as well as the risks posed by the structure.

Integrate dam safety communications early in the process of responding to dam safety issues. This is beneficial because by including individuals in the process and giving them the opportunity to provide input and, possibly, influence decisions, they are more likely to accept the decisions being made.

Focus communications on actions that individuals/organizations need to take. This is important because an effective dam safety program and effective dam safety actions involve a number of organizations and individuals: those that monitor and maintain dams, those that evaluate and make decisions regarding the safety of dams, and those that react and respond to emergencies at dams.

Uncertainty is inherent in dam safety. It is important to acknowledge the uncertainty and put it into the proper context. Uncertainty doesn’t necessarily mean that there is a dam safety issue. It means that there are a number of unknowns that can’t be fully quantified with a high degree of confidence. The following aspects of uncertainty in dam safety evaluation conclusions and the supporting case should be discussed:

- What is certain
- What is likely, but not certain
- What is possible, but not likely

2.6.4.4 Between MEM and Organizations from Other Countries

This communication will likely take place when transboundary issues develop for dams experience may be limited. There are a variety of ways to accomplishing this, including the following:

- Advanced Degrees in applicable fields of study.
- Attending and presenting papers at dam safety conferences.
- Preparing and attending dam failure and incident case history presentations.
- Having outside experts present focused trainings on key technical topics
- Sharing of experiences/issues within the groups responsible for dam safety.

A training program should be developed both for groups involved in dam safety and the individuals in those groups. Progress towards training goals should also be tracked.

2.7 Inundation, Consequences and Dam Classification

Evaluating the impacts of a potential dam failure is important for several reasons. The extent of dam failure flooding is important from an emergency action standpoint, in that it allows local authorities to identify the downstream areas that need to be warned and evacuated in advance of the flood flows. Information on the lateral extent of the inundated area as well as the flow depths and velocities at populated downstream areas and flood wave travel times to key downstream locations will allow for the most critical and life threatening conditions to be identified and to focus the emergency efforts. Emergency action personnel should be familiar with the dam failure inundation maps (which should include a range of dam failure scenarios) and advance planning should occur relative to communication protocols during an emergency and the specific directions that will be given to people being evacuated (including safe evacuation routes and shelters that will be out of harm's way). All of this should be documented in an Emergency Action Plan (see section 2.8) that is specific for each dam. Regular exercises should be conducted to rehearse the implementation of the emergency action plan.

Inundation maps and the associated information on flow depths and velocities are also helpful in evaluating the level of consequences associated with dam failure. This can be done qualitatively, using the guidance provided on Qualitative Risk Analysis in Appendix A. Additional insights into the potential for loss of life can found in Reclamation's RCEM methodology (Reclamation 2013). Once the potential for life loss is qualitatively estimated, a hazard classification scheme can be used to identify a given dam as low, medium or high hazard. Table 2 identifies these three categories and provides the basic information to classify a given dam.

Table 2 - Dam Classification (from Table 17-2 of the LEPTS)		
Dam Classification	**Loss of Human Life**	**Impact on Economy, Society and Environment**
High	Large increase in loss expected	Excessive increase in economic, social and/or environmental impact
Significant	Some increase in loss expected	Substantial increase in economic, social and/or environmental impact
Low	No increase in loss expected	Low increase in economic, social and/or environmental impact

These guidelines are intended to apply to high and significant hazard dams. Low hazard dams should be inspected regularly, but other dam safety activities need not be performed. The hazard classification of a dam may also determine the frequency of inspections and monitoring.

2.8 Dam Safety Emergency Planning

Residents of areas that could be affected by a dam failure or dam safety incident have a risk of loss of life, injuries, and damage to property. The purpose of an Emergency Action Plan (EAP) is to protect lives and reduce property damage. An EAP is a formal document that identifies potential emergency conditions at a dam and specifies actions to be followed to minimize loss of life and property damage. The EAP includes:

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

affect the safe operation of the dam. The release of water may or may not endanger human life, downstream property, or the operation of the structure.

Uniformity of Emergency Action Plans

EAP effectiveness can be enhanced by a uniform format that ensures that all critical aspects of emergency planning are covered in each plan. Uniform EAPs and advance coordination with emergency management authorities should facilitate a timely response to a developing or actual emergency. Organizations and individuals who own or are responsible for the operation and maintenance of dams are encouraged to use these guidelines to develop, update, revise, and exercise their EAPs.

Scope

The EAP guidelines in this document are focused on developing or revising EAPs for dams that would likely cause loss of life or significant property damage as a result of a failure or other life-threatening incident. The areas downstream of each dam are unique. Therefore, the extent and degree of potential impacts of each dam vary.

The level of detail in the EAP should be commensurate with the potential impact of a dam failure or operational incident. A dam with low or no potential impact should not require an extensive evaluation or be subject to an extensive planning process while high- and significant-hazard dams (see Section 2.7 for a description of low-, significant- and high-hazard dams) may require a larger emergency planning effort. In addition, high- and significant-hazard dams tend to involve more entities that must coordinate responsibilities and efforts to effectively respond to an incident than low-hazard dams. Every EAP must be tailored to the site conditions.

EAPs generally contain six elements:

- Notification flowcharts and contact information
- Response process
- Responsibilities
- Preparedness activities
- Inundation maps
- Additional information in appendices

All elements should be included in a complete EAP. Although the dam owner is responsible for developing and maintaining the EAP, the plan will not be effective unless it is developed and implemented in close coordination with all applicable emergency management authorities and the Ministry. Emergency management authorities will use responsibilities for warning, evacuation, and post-incident actions. The EAP should contain clearly defined roles and responsibilities for each entity.

Evacuation
Evacuation planning and implementation is typically the responsibility of local emergency management authorities. Although an EAP does not need to include an evacuation plan, it should indicate who is responsible for evacuation and whose plan will be followed.

Inundation maps developed by the dam owner must be shared with emergency management authorities and included in the EAP. These maps may help in the development of warning and evacuation plans. It is important for dam owners to coordinate with the appropriate emergency management authorities and provide information from dam inundation studies that can assist with evacuation planning. Dam owners should also include procedures in the EAP for ensuring that emergency management authorities are provided with timely and accurate information on dam conditions during an incident. This information will help agencies make the appropriate decisions on evacuations.

Planning Session
Dam emergency evacuation plans should be developed before an incident occurs. The plans are recommended to be based on a worst-case scenario and to address the following:

- Initiation of emergency warning systems
- Pre-incident planning
- Identification of critical facilities and sheltering
- Evacuation procedures, including flood wave travel time considerations (e.g., evacuation of special needs populations, lifting evacuation orders)
- Distance and routes to high ground
- Traffic control measures and traffic routes
- Potential impact of weather or releases on evacuation routes such as flooded portions of the evacuation route before the dam incident occurs
- Vertical evacuation/sheltering in place
- Emergency transportation
- Safety and security measures for the perimeter and affected areas
- Re-entry into affected areas

trained on the importance and use of the plan. Examples of duties may include opening spillway gates according to a required sequence and opening or closing water intakes, as appropriate. Instructions for the operation of the project during the anticipated emergency should be provided. The chain of command in the dam owner's organization should be clearly described. Officials and alternates that must be notified should be identified and priority of notification determined. Notification of supervisory personnel is recommended if time permits. Advice may be needed concerning predetermined remedial action to delay, moderate, or alleviate the severity of the emergency condition. Responsibilities should be coordinated with appropriate levels of management to ensure full awareness of organizational capabilities and responsibilities.

