

A Role for Risk Assessment in Dam Safety Management

David S. Bowles

Utah Water Research Laboratory, Utah State University, U.S.A.

Loren R. Anderson

Department of Civil and Environmental Engineering, Utah State University, U.S.A.

Terry F. Glover

Department of Economics, Utah State University, U.S.A.

ABSTRACT: In this paper we examine various factors which have lead to the trend for using the risk based approach to support dam safety decision making. The relationship between the standards based and risk based approaches is reviewed. Dam safety management is cast in the context of comprehensive risk management. The importance of defining the decision process, the role of decision criteria, and the involvement of owners and stakeholder in a “decision-driven” and staged risk assessment process is presented. The role of risk assessment in short term (emergency) dam safety decisions is addressed, in addition to long term decisions on meeting extreme events.

1. INTRODUCTION

Risk assessment is still a relatively new approach in the field of dam safety evaluation and decision making. When properly conducted it can provide valuable information which may not otherwise be available from conventional approaches. Quantitative examples include: estimated probabilities of dam failure and the consequences of failure, and estimates of risk reduction for various structural and non-structural rehabilitation alternatives. In addition, the process of conducting a risk assessment can provide qualitative benefits such as insights into the relative importance of various failure modes and loading types and ranges, and the potential value of additional analyses or field investigations. Even for high hazard dams, where acceptable risk considerations may lead to the adoption of “worst case” (evaluation) events, the systematic risk assessment process can be useful as a quality assurance tool for identifying risk reduction options in the design of rehabilitation measures, project operation, or emergency action planning. Also

the open display of information obtained from a risk assessment can be a very useful means of conveying the implications of highly technical issues to non-technical owners and to the general public.

Dam safety management is intrinsically a problem in risk management and decision making under uncertainty. In the past we have tended to view dam safety as primarily an engineering problem. In many countries engineering standards approaches are leading to requirements for very costly remedial measures at existing dams. As a result, the underlying foundations for these standards are being examined and risk assessment approaches are being adopted to make explicit tradeoffs of risks, costs, and benefits. This leads us to ask the following questions. Are the standards based and risk based approaches incompatible? What is driving the trend towards risk based approaches? How should risk assessment approaches fit into the broad framework of dam safety decision making in a world in which regulations are becoming less prescriptive; dams are being moved from public to private responsibility; there is growing

competition for financial resources; and the public is becoming more risk averse and wants to be more involved in decisions which effect their well being?

In this paper we seek to address these questions based on the current state-of-the-practice in dam safety risk assessment and our experience in performing such assessment for public and private sector clients in the USA and other countries. For a discussion of risk assessment procedures and several case studies, the interested reader is directed to Bowles (1990).

2 COMPREHENSIVE RISK MANAGEMENT

As dam safety evaluation is to dam safety management, so is risk assessment to risk management. A comprehensive dam safety risk management program should include many other components in addition to risk assessment for evaluating existing dam safety and alternative remedial actions. These other components should include the following:

1. Provision of an appropriately designed, well maintained, and regularly exercised emergency warning system and emergency action plan.
2. A comprehensive monitoring and surveillance program with clear assignment of responsibilities for timely review and follow-up on collected data and reports.
3. A well trained operations and maintenance staff.
4. A well planned, adequately funded, and properly executed maintenance program.
5. Routine inspections and periodic in-depth inspections and comprehensive dam safety reviews and updates of any previously conducted risk assessments that are being relied upon for dam safety decisions.
6. An effective public consultation program.

All of these are important interrelated components in a comprehensive risk management program for any high hazard dam. Each is necessary for the proper exercise of duty of care of the owner and each should play a coordinated role in managing dam safety risks. A fragmentary approach to dam safety management can lead to overlooking the implications of information held in other program components. Dams are integral structures and their safety should be managed in a holistic manner (Perrow 1984).

