THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by - SHANE MCGRATH - 2000 Churchill Fellow

Project:

To Study International Practice and Use of Risk Assessment in Dam Management

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1. INTRODUCTION

This report is the product of a three-month Churchill Fellowship study into international practice and use of risk assessment in dam management.

The Countries visited during the study were the United Kingdom, France, the Netherlands, Norway, Sweden, the United States and Canada.

Discussions were held with dam owners, dam safety regulators, academics, public authorities, consultants and nuclear industry representatives

The report sets out the regulatory framework for dam safety and extent of the use of risk assessment in each Country. Where appropriate, indicative details of the risk assessment processes are given.

The Conclusions bring together the relevant information and are followed by specific recommendations in relation to the use of risk assessment in Australia.

In this report, the term:

- ‘Risk analysis’ is used to describe a procedure aimed at determining the risk posed by a dam. The analysis can be qualitative (for example, using a ranking system for likelihood of failure estimates and consequences, such as Failure Mode and Effect Criticality Analysis, FMECA) or quantitative (Quantitative Risk Analysis, QRA or Probabilistic Risk Analysis, PRA).

- ‘Risk criteria’ is used to describe criteria used in the risk assessment process to determine if the risks calculated through qualitative or quantitative risk analysis are acceptable.

- ‘Risk assessment’ is used to describe the process of decision making using the outcomes from risk analysis and risk criteria.

2. ACKNOWLEDGMENTS

I wish to acknowledge the Winston Churchill Memorial Trust and my employer, Goulburn-Murray Water for providing me with the opportunity and support to undertake the study.

I also acknowledge the personal assistance provided by Mr Adrian Williams (Deputy Chairman, New South Wales Dams Safety Committee and Past Chairman of the Australian National Committee on Large Dams) and Mr Dick Davidson (Senior Principal and Vice President, URS Australia Pty Ltd) in assisting to establish the many contacts required for a study of this scope in so many corners of the world.

To the many organisations that provided support and individuals that gave their time to assist me in completing the study, I wish to extend my sincere gratitude. Unfortunately, there are far too many to mention here, but they are named in the Program section of this report. I apologise to any that I have inadvertently neglected to include.

Finally, and most importantly, to my wife Anne and sons Patrick and Ryan. Without their support and forbearance the study and this report would not have been possible.

Shane McGrath
Shepparton
December 2000

3. EXECUTIVE SUMMARY

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International Practice and Use of Risk Assessment in Dam Management.

Dam safety around the world is largely determined by standards. However, over the past decade activity in the development of risk analysis techniques for dams has accelerated and is now widespread. In every country visited, the use, or at least trialling, of risk analysis techniques to supplement normal dam safety practices was observed.

It was concluded that the practice results in improved understanding of dam behaviour. It assists in determining investigation and surveillance needs, identifying interim risk reduction measures and priorities between dam safety investments at one dam or between several dams. The Australian dams industry should continue to develop and use risk analysis techniques to assist in the management of dams.

In Australia, Goulburn-Murray Water is currently using risk analysis to assist in a dam safety risk reduction program and are using simplified tools to establish priorities for major remedial works.

The comparison of risk analysis results to acceptable public safety criteria in order to determine acceptable levels of dam safety is not common and a somewhat controversial concept for dams. Two organisations using the methodology were identified in the study. The United States Bureau of Reclamation use risk criteria explicitly as part of their decision making process for dam safety and in Washington State the dam safety guidelines implicitly include risk criteria.

I believe that the arguments for using acceptable risk criteria for dams are persuasive. It has the potential to assist in applying society's limited resources for public safety from high hazard industries in a rational way. However, it is considered necessary to benchmark current dam risk analysis practices against those in industries where acceptable risk criteria are used. Benchmarking will provide information to determine if the practice is reasonable or what further research and development is required. The Australian dams industry should encourage investment, in conjunction with Government and regulators, to further the development of risk analysis and acceptable risk criteria for determining appropriate levels of dam safety.