Notification and Communication Responsibilities

The individuals authorized to notify emergency management authorities should be determined and clearly identified in the EAP. If time allows, onsite personnel may be able to seek internal advice and assistance. However, under an Imminent Failure condition, the responsibility and authority for notification may have to be delegated to the dam operator or a local official. When developing the EAP, the dam owner and emergency management authorities should discuss and determine the most efficient notification protocol to follow.

Once notified of an incident at the dam, local emergency management authorities may activate an Emergency Operations Center (EOC) to serve as a central coordination center for emergency response, warning, and evacuation activities. A representative of the dam owner should go to the EOC to help agency personnel understand the project-specific information and inundation maps.

Interaction with the media should be implemented through the local or national emergency management authority. These agencies should have a Public Information Officer (PIO) and/or a Joint Information Center for disseminating information and handling inquiries. It is highly recommended that the dam owner and the appropriate incident or emergency management authority work in partnership to accomplish this task. Proper coordination and communication among onsite technical personnel at the dam, PIOs, and emergency personnel at the EOC are of critical importance to the successful implementation of the EAP. These activities should be thoroughly tested during comprehensive EAP exercises and modified as necessary.

Training and Exercise

Results of training and exercise programs are critical components in evaluating the effectiveness of an EAP. Training and exercise plans should be designed and emergency management authorities to facilitate timely notification and evacuation of areas potentially affected by a dam failure or flood condition. Inundation maps and EAPs should be developed for all high and significant dams in Laos.

Inundation maps should be developed by the dam owner in coordination with the appropriate emergency management authorities. The purpose of this coordination is to ensure that (1) the authorities understand how to interpret the maps and (2) the maps contain sufficient and current information for the authorities to warn and evacuate people at risk from a dam failure.

Determining Downstream Impacts

Several factors have to be evaluated when dam failure inundation zones are being determined. The type of dam and the mechanisms that could lead to failures require careful consideration if a realistic breach scenario is to be developed. Size and shape of the breach, time of breach formation, hydraulic head, and storage in the reservoir are all inputs into the development of a dam failure hydrograph. The best available topographic data should be used for developing accurate volume and routing estimates. There are several methods and computer models available for developing the dam failure hydrograph and routing dam break flows downstream. Models that use unsteady flow and dynamic routing method are preferable. Dam breach analyses and the development of inundation maps should be prepared at the feasibility stage for dams in Laos.

Different inflow conditions at the time of the dam failure should be considered to ensure that the EAP includes all communities that need to be notified. A “fair weather” or “sunny day” dam failure, in which the reservoir is at normal full pool elevation and normal stream flow is prevailing, is generally considered to have the most potential for loss of human life due to the element of surprise. Failure of a dam during flood flow conditions, however, will result in downstream inundation at higher elevations and will include additional affected populations, but could possibly result in less loss of life if certain areas downstream of the dam are already evacuated because of non-failure releases through the spillway. A failure during the dam’s Inflow Design Flood (IDF) is considered to show the upper limit of inundation. A sensitivity analysis (i.e., varying the breach parameters such as breach width and time to failure for the various flood inflow conditions) is recommended in order to fully investigate the effect of a failure on downstream areas. A sensitivity analysis allows the reviewer to identify the effect of various failure scenarios in order to select the most appropriate failure mode(s) for developing the EAP. If the assumed failure of a dam would cause the failure of any downstream dams, the analysis should consider the domino effect in routing the flood downstream dam owners should be undertaken when feasible and are highly encouraged. The flood wave should be routed to a point where it no longer presents a hazard to downstream life or property.

Preparing Inundation Maps Inundation maps should clearly show inundation zones, cross section information, dams, streets, buildings, railroads, bridges, and any other significant features. At the request of emergency management authorities, additional features, such as highlighted evacuation routes and emergency shelters may be included on the maps. All features should be shown using local names or terms. Printed inundation maps should be at a scale that is sufficient to clearly show the downstream inhabited areas within the inundation zones. To assist emergency management authorities with potential evacuations, the maps typically should show areas inundated from a dam failure during “fair weather” and IDF conditions. The maps also typically show normal water levels. If inundated areas for the “fair weather” breach and the IDF breach are essentially the same or too close to be shown separately on the inundation maps, a single inundation area for the two breach conditions may be shown. The lines delineating the inundated area should be drawn in such thickness or form (solid line, dashed line, dotted line) as to readily identify the inundation limits as the main features of the map but not bold enough to block houses, roads or other features which are inundated by the flood waters. The area between the inundation lines representing the water level may be shaded or colored to distinguish the area of inundation. Care should be taken to select shading or colors that will not block important features on the map. Additionally, critical features or inundated structures can be highlighted to ensure visibility.

Additional Information Care should be taken not to include too much technical information on the inundation maps. Excess information will hamper the first responder’s ability to quickly glean critical information from the map. A “Notes” sheet can be included to provide additional information, and detailed information supporting the development of the maps can be provided in an appendix for reference. The following information should be included with the inundation maps, as applicable:

- A map index if inundation maps are shown on several sheets
- The antecedent flow conditions the maps are based on and any other pertinent dam breach information
- Water surface profiles showing the elevation prior to failure, the peak water surface elevation after failure, and highlighted locations of critical structures

warning systems are used. Early warning systems can be effective but they must be well designed and properly maintained. If the system is unreliable and a number of false alarms occur, or if the system is not maintained and does not fully function during a dam failure, the benefits of the system will not be achieved.

2.9 Records

Comprehensive records of a dam are a critical component of an effective dam safety program. Good records provide valuable data that can be used in future evaluations and analyses of the dam. In the absence of good records, considerable expenditures may be required to determine/confirm site conditions or material properties of the dam, redo key stability analyses or redo other studies. The following records should be maintained as part of the dam safety records for any dam:

1. Geologic reports/maps/drawings/drill logs that document the site conditions and any exploration programs performed.
2. Material testing data that includes testing and characterization of dam materials (gradations, permeability and strength data on embankment materials, filter compatibility evaluations for embankment materials, gradations and durability data on concrete aggregates, mix design, mix design testing data and strength data for concrete materials).
3. Loading information from the original design including load cases considered for the dam and appurtenant structures
4. Key design documentation including: flood routing studies, stability/stress analyses for embankment and concrete dams including considerations of normal, flood and seismic loading, hydraulic analyses for spillways and outlet works structures and structural analyses for spillways and outlet works structures.
5. A complete set of as-built drawings for the dam and appurtenant structures.
6. Construction photographs/videos that document the as excavated foundation conditions, unexpected geologic conditions encountered during construction, and the staged construction of the dam and appurtenant structures.
7. Periodic construction reports that document the construction progress.
8. A complete set of instrumentation data from the monitoring program established for the dam at the beginning during first filling and though operation of the dam.
9. Inundation studies/maps of the downstream channel for various dam failure scenarios.
10. Consequence studies/evaluations performed for the applicable dam failure scenarios.
11. Inspection reports and checklists for all formal/informal dam inspections

14. Reports that document dam safety incidents/failures that have occurred at the dam.
15. PFMA reports and Qualitative Risk Analysis reports (if prepared).
16. Periodic dam safety review reports.
17. Consultant review reports and accountability reports in response to consultant review reports.
18. All key correspondence (review reports and letters that document issues that develop and their resolution) related to the planning/design/construction/operations/dam safety aspects of the dam.