The on-going aspects of a comprehensive dam safety program, such as monitoring and surveillance, should play an important and complementary role to periodic comprehensive dam safety reviews. Neither the engineering analysis tools that are used in these reviews nor the monitoring and surveillance programs provide perfectly accurate or complete insights into dam performance (Fanelli 1992). Analysis tools are based on idealized representations of complex structures and their foundations and must rely on estimates of materials properties and postulated future loading conditions. Monitoring and surveillance of actual performance can be important in verifying the results of theoretical analyses. They can also provide valuable information where no analysis tools currently exist. However, monitoring and surveillance cannot always directly measure or observe the parameters which are of direct importance, and it takes time and expertise to make interpretations. Analysis tools must often be used as part of the interpretation process for monitoring data, or for predicting the limits of acceptable behavior against which satisfactory performance is judged. Thus in an overall risk management program both on-going observations and on-going analysis are important for developing confidence that a dam is, or is not, performing satisfactorily. Observations and analyses complement each other and neither can be entirely substituted for the other.

It is normal practice to perform comprehensive dam safety reviews approximately every five years (ICOLD 1987). In part, the purpose of such reviews is to assess the effects on dam safety of any changes in technical standards or the state-of-the-art. If a risk based approach is adopted, the risk assessment should be updated as part of the comprehensive review. Any changes to risk assessment inputs, such as loading conditions, factors that would effect predicted performance of the dam, the consequences of failure, or other operational outcomes should be updated. In this way a risk assessment becomes a "living document" which can be used by decision makers to periodically reassess their current duty of care position in light of changing business considerations, evolving community values, and other factors.

3 TREND TOWARD RISK BASED APPROACH

Interest in the potential for applying risk based approaches to dam safety decision making has accelerated in the last two decades. An increasing number of organizations have begun to routinely use risk based approaches in dam safety evaluation. These now include the U.S. Bureau of Reclamation (Von Thun and Smart 1996), the Government of South Africa (Oosthuizen et al, 1991), the Government of the Netherlands (CUR 1990), various Australian dam owners and regulators (SMEC/RAC 1995), and B.C. Hydro (1993). Many other organizations are actively considering using the risk based approach.

Some factors which have lead to the increasing use of risk based approaches are common to dam owners and operators in different countries. They include the following:

1. The absence of functional features, which are now considered to be the state-of-the-art in dam design, but which were not incorporated in many existing dams (e.g. downstream filters in embankments to dissipate pore pressure in the event of significant seepage).

2. The greater magnitude of extreme (worst case) evaluation (design) flood and earthquake events (i.e. PMF and MCE, respectively) which are prescribed using today's standards based approaches compared with those for which existing dams were designed or are capable of accommodating.

3. The high cost of correcting state-of-the-art and extreme event "deficiencies" which has lead to question the justification for the standards, cost effectiveness, and due diligence from a legal and overall business perspective.

When considering the need for remedial works to address state-of-the-art "deficiencies" under a risk based approach, the goal should be to confidently predict that the dam will perform satisfactorily under a full range of loading conditions. Satisfactory performance can be defined using tolerable risk criteria such as those summarized in Section 6.

One of the following four outcomes could result from a risk based evaluation of an existing dam with state-of-the-art and extreme event "deficiencies":

1. Accept the existing dam, without modification, if it can be demonstrated, with sufficient confidence, that the existing dam can be expected to perform

satisfactorily, even though it might not meet current standards.

2. Modify the existing dam so that the modified dam would be expected to perform satisfactorily, with sufficient confidence, but not necessarily to current standards.

3. Remove and reconstruct the dam, so that the new dam would be expected to perform satisfactorily, with sufficient confidence, and meet current standards.

3. Decommission the dam so that it no longer poses a threat to downstream populations at risk.

The costs and risks associated with the drastic action of removing an existing dam and reconstructing it would often be unacceptably large, and the resulting benefits might be questionable or difficult to prove. Nevertheless, in some cases this may be the only way to achieve the goal of satisfactory predicted performance with sufficient confidence.

Satisfactory performance under loading conditions that are within the range experienced at an existing dam may be demonstrated through monitoring and surveillance and engineering analysis. For extreme floods, earthquakes, and static loading conditions, which are outside of the range that has been experienced since a dam was constructed, the sole use of monitoring and surveillance to demonstrate satisfactory performance is problematic. However, testing of material properties, structural and stability analyses, and the transfer of experience from similar dams can all be used to predict performance under extreme loading conditions.