It is intended that the dam improvement program I manage will engage communities and Government in the process of developing a risk reduction strategy. In this way, the key stakeholders in dam safety will be exposed to the current debate and gain an understanding of the issues relating to investment in dam safety. Processes such as this should assist in widening the discussion to include broader representation in moving forward with the use of risk assessment for dams.

The Australian National Committee on Large Dams is a key forum for the development of dam safety concepts and it is intended that it be consulted, along with other key industry groups, to further the issues raised in this report.

4. PROGRAM

UNITED KINGDOM			
City	**Primary Contact**	**Contacts**	**Organisation**
Berkeley	Keith Hoyle, Safety Advisor.	Dick Tailor, Head of Safety. Dave Tubb, Industrial Safety Engineer. Peter James	BNFL Magnox Generation
Glasgow	Alex Macdonald, Director. Jim Findlay, Technical Director.	Martin Hewitt, Principal Engineer. Alan Johnson Chief Executive (ret.)	Babtie Group
Perth	Neil Sandilands, Civil Asset Manager.	Kenny Dempster, Reservoir Safety Engineer. Mark Noble, Civil Projects Engineer.	Scottish and Southern Energy

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City	**Primary Contact**	**Contacts**	**Organisation**
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Grenoble	Patrick Le Delliou, Chef du BETCGB	 Bernard Soudan, Deputy Director. Thierry De Beauchamp, Civil Engineer.	Bureau D'Etude Technique et de Controle des Grands Barrages Electricite de France (EDF)
Le Tholonet, Aix-en-Provence	Paul Royet, Head of Hydraulics and Irrigation Engineering Research Unit.	Patrice Meriaux, Research Engineer. Laurent Peyras.	Cemagref

THE NETHERLANDS			
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		R.E. Jorissen, Head Flood Protection Section. Spike E. van Manen, Senior Advisor Risk Analysis.	Ministry of Transport, Public Works and Water Management
		Jos Dijkman	Delft Hydraulics
		Ed Berendsen, Hydraulic Engineering Innovation Centre.	Ministry of Transport, Public Works and Water Management
Rotterdam		Dick van den Brand, Teammanager Risk Management.	Ministry of Transport, Public Works and Water Management
Bilthoven		Dr. B.J.M. Ale	National Institute for Public Health and the Environment

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		Elvind Torblaa, Senior Advisor, Production Division.	Statkraft

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City	**Primary Contact**	**Contacts**	**Organisation**
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UNITED STATES OF AMERICA (continued)			
Denver CO	Dr John Smart, Dam Safety Officer. Leanna Principe, Team Leader International Affairs. Steven Vick, Consulting Geotechnical Engineer. Han Ilhan, Senior Project Engineer.	Dave Achterberg, Chief Dam Safety Office. John Cyganiewicz, Sr Geotechnical Engineering Specialist. Karl Dise, Technical Specialist. Wayne Graham, Hydraulic Engineer. John England, Hydraulic Engineer. Dan Levish, Geomorpholgist. Lex Kamstra, Hydraulic Engineer.	U.S. Department of the Interior, Bureau of Reclamation URS Greiner Woodward Clyde
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		Dr Marty McCann, Professor Consulting, Dept. Civil & Env. Eng. Dr Allin Cornell, Professor Research, Dept. Civil & Env Eng.	Stanford University
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	Dr Mel Schaefer		Consulting Engineer

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	Michael Boss, Senior Engineer.		Greater Vancouver Regional District Water Supply Division

5. THE UNITED KINGDOM

Upper Glendevon Dam
Scotland
(Scottish and Southern Energy)

5. THE UNITED KINGDOM

5.1 Regulation[1]

Legislation was introduced to the United Kingdom (UK) in 1930, following the failure of Coedy Dam in Wales, with the Reservoirs (Safety Provisions) Act. In 1975 the legislation was superseded by the Reservoirs Act. The Reservoirs Act applies to large reservoirs, defined as those reservoirs holding a volume of water greater than $25 * 10^3$ m^3, resulting in more than 2,500 reservoirs being covered by the Act.