The responsibility for creating documents that become part of the official dam record will the responsibility of the organization performing the investigation, study, design, review, analysis or evaluation. A complete set of records should be kept and maintained at the dam, at the dam owner's offices (during the period of the concession agreement) and at the MEM. Electronic copies (with appropriate backups) should be kept as the record copies and hard copies may also be kept as desired.

2.10 Operations and Maintenance

An Operations and Maintenance **(**O&M) Manual, which contains the Standing Operating Procedures (SOP) for the dam should be provided for each dam under the jurisdiction of the MEM. These manuals are necessary to ensure the safe operation of the dam and to ensure that appropriate inspections and maintenance are performed at the dam. The O&M manual addresses required routine maintenance at the dam and should include a discussion of routine exercising of gates, schedule for lubrication of mechanical equipment, frequency of drain inspection and cleaning, frequency of replacement of wearable parts of the electrical/mechanical systems.

The SOP should provide specific detailed instructions for operating mechanical and electrical equipment during both normal operations and during flood operations. For spillways that are controlled by gates, specific instructions should be provided that define the required outflows in response to flood inflows. The SOP should identify the frequency and level of inspections of the dam and appurtenant structures and should include checklists for the inspections of features to be inspected and conditions to look for (see Appendix B for examples). The SOP should also include the schedule for collecting data from any instrumentation provided at the dam (see Appendix D for examples). If no instruments are provided at a given dam, regular visual inspections of the dam should still be performed.

completely removed and a remnant is left in place that could store water temporarily if the breach opening of the dam becomes blocked or if the inflows are very large and the breach opening constricts flows. Under these conditions, a temporary reservoir could be created that could be released if the remnant dam failed. These scenarios should be considered if the entire dam is not removed and the breach configuration should be designed so that the risk is low for potential failure modes affecting the remnant dam.

3. Dam Safety Evaluations/Corrective Actions

3.1 General

There are a number of approaches and methods that are used to evaluate dams and either confirm that the dam is performing as intended or identify a potential dam safety issue.

3.2 Monitoring

Monitoring involves the ongoing process of observing a dam's performance over the course of its service life, and as such is a key part of dam safety evaluations. Monitoring of a dam can be accomplished through visual inspections and observations at a dam (either on a regular schedule or as a result of a triggering activity such as an earthquake or an unexpected condition developing at the dam) and through the collection of data from instruments and field measurements (such as piezometer readings or seepage measurements; data is collected on a regular schedule and in response to an unexpected condition). Monitoring of a dam is important for several reasons. It can be helpful in identifying the initiation of a potential failure mode at a dam or in identifying a condition that would make the dam vulnerable to the initiation of a potential failure mode. Timely recognition of a developing situation will often provide enough time for dam safety staff to evaluate the problem and to initiate corrective actions if they are warranted. Monitoring of a dam is also important to establish and update the baseline condition of the dam, so if an unusual or extreme loading event occurs (a large flood or earthquake) or if conditions change significantly (seepage through the foundation of the dam increases dramatically) changes in or related to the dam can be quantified.

Monitoring at a dam should be focused on potential failure modes. Most of the installed instrumentation should be tied to specific potential failure modes at the dam and should provide early indications that the potential failure mode is developing. If instrumentation does not provide evidence of the development of a potential failure mode, it should be questioned if the instrumentation is really needed. Some reasons for preserving

The frequency of readings for instrumented monitoring will depend on the parameter being monitored. The frequency should be adequate to capture changes related to reservoir levels and temperature changes at the dam.

3.3 Periodic Dam Safety Reviews

Dam safety reviews are required on a recurring basis to ensure that an existing dam remains safe under potentially changing conditions. Changing conditions can involve a change in the physical condition of the dam and foundation, changes in operations, a change in predicted loadings that may be more severe than what was previously considered at the dam (this could be the result of the identification of new faults in the region which increases the seismic risk or recent large storms or loss of vegetation in the drainage basin that increases the hydrologic loading), the recognition of new potential failure modes at the dam, a change in estimated risk at the dam, or a change in the downstream consequences in the event of dam failure. The reviews should consider changes in the physical condition of the dam, including change in seepage volumes and locations, deformations of the dam and appurtenant structures, and deterioration of materials in the dam and appurtenant structures. The reviews should also consider changes in the possible loadings at the dam. This will require a reevaluation of the seismic hazard and the hydrologic hazard at the dam site. This review does not imply that new hazard studies will be conducted, but if a review indicates that new information is available that may significantly alter the risk estimated at the dam, then new studies may be warranted. Increases in loadings will not necessarily result in the need to modify a dam. The impacts of the change to the dam should be evaluated (possibly through updated analyses) and a determination made if the loading changes will significantly increase the dam safety risks.

The reviews should consider changes in downstream development and the possible impact on consequences in the event of dam failure. If significant changes have occurred, an updated qualitative consequence estimate should be considered. If new potential failure modes are developed that result in a unique breach scenario or if it is determined that previous inundation studies are not representative, then new inundation studies should be considered.

The dam safety reviews should be conducted on 10-year intervals. They should be performed by a registered professional engineer who is independent of the dam owner and the MEM. The dam safety review should be summarized in a written report, which should include the following sections:

Recommendations – This section should summarize both existing and new dam safety recommendations (related directly to potential failure modes) and O&M (Operation and Maintenance) recommendations (related to routine activities associated with maintaining the condition and the functionality of the dam, waterways and associated mechanical and electrical equipment).

Description – This section should provide a concise description of the dam and appurtenant structures, including the listing of key features, providing key dimensions and capacities of the waterways. The historical maximum reservoir water surface and the historical maximum discharge from the dam should also be provided. The dam owner should be identified and the frequency with which the dam is visited should also be identified. Dams that are immediately upstream and downstream of the dam being evaluated should be identified.

Evaluation of Design, Construction and Analysis – This section should document the original design and construction of the dam and include any updated analyses and studies performed after the dam was placed in operation. Summary information should be provided, with a list of references that provide more detail on previous studies/evaluations.

Evaluation of Performance Monitoring and Instrumentation – This section should summarize and provide an evaluation of the performance monitoring and instrumentation (including what instruments are monitored and how often and how often visual inspections are provided). Plots of monitoring and instrumentation data should be included that show trends in performance.

Examination Report – This section should document the detailed physical examination of the dam that is performed as part of the periodic dam safety review. The report should include photographs that document the inspection.

Hydrologic Hazard - This section should summarize the current hydrologic hazard study for the dam. Hydrologic hazard curves should be provided that relate peak inflow values and flood volumes to return period.