The degree of confidence in performance predictions can often be improved with additional testing, monitoring, and analysis. Risk based approaches focus on predicting dam performance and the confidence (or uncertainty) associated with these predictions. In contrast, the sole use of traditional approaches emphasizes factors of safety and compliance with standards provides only vague indications of the level of confidence that is being attained in achieving satisfactory performance. Thus it is seldom clear if the level of confidence is unjustifiably excessive or undesirably small.

The magnitudes of extreme evaluation events have increased over the past few decades for various reasons, including the following:

1. The "unknowable" nature of worst case events.
2. Changing methodologies which tend to produce increasingly more conservative design events.

3. Difficulty in determining the plausibility of combinations of contributing factors used to calculate worst case events (e.g. very small loss rates coinciding with worst case precipitation to define a probable maximum flood event).

4. The tendency for design professionals to favor more conservative definitions of worst case events.

5. An improved understanding of the potential for inadequate performance of dams and their foundations under dynamic seismic loads.

A danger of focusing dam safety studies on worst case scenarios is that deficiencies associated with lower magnitude more frequently occurring loading conditions may be given too little attention. Thus, by focusing on the most unlikely fraction of one percent of the event magnitudes, one might overlook the range of events which are much more likely to cause failure of an existing dam. An example would be focusing on the capability of a spillway to cope with a PMF while deficiencies under static (water) loads are given little attention.

4 STANDARDS V. RISK BASED APPROACHES

We use the term, “standards based approach”, to refer to the approach to design and evaluation of dams in which a satisfactory safety condition is defined by either: a) compliance with prescribed performance measures or loading conditions; or b) use of the current state-of-the-art (or practice) meaning the generally accepted present-day approach to dam design, evaluation, and construction.

The term “risk based approach” is used to refer to the approach to design and evaluation of dams in which an acceptable safety condition is defined using information provided from a risk assessment and other decision inputs. Risk assessment is a systematic process wherein experienced dam engineering professionals provide decision makers with estimates of the risks and associated uncertainties of system responses, outcomes, and consequences, which characterize the performance of an existing dam and various remedial action alternatives under a full range of loading conditions.

It might appear that the choice between a standards based v. a risk based approach is between a “clear cut” standards approach and a risk based approach which might lead to the acceptance of a higher risk of failure than would be the case under the

standards approach. However, a standards based approach is not necessarily as clear cut as it might first appear. For example, under the standards based approach professional opinions and practice can vary over the selection of appropriate design criteria. A standards based approach does not ensure a “zero risk” solution to a dam safety concern. Furthermore, a standards based approach involves “blind” risk tradeoffs whereas these tradeoffs can be made more explicit under the risk based approach. If a purely standards based approach is used it is unlikely that the implied risk tradeoffs will be understood by the decision makers, their technical advisors, other stakeholders, and their legal and financial advisors. In contrast, a properly conducted and well communicated risk assessment can be expected to provide all parties with valuable understanding and insights of potential risk tradeoffs. In addition, risk assessment can be expected to provide: a basis for prioritizing remedial works; a clearer picture of the potential benefits of non-structural measures, such as emergency warning systems and a basis for deciding on any temporary operating restrictions.

In some cases the outcome of a risk assessment could be a decision to adopt standards based design criteria. In fact, the standards based approach can be thought of as a prescribed point on a continuum of different performance standards or design (evaluation) loading conditions. The risk based approach can be readily used to examine a range of these performance measures or loading conditions to evaluate the effects on reliability, consequences, cost effectiveness, and due diligence of deviating from the standards based approach. In this way the risk based approach can be used to explore the appropriateness of a standards based approach. Sole use of a standards based approach without risk assessment can lead to the adoption of design criteria which might be unjustifiably conservative or lax for a particular dam.