The areas of responsibility in the Act are divided between:
- Owners,
- Councils as Enforcement Authorities,
- Government Departments as support to Legislators and checking compliance of Enforcement Authorities, and
- Panels of qualified civil engineers.

The Act is ‘non technical’ in that specific levels of safety are not stated.

There are four Panels of qualified civil engineers. The panels are defined by three reservoir types – all reservoirs, non impounding reservoirs and service reservoirs, with the fourth panel being ‘Supervising Engineer’. The duties of each Panel are specified and include ‘Supervising Engineer’, ‘Construction Engineer’ and ‘Inspecting Engineer’.

The Institution of Civil Engineers undertake the selection of Panel Engineers and make recommendations to the Secretary of State based on the suitability of the individual’s qualification and experience.

5.2 Use of Risk Assessment

There is no current official support or use by dam owners of quantitative risk analysis (QRA) and societal risk criteria in the UK. A reluctance to use QRA is reported as stemming from the difficulty in assigning credible probabilities of failure, the adverse ratio between the cost of QRA and the normal upgrade costs at UK dams and the success of the Reservoirs Act in limiting safety incidents[2].

5.2.1 Scottish and Southern Energy

Scottish and Southern Energy is a major dam owner in the UK with 84 dams, 56 of which are included in the International Commission on Large Dams (ICOLD) world register.

Since 1996, the Company, with support from the Babtie Group Consultants have developed a Failure Modes and Effects Criticality Analysis (FMECA) process for their dams. The Company considers its stock of dams to be in very good condition relative to the UK standards. However, it also considers that surveillance, operations and maintenance practices should all be risk based, since these areas are not always adequately addressed by the standard approaches.

The initial work identified particular risks associated with flood gates and indicated that further detailed studies were required. These later studies resulted in a significant prioritised program of works to seven drum gates and to replace lifting gear for two radial gates.

Scottish and Southern Energy has also undertaken flood inundation mapping for extreme events and those associated with more frequent floods including malfunction of flood gates. It is intended that the planning for these events will be shared with emergency planning agencies.

In summary, "Scottish and Southern Energy based on experience to date consider risk assessment (their process is defined as FMECA in this report) to be a vital part of the approach to dam safety and asset management. Risk assessment is complementary to existing UK dam safety approaches and has been found to be cost effective and to make effective use of existing engineering resources and expertise. An open minded approach is essential to the success of risk assessment and we expect to continue developing our approach in the future and to continue our co-operation with dam owners in this field."[2]

5.2.2 Health and Safety Executive

In the UK, it is worthwhile considering the activities of the Health and Safety Executive (HSE). Whilst they do not currently have a role in dam safety, their development of a tolerability of risk framework for hazardous industries is useful information.

Also, within the dams industry some practitioners consider that the HSE may take a future role in relation to dam safety.

The Health and Safety Executive (HSE) advises and assists the Health and Safety Commission (HSC) in the administration of the Health and Safety at Work Act 1974 (HSW Act). These institutions were established to regulate health and safety arising from workplace activity following a fundamental review on behalf of Government in the early 1970's.

In 1999 the HSE published a discussion document, 'Reducing Risks, Protecting People'[3] and in 1998, a report, 'Societal Risks'[4]. The first document "focuses on the approach of the regulator (HSE) to the structuring of advice on policy to the HSC and the subsequent implementation of policy when decided by HSC following public consultation and Parliamentary/Ministerial approval"[5]. The second document is a report commissioned by the Risk Assessment Policy Unit of the HSE to review the historical evolution of the societal risk concept and comment critically on the present position, offering advice where feasible and appropriate.

The HSE describe "a hazard as an intrinsic property or disposition of anything to cause harm and risk as the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard"[6]

The document "Reducing Risks, Protecting People" includes background information to tolerable risk criteria. In the 1986 report of the Public Inquiry into the Sizewell B Nuclear Power Station, the Inquiry Inspector asked that the HSE should 'formulate and publish guidelines on the tolerable levels of individual and societal risk to workers and the public from nuclear stations'.