Seismic Hazard – This section should summarize the current seismic hazard study for the dam. Seismic hazard curves should be provided that relate seismic loading parameters (typically peak horizontal ground acceleration) to return period.

document the inundation studies performed. If rough economic consequences are estimated, the methodology used should be described.

Potential Failure Modes – This section should document and thoroughly describe the key contributing potential failure modes that have been identified at the dam. Potential failure modes that were considered but not judged to be plausible should also be documented.

Analysis of Risk – This section should document the qualitative analysis of risk (if performed) for the key potential failure modes. The justification for the overall risk estimate category (based on both the likelihood of failure and the general level of life loss consequences) should be provided along with the supporting information. The risk estimate category for individual potential failure modes should be plotted (on a risk matrix).

Future Performance Monitoring - this section should document a review of the existing performance monitoring and instrumentation program and include proposed revisions to the program. The performance monitoring and instrumentation program should include a schedule for collecting readings and for performing inspections of the dam. The performance monitoring and instrumentation program should consider the potential failure modes and how information would help in identifying the development of the key potential failure modes. Ranges of expected performance for each instrument or reading should be provided along with a threshold level, where additional readings, further evaluations or actions are required.

Key Drawings – this section should include copies of the key drawings for the dam and appurtenant structures.

The dam safety review report will provide a valuable reference of key information for the dam. This will likely be very useful for future reviews and in the event that a dam safety issue develops in the future. Once an initial dam safety review report is generated for a dam, it can be stored electronically and revised as necessary during the next dam safety review.

3.4 Issue Evaluations

As mentioned in Section 2.3, the need for a detailed evaluation of a potential dam safety issue may be identified from a number of different paths. It may be the result of a periodic dam safety review, in which a review of viable potential failure modes at a given information is collected (possibly including an exploration program, material testing and an updating of the hydrologic and seismic loads), studies and analyses are performed and conclusions are made on whether a dam safety deficiency exists. The determination of whether or not a dam safety deficiency exists may be based on comparing analysis results to standards and criteria or may consider the results of a qualitative risk analysis (see Appendix A). If a dam safety deficiency is identified, a decision will be needed on whether further studies should be performed or whether remedial actions should be initiated. If the confidence in the dam safety studies indicating a dam safety deficiency is high (high confidence would indicate that decision makers are comfortable with completeness of the dam safety studies and that they are comfortable with the conclusions drawn from the studies), a decision to move to remedial actions is likely appropriate and if the confidence is low and if refined or additional studies can be performed, this is probably the appropriate course of action.

3.5 Remedial Action

Remedial action at a dam will be required when a potential failure mode is in progress and a lack of action would likely lead to dam failure; when the chance of a potential failure mode is identified as being unacceptable, either based on stability analyses, stress analyses or flood routings or other studies that can be related to dam safety criteria, or based on a qualitative risk analysis. The need for remedial action will be based on the identification of a dam safety issue (potential failure mode) that has a high enough potential to result in failure of the dam or failure of an appurtenant structure. The determination of whether a dam safety issue has risen to the level where remedial action is needed should be supported by data, engineering studies and analyses and possibly qualitative risk analyses. If remedial actions are proposed, a solid justification for this recommendation should be provided and appointed decision makers should review the available information and decide whether or not to adopt the recommendation.

The need for remedial action can be triggered by several mechanisms. One mechanism would be through an incident at the dam where unexpected conditions develop and are determined to be symptoms of a developing potential failure mode or dam safety issue. An example of this would be seepage through an embankment dam foundation that increases suddenly and continues to increase over several days, with no change in the reservoir water surface. A second mechanism would be the identification of a significant potential failure mode (either a new potential failure mode that had not been previously identified or a potential failure that was previously identified but was now perceived to have increased risk due to new information) during a periodic dam

If it is decided that remedial action is warranted, a suite of alternatives should be considered, ideally utilizing different concepts for improving the stability or strength of the dam/appurtenant structure. The alternatives should be evaluated on several factors including: technical feasibility, whether or not the alternative increases stability, strength or risk to acceptable levels, the cost of the alternative (considering construction cost and total project cost), construction risks, environmental impacts and other factors deemed important by the decision makers. The preferred alternative should be selected based on the above factors and the best value for the money expended. It should be demonstrated that the preferred alternative adequately improves the conditions at the dam to the point where the dam safety concern is addressed. This can be based on analysis results that show improved predicted performance of the dam (related to reduced stress levels, improved stability factors of safety or safe passage of the design flood without dam overtopping) or by providing defensive design measures that will prevent a potential failure mode from progressing.

Examples of remedial action would be raising an existing dam to allow for safe passage of the Probable Maximum Flood (PMF), constructing a stability berm against the downstream face of a rockfill dam to stabilize the dam during seismic loading or installing foundation drains in an RCC dam foundation to improve foundation stability.

3.6 Environmental and Social Factors

Environmental and social factors are important considerations in dam safety. Adverse effects on the environment and communities along the upstream and downstream watersheds should be avoided as much as possible, during the original construction of the dam, during modifications to the dam, during dam operations and in the event of dam failure. When selecting the original dam type and alignment and during any subsequent modifications to the dam, these factors should be considered and part of the criteria used to select alternatives.

Environmental and social factors should also be considered when evaluating the potential consequences of dam failure. If environmental or social factors are significant, this could be a contributing factor in a decision to modify a dam.

3.7 Transboundary Considerations

Transboundary considerations apply to situations were dams can affect the safety of dams upstream or downstream of them. These dams in series may extend across country boundaries or can be owned and operated by different entities. For dams in

REFERENCES

[1] Australian National Committee on Large Dams. 2003. *Guidelines on Risk Assessment*. Sydney, New South Wales, Australia.

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[3] Bureau of Reclamation and U.S. Army Corps of Engineers. 2012. Best Practices in Dam Safety and Levee Safety Risk Analysis, Denver, Colorado.

[4] Bureau of Reclamation. 2014. *RCEM – Reclamation Consequence Estimating Methodology – Interim Guidelines for Estimating Life Loss for Dam Safety Risk Analysis*" *Bureau of Reclamation, Denver, Colorado*, *February* 2014.

[5] Federal Emergency Management Agency. 2005. *Federal Guidelines for Dam Safety.*

[6] Federal Emergency Management Agency. 2013. Federal Guidelines for Dam Safety, Emergency Action Planning for Dams, FEMA 64, July 2013.

[7] New South Wales Government Dams Safety Committee. 2006. *Risk Management Policy Framework for Dam Safety*. New South Wales, Australia, August.

[8] U.S. Army Corps of Engineers. 2011. *Safety of Dams – Policy and Procedures*. ER1110-2-1156. October 28, 2011. Web site: (http://140.194.76.129/publications/eng-regs/ER_1110-2-1156/ER_1110-2-1156.pdf)

GLOSSARY OF TERMS

Annualized Failure Probability: Annualized failure probability is the probability of dam failure occurring in any given year. It is the product of the probability of the load and the probability of dam failure given the load. This term applies to quantitative risk analyses. A quantitative risk analysis approach is not recommended in these guidelines but a gualitative risk analysis approach is presented as something that could be applied to certain dams in Laos. The qualitative risk analysis approach is outlined in Appendix A and the likelihood of failure assigned to individual potential failure modes is a more general portrayal of the annualized failure probability.