There is an important difference between the way in which the standards and risk based approaches treat different worst case event estimates. The standards based approach tends to treat less conservative and more conservative estimates of evaluation events without recognition that they differ in their likelihood of occurring. In the risk based approach smaller probabilities of occurrence (annual exceedance probabilities) can be associated with more conservative estimates of extreme events. In this way,

risk assessment provides a framework within which differences in the degree of conservatism in extreme even estimates can be accounted for in selecting and justifying an evaluation event for a particular dam. This can be done using the joint probability distribution for the occurrence of various contributing factors which define an evaluation event (e.g. initial reservoir level and antecedent moisture levels for a flood event). It also provides a means for quantifying the uncertainties that exist in defining worst case event scenarios. Other benefits of using a risk based approach are presented in Bowles (1996b) and Bowles (1987).

5 DEFINING THE DECISION PROCESS

In our experience it is important to clearly define the decision process that will be used to make a dam safety decision. Ideally this should be done before a risk assessment can be designed, in consultation with the stakeholders, to provide information inputs that will be useful at each stage in the process, and on an agreed upon schedule. The National Research Council (1996) refers to this type of approach to risk assessment as “decision driven”. Adopting such an approach will provide a basis for appropriate and justifiable limits on the level and detail of risk assessment efforts. This is important since there is virtually no end to the amount of effort which could be put into a detailed risk assessment. It is therefore important to remember that risk assessment should become an end in itself; the end should be a quality, well communicated and highly defensible dam safety decision.

In clearly defining the decision process the following questions should be addressed:

1. Who are the decision makers?
2. What will be the role for community consultation and for the various stakeholders in the decision process?
3. What decision criteria will be used by the decision makers? This should include an evaluation of the entire framework in which the dam safety decision will be made including regulatory, legal, financial, business, economic, environmental, social, and other considerations.
4. What information from risk assessment is needed by the decision makers and stakeholders throughout the decision process?

6 DECISION CRITERIA

Various criteria can be useful to judge results from a risk assessment when a long term dam safety decision (Bowles 1996a) is to be made (for a short term decisions see Section 9). They include life safety, economic, and other types of criteria. Care must be taken that the selected criteria are consistent with the dam safety decision framework and that they serve the dam safety decision process which is identified at the outset of the risk assessment (see Section 5). A search for internationally applicable dam safety risk criteria could result in criteria which do not serve all dam owners in all countries equally well. This is particularly true if, as is often the case with a strict standards approach to accommodating extreme events, the focus is on selecting and meeting a criterion rather than prioritizing a sequence of risk reduction measures, giving consideration to the cost effectiveness of each measure.

Life safety is always an important consideration. It can be evaluated using both societal and individual tolerable risk criteria such as those in the ANCOLD (1994) Guidelines on Risk Assessment and by BC Hydro (1993). Societal criteria are commonly expressed as F-N curves of cumulative frequency, F, of life loss exceeding various magnitudes, N. It provides a means of judging the scale of potential life loss from individual failure modes, or combinations of failure modes, for a single dam. Overall life loss can also be evaluated against an expected annual life loss criterion as in USBR (1997). In either case it is still important to evaluate individual life safety criteria to assess the potential for individuals to be excessively exposed to the risk of dam failure.

Public and private investments are typically evaluated against a benefit/cost or rate of return criterion. Dam safety projects seldom fair well in such evaluations because the probability of failure is often small and thus the expected benefits are very small relative to the certain investment of capital and maintenance funds. Out of more than seventy dam safety risk assessments we have completed only one has shown a benefit/cost ratio greater than unity. Benefit/cost ratios could be increased by adding a value for human life to the assessment of benefits. However, we feel that this raises serious ethical and moral issues and we do not recommend such an

approach to evaluating the benefits of increased public safety.

We have found that a useful approach to considering the benefits of increased public safety is to evaluate the cost effectiveness of structural and non-structural alternatives. This can be done by calculating a cost-per-life-saved for each alternative and comparing these with similar costs for other facilities which expose the public to risk of life loss. By pursuing alternatives with costs-per-life-saved which are less than those in these other fields, an owner is at least being consistent with the extent to which these other fields invest in public safety. Care must be exercised in selecting fields in which risks are similar in nature to those created by dams. The U.S. Office of Management and Budget (OMB 1992) argued that the cost effectiveness approach is a “sensible” way to justify the investment of federal government dollars, or private funds as the result of regulations in public health and safety measures.