The report states, "As a result the HSE published in 1988 the document 'The Tolerability of Risk from Nuclear Power Stations[7].' The document set out a framework, which has since become known as the Tolerability of Risk or TOR framework, which describes HSE's philosophy of risk control for nuclear power stations. The philosophy specifically addressed in that context the need to advance from the division that things were either safe or not safe. The document was reissued in 1992 following public consultation, and the underlying philosophy has since gained considerable acceptance by other regulators and industry as having wider applicability beyond nuclear power. In particular, the argument is now widely accepted that a properly informed balancing act between risks and benefits is of central importance to decisions on the levels of risk that are tolerable."[8]

The HSE believes that the TOR framework incorporates the three criteria used by regulators in the health, safety and environmental field. These three criteria are equity, utility and technology. Equity refers to standards setting limits to the maximum level of risk above which no individual can be exposed. Utility refers to comparing the monetary benefits of risk prevention versus the cost of producing it. Technology refers to ensuring that state of the art technology is employed to control risks.

The framework is illustrated in Figure 1 below.

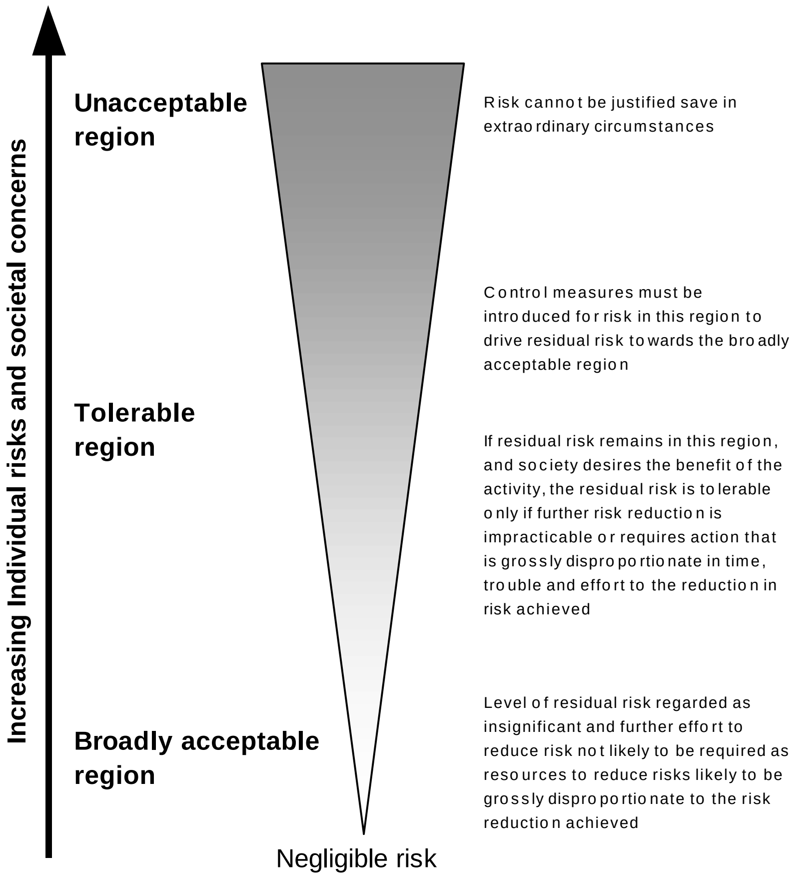

Figure 1
HSE Criteria for the Tolerability of Risk[3]

In relation to the risk of death, "the HSE believes that an individual risk of death of one in a million per annum for both workers and public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions"[9]. The HSE do not have a widely applicable criteria for the boundary between the tolerable and unacceptable. However, in their document on the tolerability of risks in nuclear power stations, an individual risk of death of one in a thousand per annum for workers and one in ten thousand per annum for members of the public who have a risk imposed on them were suggested.

The HSE note that the limits “rarely bite”[10], firstly because of societal concerns that arise about high-risk low-probability events and secondly that the limits reflect international agreements and UK industries usually do better than the limits.