Breach: An opening through the dam resulting in partial or total release of the reservoir.

Consequences: Consequences are primarily focused on the potential loss of life downstream of a dam caused by floodwaters released at the dam or by waters released by partial or complete failure of dam. Economic, environmental, cultural and societal consequences can also be considered.

Credible potential failure mode: A potential failure mode that is considered to affect the total risk at a given dam and for which action could potentially be taken to reduce risk (if risks are high enough). A non-credible potential failure mode is a potential failure mode which is judged to have very low risks and for which a strong case can be made to that affect. Non-credible potential failure modes are often judged to represent a risk that is well below tolerable risk guidelines and orders of magnitude less than that of the more dominant potential failure modes at a given dam.

Dam failure: Catastrophic type of failure characterized by the uncontrolled release of the reservoir. A dam failure can be sudden and rapid or may proceed at a slower rate.

Dam owner: Entity that owns the dam and associated facilities. The dam owner also includes the dam operator and operating organization.

Emergency Action Plan (EAP): Formal document that identifies potential emergency conditions at a dam and specifies preplanned actions to be followed to minimize property damage and loss of life. The EAP describes actions the dam owner will take to moderate or alleviate a problem at the dam, as well as actions the dam owner, in coordination with emergency management authorities, will take to respond to incidents or emergencies related to the dam.

document. Exercises consist of testing and performing the duties, tasks, or operations identified and defined within the EAP through a simulated event.

Emergency: Any incident, whether natural or manmade, that requires responsive action to protect life or property.

Emergency alert system: A nationally established network of television and radio stations that voluntarily provide official emergency instructions or directions to the public during an emergency.

Emergency management authority: National or local agency responsible for emergency operations, planning, mitigation, preparedness, response, and recovery for all hazards. Names of emergency management authorities vary (e.g., Division of Emergency Management, Comprehensive Emergency Management, Disaster Emergency Services, Emergency and Disaster Services).

Emergency Operations Center: The location or facility where responsible officials gather during an emergency to direct and coordinate emergency operations, to communicate with other jurisdictions and with field emergency forces, and to formulate protective action decisions and recommendations during an emergency.

Flood hydrograph: Graph showing the discharge, height, or other characteristic of a flood with respect to time for a given point on a stream.

Flood routing: Process of determining progressively, over time, the amplitude of a flood wave as it moves past a dam or downstream to successive points along a river or stream.

Hazard potential: Situation that creates the potential for adverse consequences, such as loss of life, property damage, or other adverse impact. Impacts may be for a defined area downstream of a dam from floodwaters released through spillways and outlet works of the dam or waters released by partial or complete failure of the dam. They may also be for an area upstream of the dam from the effects of backwater flooding or the effects of landslides around the reservoir perimeter.

Headwater: Water immediately upstream from a dam. The water surface elevation varies due to fluctuations in inflow and the amount of water passed through the dam.

Incident: An incident is an event at a dam that results in the initiation of a potential maximum height of the dam, freeboard, and temporary storage requirements. The upper limit of an IDF is the Probable Maximum Flood.

Inundation map: Map delineating areas that would be flooded as a result of a dam failure.

Inundation zone: Area downstream of the dam that would be inundated by the released water. This zone is typically demarcated by a boundary reflecting the vertical elevation of the peak flow of water for both a flood failure and "sunny day" failure situation.

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

Potential failure mode: A way that dam failure can occur (i.e., the full sequence of events from initiation to failure) for a given loading condition. A condition of a potential failure mode is that it results in an uncontrolled release of the reservoir.

Probable Maximum Flood (PMF): Flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that is reasonably possible in the drainage basin under study.

Risk: The product of the likelihood of a structure being loaded, adverse structural performance, (e.g., dam failure), and the magnitude of the resulting consequences. This term is typically referred to as the annualized life loss in a quantitative risk analysis and consequences are defined as the estimated loss of human life. A quantitative risk analysis approach is not recommended in these guidelines but a qualitative risk analysis approach is presented as something that could be applied to certain dams in Laos. The qualitative risk analysis approach is outlined in Appendix A and the risk or annualized failure probability can be conceptually displayed on the qualitative risk matrix, considering the combination of likelihood of failure and the consequence category. Potential failure modes that are plotted near the upper right hand corner of the matrix would have the highest risk.

Risk analysis/risk estimation: A qualitative or quantitative procedure that identifies potential modes of failure and the conditions and events that must take place for failure to occur. A quantitative risk analysis yields a numerical estimate of the risk of adverse consequence, multiplying the probability of load times the probability of dam failure given the load times the magnitude of adverse consequence given dam failure. A

Risk assessment: The process of considering the quantitative or qualitative estimate of risk, along with all related social, environmental, cost, temporal, and other factors to determine a recommended course of action to mitigate or accept the risk.

Risk management: Actions implemented to communicate the risks and either accept, avoid, transfer, or control the risks to an acceptable level considering associated costs and benefits of any action taken.

Residual risk: Risk remaining at any time.

Societal risk: The probability of adverse consequences from hazards that impact society as a whole and that create a social concern and potential political response because multiple fatalities occur in one event. Society is increasingly adverse to hazards as the magnitude of the consequences increases. Societal risk is typically expresses as the annualized life loss (in a quantitative risk analysis) which is the product of the annualized failure probability and the estimated life loss for a given potential failure mode.

Tailwater: Water immediately downstream from a dam. The water surface elevation varies due to fluctuations in the outflow from the structures of a dam. Tailwater monitoring is an important consideration because a failure of a dam will cause a rapid rise in the level of the tailwater.

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 risk that is not to be regarded as negligible or ignored, but needs to be kept under review and reduced further if possible.

Uncertainty: The result of imperfect knowledge about the present or future state of a system, event, situation, or population under consideration.

Appendix A – Qualitative Risk Analysis

Qualitative Risk Analysis

A qualitative risk analysis can be a useful tool at any phase of dam studies. In the planning or design phase, it can be used to make sure that key dam safety issues are identified. It can also be used to focus a monitoring program by identifying the most likely potential failure modes. A qualitative risk analysis starts with a Potential Failure Modes Analysis (see Section 2.4) and then a categorization of the potential failure modes, based on the likelihood of occurrence and the level of estimated consequences.

For existing dams, a qualitative risk analysis can be used to identify the most critical dam safety issues at a dam and also to prioritize the most critical dam safety issues at a dam, and also to prioritize dam safety actions within a portfolio of dams. Given this background information, the following likelihood categories and descriptions can be used to approximate existing tolerable risk guidelines:

Failure Likelihood Descriptions

- **Very High** – There is direct evidence or substantial indirect evidence to suggest it has initiated and/or is likely to occur. Or, a flood or earthquake with a return period less than 1,000 years would likely trigger the potential failure mode.

- **High** – The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible, and key evidence is weighted more heavily toward likely than unlikely. Or, a flood or earthquake with a return period between 1,000 and 10,000 years would likely trigger the potential failure mode.