Cost effectiveness measures can also provide a very useful basis for prioritizing dam safety investments such that those which are expected to result in the greatest reductions in risk for a given level of available funding are undertaken first. When this approach is applied to a portfolio of dams it should maximize the rate of (public) risk reduction to which the dam owner is exposed. Typically one can expect that such an approach to prioritization will lead to a high priority being given in a dam safety program to implementation of early warning systems (EWS). In this case, EWSs would not necessarily be used as a substitute for structural options, but as an early and typically very cost effective step in improving public safety. If structural measures are subsequently implemented, an EWS might be retained as a supplement to structural measures.

In addition to these life safety and economic criteria, consideration should be given to financial, business, legal, and other factors which the owner and other stakeholders must take into account in their decision process. This should include an appropriate role for community consultation in the overall decision process so that the dam owner meets its social responsibilities as well as its business objectives and regulatory requirements.

7 STAGED APPROACH TO RISK ASSESSMENT

Much of the information needed to perform a risk assessment is commonly developed in the course of a traditional periodic comprehensive dam safety review.

However, some additional work is always required to provide the necessary inputs for a risk assessment. The amount of additional work depends on the scope and level of detail of the risk assessment.

In conventional engineering analysis it is common practice to select parameters conservatively. In performing these analyses to provide inputs to risk assessment, it is usually desirable to rerun these analyses using best estimates of parameters to obtain realistic performance predictions. Also it may be useful to analyze steps partially failed sections in the case of progressive failure mechanisms that would be expected to result from foundation liquefaction, for example. In addition, sensitivity analyses using ranges of values for key input parameters can provide valuable information upon which to base risk assessment inputs and judgements that experienced engineers are expected to make in conducting risk assessments.

We advocate using a staged approach to risk assessment. Under this approach, later more detailed stages are performed only if warranted by the potential value added to the dam safety decision making process through reduction in the level of uncertainty in risk assessment outputs. More detailed stages of risk assessment usually require that more detailed inputs be obtained from additional field investigations, testing, or engineering analyses. Before proceeding with a more detailed risk assessment, the extra cost it would entail should be weighed against the expected improvement in the quality of the decision that is to be made using risk assessment outputs. This is another example of making dam safety risk assessment a “decision driven” activity.

8 OWNER AND STAKEHOLDER INVOLVEMENT

We have had direct experience with involving water users groups, regulators, owners, operators, legal advisors, senior management, and politicians in the dam safety decision process using risk assessment. So far our involvement with community groups has been mainly through our clients. However, we have found

that in most cases the understanding provided by the systematic and transparent risk assessment process has been acclaimed by all parties. In our experience it has been important to involve these groups throughout the process and not just through the presentation of a final report. Such a process of continual involvement presents communications challenges and one must be careful in presenting preliminary risk assessment results to lay audiences. Credibility can be shaken if significant changes occur in these results in later stages of the risk assessment. Of course similar difficulties can exist with a standards based approach if conclusions based on preliminary analyses are made public, and significantly different conclusions are released after additional analyses are completed. The open and honest communication of uncertainties is highly recommended. Also it is recommended that the technical risk assessment team enlist the assistance of experts in risk communication and community consultation.

Where they exist, community consultation requirements contained in environmental impact assessment processes might be used to provide for community consultation in dam safety decision making. However, care should be taken to avoid diluting dam safety issues.

We have repeatedly found that it is difficult for lay people, and in many cases technical people, to have a holistic and balanced perspective on dam safety issues when a purely standards based approach is used. The difficulty is that the standards approach often masks the true nature of dam safety management which is intrinsically a problem in risk management and decision making under uncertainty. When a standards approach is used, there is a danger of misleading the public into thinking that the adoption of standards based design (evaluation) criteria will provide absolute protection against the risk of dam failure (i.e. zero risk). This is obviously false and the fact that dams have been built to meet these standards have failed proves the point. Even though following a risk based approach presents challenges in risk communication, we have found that the additional effort is well worthwhile considering the benefits of sharing a more complete and honest picture of the true risks and uncertainties that are inextricably associated with dam safety decisions. This has been repeatedly borne out by client testimonials such as Waite (1989).