In relation to criteria on tolerability of risks for societal concerns, the HSE proposes criteria based on the limit of tolerability in relation to risk from industrial installations at Canvey Island on the Thames. “The HSE proposes that the risk of an accident causing the death of fifty people or more in a single event should be less than one in five thousand per annum.”[11]

For some planning purposes, “the HSE advises against granting planning permission for any significant development where individual risk for the hypothetical person is more than 10 in one million per year, and does not advise against granting planning permission on safety grounds where such individual risk is less than 1 in one million per year.”[12]

The HSE consider that “the results of a risk assessment often provide an essential ingredient in reaching decisions on the management of risk”[13]. Also, this view is clarified by advising cautious use, understanding of the limitations and that the outcome should inform and not dictate decisions. It is recognised that risk assessments will often be qualitative and not quantitative.

There is only one comment about dams in the document. The comment is made in relation to “acceptable risk” criteria used with the societal risk diagrams known as FN-curves. (FN curves are usually presented on log-log plots with the x-axis representing the scale of consequences in terms of the number, N, of fatalities and the y-axis representing the likelihood, F, of N or more fatalities). HSE express the belief that the use of FN curves has drawbacks but has proved useful. “These criteria are, however, directly applicable only to risks from major industrial installations and may not be valid for very different types of risks such as flooding from a burst dam or crushing from crowds in sports stadia”[14] The reason for the HSE’s view appears to be based on the fact that the limits adopted by the HSE are based on the risk that society was prepared to tolerate from industrial installations at Canvey Island on the Thames.

As a general comment, the HSE appears to have developed a stronger position over time in relation to the ‘As Low as is Reasonably Practical’ (ALARP) concept. This is a concept whereby the duty holder must demonstrate that measures introduced to control risks have been taken to the point where there would be a ‘gross disproportion’ between the effort to control risks further and the risk reduction that would be achieved. The HSE state that “normally, risk reduction can be taken using good practice as a baseline – the working assumption being that the appropriate balance between costs and risks was struck when the good practice was formally adopted and the good practice then adopted is not out of date.”[15]

It is my understanding that the stronger leaning to ALARP through ‘best practice’ is well recognised by the nuclear industry. Industry understands that meeting risk criteria is not sufficient in itself and must also demonstrate that world industry ‘best practice’ has been used in the design of any works or practices. It may be that this is not necessarily welcomed because of the additional costs that may be involved in meeting the requirement, if these are not properly balanced against the risk reduction benefit. It is not clear to the author that the costs and benefits have always been measured in the development of ‘best practice’.

The Societal Risks report was commissioned by the HSE to "review the historical evolution of the societal risk concept and comment critically on the present position, offering advice where feasible and appropriate."[16]

The report concludes, inter alia, that whilst there appears to be a role for societal risk considerations, the issues are very complex. Also, that the methods are not well developed.

Specifically, "Societal risk criteria should not, in other words, be viewed as more than broad indicators of a desirable objective, with many other non-technical factors needing to be weighed in any final decision."[17]

In relation to setting criteria, the report briefly considers the example of a dam. In this case, the report mentions matters that may be considered such as, if there were already criterion for the community, consideration of the anchor points, whether the standard could be achieved in practice and if the standard should be different to other hazardous installations.

5.2.3 CIRIA Report

At the time of writing the Construction Industry Research and Information Association (CIRIA), the UK based research association, had a research project in place in relation to dams and risk assessment – "CIRIA 568 Risks & Reservoirs". The project is due to publish its final report in the Northern Autumn of 2000.

Whilst the report is in draft form at this time, it is understood to support FMECA (Failure Mode Effect and Criticality Analysis) for significant hazard dams rather than full probabilistic analysis. This is thought to be at least partly because of the current difficulty in estimating probabilities of failure events and the expense of such analyses.

FMECA can be undertaken on a semi quantitative basis, but does not result in specific probabilities of failure. It is therefore most useful in ranking dams for further investigations or works. Such a system is therefore not compatible with considering individual or societal risk from dam failure. The underlying foundation of this approach is then that current practice is in fact "authoritative good practice" as defined by the HSE.