- **Moderate** – The fundamental condition or defect is known to exist, indirect evidence suggests it is plausible, and key evidence is weighted more heavily toward unlikely than likely. Or, a flood or earthquake with a return period more remote than 10,000 years would likely trigger the potential failure mode.

- **Low** – The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to its development. Or, a flood or an earthquake with a return period much more than 10,000-years would likely trigger the potential failure mode.

- **Remote** – Several events must occur concurrently or in series to trigger failure.

an “order of magnitude” range in failure likelihood. An evaluation of dam failure case histories indicates that the number of fatalities is primarily dependent on: (1) the population at risk within the dam break inundation boundary, (2) the severity of the flooding, and (3) the amount of warning time the population at risk has to evacuate the area as well as how well the population understands what is about to happen [10]. The population at risk can be broadly categorized by transient activity and the size of the towns within the inundation zone. The severity of flooding is a function of the potential destruction to structures and trees within the flood plain. The warning time is a function of when the warnings are issued and the time it takes for the flood wave to reach the population at risk. Based on this, the following broad consequence categories can be defined:

Consequence Descriptions

Level 0 – No significant impacts to the downstream population other than temporary minor flooding of roads or land adjacent to the river. Or downstream discharge results from fuse plug operation or from an intended overtopping at a designated emergency release location, to help ensure discharge occurs from this designated location rather than causing failure of larger structures. Discharge from these locations results in an incremental spike in what is generally a high discharge flow level. It may also result in some minor increase in downstream damages over what would occur from passing the flood discharge through a conventional spillway. (Note: this category may be excluded from the risk matrix.)

- **Level 1** – Downstream discharge results in minor property and environmental damage. Damage is likely to recreation areas, roads, and bridges in low-lying areas. Direct loss of life is unlikely. Costs of reconstructing the project features and the negative publicity associated with a dam failure would also be incurred.

- **Level 2** – Downstream discharge results in moderate property and environmental damage. Damage to permanently occupied structures, recreation areas, roadways, and bridges in low lying areas is possible. The potential exists for some direct loss of life, related primarily to difficulties in warning and evacuating recreationists/ travelers and small population centers. Costs associated with re-constructing the project features and negative publicity associated with a dam failure would also be incurred.

- **Level 3** – Downstream discharge results in extensive damage to permanently associated with re-constructing the project features and negative publicity associated with a dam failure would also be incurred.

- **Level 4** – Downstream discharge results in extensive damage to permanently occupied structures, roadways and bridges throughout the inundation zone. Direct loss of life could be high due to limited warning for large population centers and/or limited evacuation routes. Costs associated with re-constructing the project features and negative publicity associated with a dam failure would also be incurred. In a general sense, each category represents an order of magnitude range in consequences, with loss of life occurring in Categories 2 through 4.

Once the likelihood of failure category and the consequence category have been determine for the potential failure modes at a given dam, the qualitative risks for the dam can be plotted on a risk matrix (see Figure 2). Different levels of risk are indicated by the color shading on the risk matrix. The red area indicates risks that require further evaluation. The yellow area indicates risks that are borderline with respect to risk and the green area indicates risks that are not a pressing concern.

Note: The potential for intervention must be considered when assigning the likelihood category, and the potential for evacuation must be considered when assigning the consequence category**.**

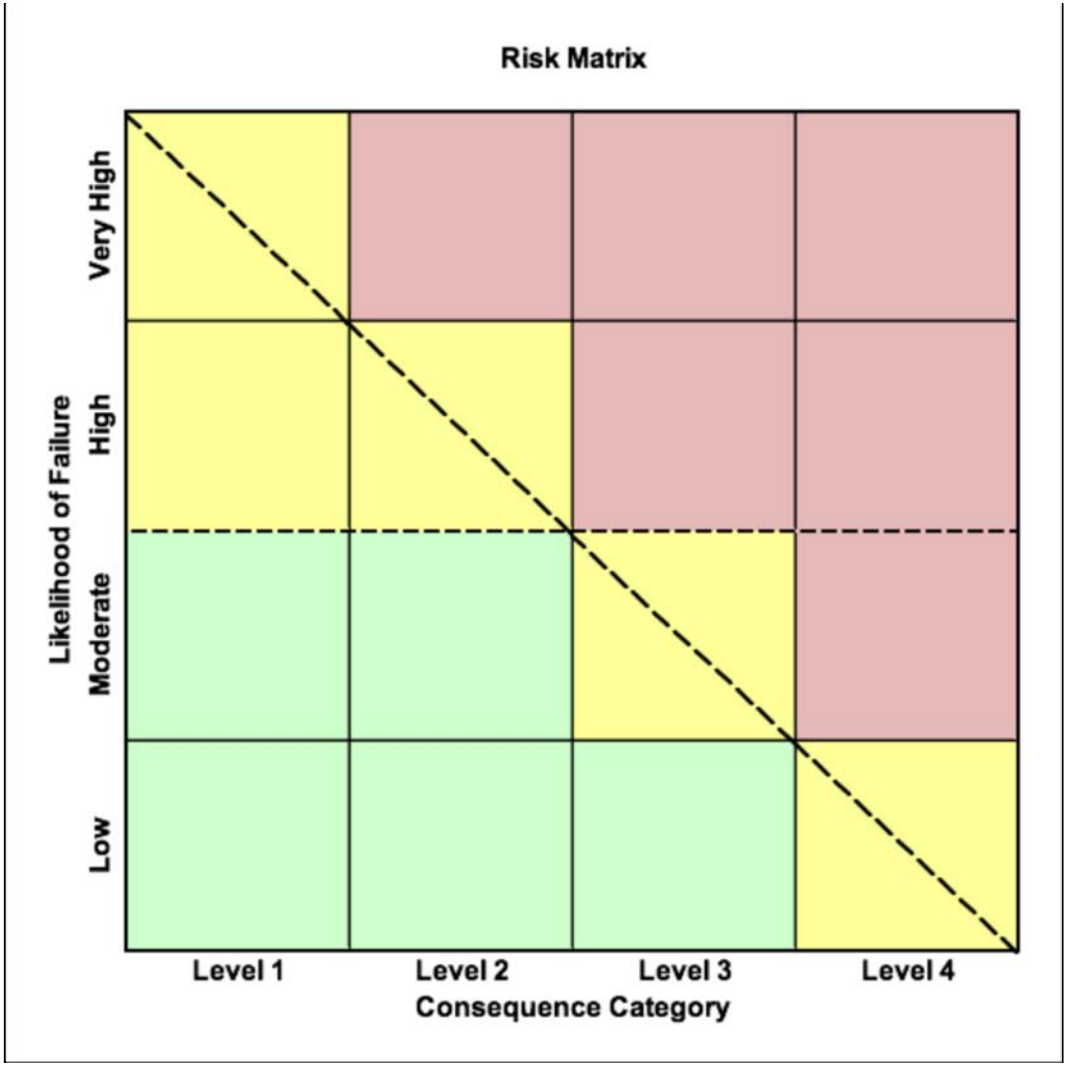

Figure 2 - Qualitative Risk Matrix

Appendix B – Ongoing Visual Inspection Checklists

Ongoing Visual Inspection Checklist
Example Embankment Dam

Date: ______________________

Schedule: Under normal operating conditions, perform monthly, as indicated on the "Schedule for Periodic Monitoring (L-23)". In the event the reservoir elevation exceeds its historic high elevation (currently 6168.1 feet), perform daily while the reservoir is above this elevation. Additionally, perform immediately following a significant earthquake in the vicinity of the dam, and as appropriate after a major flood event.