9 LONG TERM AND SHORT TERM DECISIONS

Dam safety risk assessments have most commonly been conducted to provide inputs to long term decisions on the level and priority of remedial works needed to meet extreme events. Risk assessment can also be used to provide inputs for short term decisions, including emergencies and the need for reservoir operating restrictions (for example, USBR 1996). Three time frames can be distinguished for such decisions:

1. Prior to construction of remedial works;
2. During construction of each phase of remedial works; and
3. At the completion of each phase of remedial works.

The outcome of these short term decisions can be used to establish reservoir level restrictions during each phase of remedial work, and perhaps the timing of the works with respect to seasonal reservoir inflows. At the completion of each phase of remedial works, risk assessment can be used to provide inputs to the decision to allow increases reservoir levels as a result of the additional margin of safety added by those remedial works.

In long term decision applications of risk assessment the emphasis is on balancing risks, costs, and benefits over a long period of time when selecting an appropriate level of protection against extreme events. When using risk assessment in support of short term decisions the concern is for the imminent development of a failure condition. In this case the long term time frame can not be counted on for balancing risks, costs, and benefits. We suggest that when used in support of short term decisions, risk assessment should be used for the following primary purposes:

1. To identify the relative risk (likelihood and consequences) of various failure modes; and
2. To reduce the risk of each failure mode through
 - a) management actions (e.g. reservoir operating restrictions, emergency repairs);
 - b) improved detection of worsened conditions that could lead to failure;
 - c) contingency planning covering all aspects of the owner's responsibilities, including the decision and notification steps that lead to initiating a downstream evacuation; and
 - d) coordination of contingency planning with the local authorities who are responsible for evacuation.

It must be stressed that the use of risk assessment in support of short term decisions must not delay taking immediate emergency action, when such action is prudent and necessary. However, we believe that even when immediate action has been taken risk assessment can be used to help guide the on-going decision process. Benefits of this use of risk assessment in this short term context include the following:

1. Understanding of the development of event sequences which might lead to imminent failure.
2. Assessment of the need for additional instrumentation to identify changed conditions.
3. Identification of critical values of performance parameters for initiating additional investigation or emergency action.
4. Assessment of the benefits of various short term actions such as reducing reservoir levels, or improving response times for making emergency releases.
5. Assessment of the adequacy of warning time and ways to increase warning time and its reliability.

10 CONCLUSIONS

We have stated that the true nature of dam safety management is intrinsically a problem in risk management and decision making under uncertainty. In a world in which regulations are becoming less prescriptive, dams are being moved from public to private responsibility. There is growing competition for financial resources, and the public is becoming more risk averse and wants to be more involved in decisions which effect their well being. The continuous risk management framework can provide a valuable approach to meeting these challenges. The risk management approach should treat dams as integral structures whose safety should be managed in a holistic manner. It should also take into account the uncertainties which exist as a result of the current limitations in our capabilities to predict and monitor dam performance.

Risk assessment is a component of the risk management approach. It provides the opportunity for engineering inputs to be considered along side the many other factors that owners and others must consider when making dam safety decisions. In our experience it is important to clearly define the decision process that will be used. Adopting a “decision

driven” approach to risk assessment will provide a basis for appropriate and justifiable limits on the level and detail of risk assessment efforts with the goal of reaching a quality, well communicated and highly defensible dam safety decision.

In some situations the funds needed to meet extreme event standards simply do not exist. In many other cases reliance on a purely standards based approach does not provide adequate justification to convince lay decision makers of the need to meet these standards and a “stalemate” has resulted. We do not argue with the desirability, and even the necessity, of meeting extreme event standards in many cases. However, we observe so many cases in different countries in which no risk reduction has been accomplished even though it is well recognized that standards are not being met. We suggest that in many cases the focus should be on identifying and justifying the next most cost effective risk reduction steps rather than waiting to meeting an extreme event standard. In addition, correcting for all state-of-the-art “deficiencies” is often impracticable and must be addressed by risk management rather than structural approaches. The irony is that even when expensive works are completed to meet standards, a dam may remain much more at risk to the malfunctioning of gate systems, to inadequately trained operators, or to the absence of a properly maintained early warning system, than it was to under capacity of a spillway, for example. Of course each case must be individually evaluated, and as we have sought to emphasize, in some cases standards based solutions will be justified. When properly implemented, risk assessment can serve as a valuable tool within a comprehensive risk management framework for effective dam safety management. We further suggest that such a comprehensive and systematic approach is necessary for the proper exercise of duty of care of a dam owner and to assist in meeting due diligence.