Inspector: ______________________ **Date:** ______________
Reservoir Elev.: __________ Feet **Time:** ______________
Weather: ______________________ **Temperature:** __________ ºC

A "YES" response should be given to question(s) below where observed conditions are different than previously observed conditions. Re-reporting conditions that have previously been reported and currently are unchanged should not be done ("NO" answer would be appropriate). For any question answered "YES", please provide additional information describing the situation as completely as possible under item 7, "Additional Information." Also, take photographs and include them with this report, as appropriate.

1. Upstream Slope of the Dam:

a. Any evidence of significant erosion or beaching due to wave action? ☐No ☐Yes
b. Any sinkholes, sloughs, or areas of unusual settlement? ☐No ☐Yes
c. Any evidence of whirlpools in the reservoir? ☐No ☐Yes

2. Dam Crest:

a. Any cracks, either transverse or longitudinal? ☐No ☐Yes
b. Any sinkholes or areas of unusual or excessive settlement? ☐No ☐Yes

3. Downstream Slope of Dam, Downstream Toe Area, and Abutment Groins:

a. Any new seepage areas or wet areas? ☐No ☐Yes
b. Any changes in conditions at any existing seepage areas or wet areas? ☐No ☐Yes
c. Any evidence of materials being transported by seepage flows (such as discolored water or sediment deposits)? ☐No ☐Yes
d. Any sinkholes, sloughs, slides, or areas of unusual settlements or deflections? ☐No ☐Yes
e. Any bulging of the embankment evident? ☐No ☐Yes

4. Outlet Works Tunnel Portal Area:

a. Any new or enlarged cracks, or spalls in concrete? ☐No ☐Yes
b. Any evidence of unusual deformations or displacements? ☐No ☐Yes

5. Outlet Works Gate Chamber:

a. Any significant change in the seepage flows? ☐ No ☐ Yes

b. Any significant change in the general wetness of the chamber walls? ☐ No ☐ Yes

6. Abutments:

Note: Both abutments are ancient landslides. Inspect the base of the abutment slopes within 1,000 feet of the dam, and visually scan the abutments using binoculars from the river valley.

a. Any new seepage areas or wet areas? ☐ No ☐ Yes

b. Any changes in conditions at any existing seepage areas or wet areas? ☐ No ☐ Yes

c. Any evidence of materials being transported by seepage flows (such as discolored water or sediment deposits)? ☐ No ☐ Yes

d. Any slides, sloughs, or areas of unusual settlement? ☐ No ☐ Yes

e. Any bulging evident at the base of the slopes? ☐ No ☐ Yes

7. River Valley Area Downstream of the Dam:

Note: Inspect the area within 1,000 feet of the dam.

a. Any new seepage areas or wet areas? ☐ No ☐ Yes

b. Any changes in conditions at any existing seepage areas or wet areas? ☐ No ☐ Yes

c. Any evidence of materials being transported by seepage flows (such as discolored water or sediment deposits)? ☐ No ☐ Yes

d. Any sinkholes, depressions, or other areas of unusual settlement? ☐ No ☐ Yes

8. Emergency Spillway:

Note: Inspect daily in the event of flow through the spillway.

a. Any new or enlarged cracks, or spalls in concrete? ☐ No ☐ Yes

b. Any evidence of unusual deformations or displacements? ☐ No ☐ Yes

c. Any evidence of possible slope instability along the alignment of the spillway? ☐ No ☐ Yes

9. Additional Information:

a. Mark which toe drain inspection wells are currently flowing?

Well No. 1 ☐ Well No. 2 ☐ Well No. 3 ☐ Well No. 4 ☐

b. Provide additional information concerning any of the above questions that were answered "YES"?

Ongoing Visual Inspection Checklist
Example RCC Dam

Date: October 2010

Schedule: Under normal operating conditions, perform <u>monthly</u>. Perform <u>immediately</u> after an earthquake if a measured or estimated peak horizontal acceleration (PHA) of 0.05g or greater is reported for the dam site. Perform <u>daily</u> inspections whenever the reservoir elevation exceeds 8172.8 feet.

Inspector: ____________________ **Date:** __________ **Weather:** ______________

Reservoir Elev.: ______________ feet **Time:** __________ **Temperature:** ____________ ºC

A "YES" response should be given to question(s) below where observed conditions are different than previously observed conditions. Re-reporting conditions that have previously been reported and currently are unchanged should not be done ("NO" answer would be appropriate). For any question answered "YES", please provide additional information describing the situation as completely as possible under item 8, "Additional Information." Also, take photographs of the situation, and include with this report.

Fax completed form to:

1. <u>Upstream Face of Dam</u>:

- **a. Any evidence of new cracking or changes in existing cracks?** ☐ No ☐ Yes
- **b. Any evidence of new or increased crack offsets?** ☐ No ☐ Yes
- **c. Any new or enlarged cracks or spalls in concrete?** ☐ No ☐ Yes

2. <u>Dam Crest and Parapet Wall</u>:

- **a. Any new cracks?** ☐ No ☐ Yes
- **b. Any changes in the crack openings or offsets?** ☐ No ☐ Yes
- **c. Any new or enlarged cracks or spalls?** ☐ No ☐ Yes
- **d. Any evidence of unusual deformations or displacements?** ☐ No ☐ Yes

3. <u>Dam Gallery:</u>

Provide gallery location information under Item 8 "Additional Information"

- **a. Any new or enlarged cracks or spalls?** ☐ No ☐ Yes
- **b. Any change in crack offsets or widths?** ☐ No ☐ Yes
- **c. Any new seepage areas or areas of increased seepage?** ☐ No ☐ Yes
- **d. Any weir/flume flows exceeding expected gage reading by more than 0.02 ft ?** ☐ No ☐ Yes

4. <u>Downstream Face:</u>

- **a. Any new or enlarged cracks or spalls in concrete?** ☐ No ☐ Yes
- **b. Any offsets at cracks (use straight edge or scribe marks to verify)?** ☐ No ☐ Yes
- **c. Any new seepage areas or areas of increased seepage?** ☐ No ☐ Yes

5. <u>Abutments :</u>

- **a. Any evidence of rock movement on abutment slopes?** ☐ No ☐ Yes
- **b. Any new openings between RCC and foundation?** ☐ No ☐ Yes

7. **Plunge Pool:**

a. Any new or enlarged cracks or spalls in exterior concrete? ☐ No ☐ Yes

b. Any evidence of unusual exterior deformations or displacements? ☐ No ☐ Yes

c. Any evidence of erosion or rock plucking? ☐ No ☐ Yes

8. Provide additional information such as location, physical dimensions, orientation and coinciding behaviors or operations concerning any of the above questions that were answered "YES:"

NOTE: All descriptions should include specific location information and all other seemingly relevant information. Seepage area descriptions should include: estimated seepage amount and water clarity description (clear/cloudy/muddy, etc.). Crack descriptions should include orientation and dimensions. Descriptions of changes at joints should include the estimated amount of movement, and movement direction. Deteriorated or spalled concrete descriptions should include degree of deterioration and approximate dimensions of the affected area.

Appendix C – Design Summary Outline

Design Summary Outline

1. Introduction
    a. Purpose of Project
    b. Location of Project
2. Geology
3. Field Investigations
4. Material Testing
5. Loading Studies
    a. Hydrologic Hazard
    b. Seismic Hazard
6. Consequence Studies
7. Flood Routing Studies
8. Dam Analysis and Design
9. Spillway Analysis and Design
    a. Hydraulic Analysis and Design
    b. Structural Analysis and Design
10. Outlet Works Analysis and Design
    a. Hydraulic Analysis and Design
    b. Structural Analysis and Design
11. Powerplant Analysis and Design
12. Potential Failure Modes Analysis
13. Instrumentation Design
14. Impacts Related to Upstream and Downstream Dams
15. Consultant Review Board Reports
16. Construction Considerations

Appendix D – Monitoring Program Schedule Examples

DC-622 (7-96)
Bureau of Reclamation

SCHEDULE FOR PERIODIC MONITORING (L-23)

INSTRUMENTED AND ONGOING VISUAL MONITORING

DAM: **Example Embankment Dam**

REF. DWGS.: 66-D-2777 thru -2782; 66-D-2866, -2873, -2874, -3033, and -3036; and 66-418-8164.

PROJECT:

STATE:

DAM CONSTRUCTION COMPLETED: 1993

MONITORING METHOD	MONITORING SCHEDULE
Ongoing Visual Inspections	Monthly. (1) (2) (3) (4) (10)
Vibrating-Wire Piezometers (5)	Monthly. (2) (3) (4) (10)
Observation Wells (6)	Monthly. (2) (3) (4) (10)
Seepage and Toe Drain Flow Monitoring (7)	Monthly. (2) (3) (4) (8) (10)
Horizontal Drain Flows	Annually, in June (at the time of peak flow rates). (2)
Inclinometers I-5 and I-10. (I-1 through I-4 are on standby)	Annually, in June.
Strain Meters and Strain Gauges	On standby. No routine monitoring required.
Embankment Measurement Points	Perform in 2012, and then every 6 years thereafter.
Structural Measurement Points	Perform in 2012, and then every 6 years thereafter. (9)

Notes and Remarks:

(1) Ongoing Visual Inspections should be performed using the “Ongoing Visual Inspection Checklist”. A copy of each completed “Ongoing Visual Inspection Checklist” should be filed at a convenient location as close to the damsite as is feasible.

“Notes **and** Remarks” **continued on back of this form.**

As soon as possible after it is obtained, all visual inspection information and instrumentation

Mailing address:

Date: ______________________________

SCHEDULE FOR PERIODIC MONITORING (L-23)

INSTRUMENTED AND ONGOING VISUAL MONITORING

DAM: **Example Embankment Dam**

Notes and Remarks (continued):

(2) To the extent possible, obtain instrument readings and perform ongoing visual inspections at times when no precipitation has occurred in the preceding 48 hours. If this is not possible, precipitation within the last 48 hours should be reported (amount and time).

(3) Obtain and report the reservoir elevation and tailwater elevation whenever readings are obtained.

(4) In the event the reservoir elevation exceeds its historic high elevation (currently 6168.1 feet), perform ongoing visual inspections and obtain instrument readings daily until the reservoir level drops below this current historic high elevation, except that the observation wells need only be read every third day during this period. In the event of significant seismic shaking at the damsite (estimate peak horizontal acceleration of 0.05g or greater), promptly obtain instrument readings and perform an ongoing visual inspection.

(5) Routine monitoring is required only for the following vibrating-wire piezometers: VW-1 thru VW-4, VW-10, VW-11, VW-17, VW-21 thru VW-25, VW-30, VW-31, VW-37, and VW-101 thru VW-107. Routine monitoring of the following instruments has been discontinued (but could be reinstated in the future if circumstances warrant): VW-4, -6, -7, -8, -9, -12, -14, -16, -18, -20, -26, -27, -28, -29, -32, -34, -36, -38 and -40.

(6) The following observation wells are to be monitored: OW-01, -02, and -03; and DH-301, -419, -427, -446, -448, -496, -538, -545, -546, -T_u/h, and -T_d/h.

(7) Seepage monitoring is to be performed relative to the following flows: (a) toe drain flows at the toe drain outfall line weir box, (b) the two drain flows in the outlet works gate chamber, (c) the flow that discharges into Toe Drain Inspection Well No. 1, and (d) the flow at the upper right abutment that comes from a CMP (corrugated metal pipe) that passes under the highway embankment.

(8) Whenever flow rates are being read, check for indications of sediments being carried by the flows (discolored water, sediment deposits in front of weirs, etc.) and report immediately to the contact listed below if noted.

(9) Surveying of the structural measurement point on the spillway at Sta. 32+19 is dangerous, so routine monitoring of it can be discontinued.

SCHEDULE FOR PERIODIC MONITORING (L-23)

INSTRUMENT READING AND ONGOING VISUAL INSPECTION FREQUENCY

DAM: **Example RCC Dam** REF. DWGS.: **66-418-7738**

PROJECT: ________ **and - 7739;**

STATE: ________ **66-D-2136, -2137 & -2138**

DAM CONSTRUCTION COMPLETED: **1988**

INSTALLATION	SCHEDULE FOR PERIODIC READINGS
Ongoing Visual Inspection	Monthly below RWS El. historic high (currently EL. 8172.8) and 24-hour surveillance when RWS > 8172.8 (1) (2)
Reservoir Surface Elevation	Monthly
Drainage and Seepage Flows	Report for RWS elev. 8100, 8125, 8150 & yearly max (1) (3)
Collimation Targets	Same as above (1)
Crackmeters	Same as above (1)
Piezometers	Same as above (1)
Inplace Inclinometers	Same as above (1)
Portable Probe Inclinometers (#'s 1, 2, 3 & 8)	Report deflections in August (1)
Foundation Drains	Report depths in April and flows in August

Notes and Remarks:

Ongoing Visual Inspections should be performed using the "Ongoing Visual Inspection Checklist." A copy of each completed "Ongoing Visual Inspection Checklist" should be filed at the dam or nearby location. If unusual conditions develop, follow the procedures stated in the EAP and then telephone the contact listed below to determine appropriate adjustments to monitoring schedules.

Obtain more frequent observations and readings to help document unusual conditions.
Reread and verify readings that appear to exceed the limits listed in the CFR.

(1) Following an earthquake that is felt or generates 0.05g at the site, perform a visual inspection, read drainage and seepage flows daily until it is certain that readings are still within the expected range. Measure collimation, crackmeters and all inclinometers. Survey crest benchmarks if deformation is visually apparent.

(2) If the reservoir exceeds surface elevation 8172.8 - Read and perform daily if access and weather permits until a return to below reservoir surface 8172.8 or until readings and observations are steady for 2 weeks.

(3) Obtain readings and perform inspections at times when no precipitation has occurred in the