REFERENCES

- ANCOLD (Australian National Committee on Large Dams) 1994. *Guidelines to Risk Assessment*. Sydney, New South Wales, Australia.
- B.C. Hydro 1993. *Guidelines for Consequence-based Dam Safety Evaluations and Improvements*. Interim Report.
- Bowles, D. S. 1987. A Comparison of Methods for Integrated Risk Assessment of Dams. In "Engineering Reliability and Risk in Water Resources", L. Duckstein and E. Plate (Eds.), M. Nijhoff, Dordrecht, The Netherlands. pp. 147-173
- Bowles, D. S. 1990. Risk Assessment in Dam Safety Decision Making. In: Risk-Based Decision Making in Water Resources, *Proceedings of the Engineering Foundation Conference, American Society of Civil Engineers*, (Eds. Y. Y. Haimes and E. Z. Stakiv), Santa Barbara, California, October.
- Bowles, D.S., 1993. Risk Assessment: A Tool for Dam Rehabilitation Decisions. Invited lecture in *Proceedings of Geotechnical Practices in Dam Rehabilitation, Geotechnical Publication No. 35, ASCE*, pp 111-130.
- Bowles, D.S., L. R. Anderson, and T. F. Glover 1996a. Risk Assessment Approach to Dam Safety Criteria. *Proceedings of American Society of Civil Engineers, Geotechnical Engineering Division Specialty Conference on "Uncertainty in the Geologic Environment: From Theory to Practice"*. April.
- Bowles, D.S., 1996b. Reservoir Safety: A Risk Management Approach. *International Conference on Aspects of Conflicts in Reservoir Development & Management*, The City University, London, England, September. 11p.
- CUR 1990. *Probabilistic Design of Flood Defences*, Report 141, Center for Civil Engineering Research and Codes, Technical Advisory Committee on Water Defences, Gouda, The Netherlands. 154p.
- Fanelli, M.A. 1992. The Safety of Large Dams. In: *Engineering Safety*, Ed. D. Blockly, McGraw-Hill Book Company Europe, Maidenhead, Berkshire, England. pp. 205-223.
- ICOLD 1987. *Dam Safety Guidelines*. Commission Internationale des Grande Barrages, Paris, France. 185p.
- National Research Council 1996. *Understanding Risk: Informing Decisions in a Democratic Society*. National Academy Press, Washington, D.C., 249 pp.
- OMB 1992. Reducing Risks Sensibly. *Federal Budget*
- Oosthuizen, C.D. van der Spuy, M.B. Baker, and J. van der Spuy 1991. "Risk-Based Dam Safety Analysis". *Dam Engineering II* (2).
- Perrow, C. 1984. *Normal Accidents: Living With High-Risk Technologies*. Basic Books, USA. 386p.
- SMEC/RAC 1995. *Review of Headworks*. Final report to the Office of Water Reform, State of Victoria, Melbourne, Australia, Volume 1, Main Report, 118 pp.
- USBR 1996. *Risk Assessment to Evaluate Existing Mormon Island Auxiliary Dam and Need for Operating Restrictions*. U.S. Bureau of Reclamation, Denver, Colorado.
- USBR 1997. *Guidelines for Achieving Public Protection in Dam Safety Decision Making*. U.S. Bureau of Reclamation, Denver, Colorado, January.
- Von Thun, J. L., and J. D. Smart 1996. Risk Assessment Supports Dam Safety Decisions, *USCOLD Newsletter*, November.
- Waite, R.B. 1989. Dam Safety Evaluation for a Series of Utah Power and Light Hydropower Dams, Including Risk Assessment: Owner Perspectives on the Role of the Evaluation in the Selection of Remedial Measures. *Proceedings of the 6th Annual Conference of the Association of State Dam Safety Officials*. Albuquerque, New Mexico.