6. FRANCE

Bimont Dam
Aix-en-Provence
(Societe du Canal de Provence et d'amenagement de la region provencale (SCP))

6. FRANCE

6.1 Regulation[18]

For all new dams a technical file must be presented to the Government for approval. For dams higher than 20 metres or which are considered hazardous, there are more specific regulations. In addition, dams higher than 20 metres and having a storage greater than $15*10^6m^3$ are subject to emergency planning regulations.

Three Ministries have responsibility for dams. The Ministry of Transport for structures associated with canals, the Ministry of Industry for hydro and tailings dams and the Ministry of Environment for other dams.

A committee with representatives of the three Ministries, known as the Standing Technical Committee of Dams, reviews all proposals for repairs or construction of all dams greater than 20 metres in height. The Committee considers the proposals based on the current state of the art, rather than any specified rules. When approved, the appropriate Ministry representatives will monitor the works. For dams where public safety is an issue, compulsory continuous survey must be undertaken by the construction supervisor, who is also responsible during the first filling of any dam.

In relation to ongoing operation of dams, there are specific regulations for those dams with possible consequences for public safety. The owner and the local representative of the Ministry must separately keep all relevant records relating to the dam. The owner must carry out periodic visual inspection and monitoring at suggested frequencies and report any faults. An annual report on surveillance must be prepared and every two years include a detailed analysis of the results. The Authorities place a high priority on surveillance as the first line of defence against dam failure.

The owners must have approved procedures for flood control, operation and monitoring.

The administration inspects the dams every year. Five years after the first filling and then every ten years, reservoirs have been emptied so that the upstream face of the dam can be inspected. I understand that diving is now being used more frequently to undertake these inspections.

The owner must prepare emergency plans for dams higher than 20 metres and with a volume greater than $15*10^6$ m3. The plans are prepared based on inundation mapping for dam failure under ‘sunny day’ conditions. The owner must install and maintain a surveillance site building with provision for lighting the downstream face of the dam and secure communications. There must also be sirens installed for warning the public living within 15 minutes of the flood wave travel time. The sirens are tested every three months. For floods, the sirens are activated when the storage level reaches the “danger level”. The “danger level” is equivalent to the dam crest flood for an embankment dam and the dam crest flood plus 1 to 2 metres for a concrete dam. These dams must also have design reviews undertaken to identify any deficiencies.

Inundation maps are provided to the Mayors of the affected communities. The Mayors are responsible for planning for any emergencies in conjunction with the Ministry of the Interior.

For flood capacity, the 1:1000 AEP flood is used for the design of concrete dams whilst the 1:10,000 AEP event is used for embankment dams. These floods are used to dimension spillways and to calculate the storage level at those flows. Specified freeboard amounts are then applied to that level, depending on the type of dam.

6.2 Use of Risk Assessment

In France, the term "Risk Assessment" is commonly used to describe the process of checking whether a dam satisfies the standards defined by the regulations. This is not the process of risk assessment as defined in this paper.

I understand that the philosophy of dam safety in France is one of "not accepting risk on dams" through ensuring that dams with the potential to endanger lives meet standards and that emergency procedures are in place. I believe there is a recognition that the process does not result in zero risk, but that the residual risk, whilst not quantified, is considered to be low enough as to be considered negligible.

Dam owners in France are not currently using QRA, but I understand that some owners are using FMECA type analyses to manage component safety and direct capital and maintenance programs.

6.3 Observations

The methodology for estimating extreme flood events in France is the "Gradex Method". The Gradex method is a rainfall-runoff probability approach to computing extreme flood discharges in a river between 1:100 Annual Exceedence Probability (AEP) to 1:10,000 AEP. A FRCOLD publication[19] includes a comparison of the Gradex 1:10,000 flood against the Probable Maximum Flood (PMF). The ratio of PMF to Gradex results varied between 2.8 and 1.4.

In relation to emergency planning in downstream communities, I understand that there may be some issues relating to time for implementation to be resolved by the Ministry of Public Security before planning can be fully implemented. However, there is a case in the south of France where an emergency plan has been put in place and public consultations held with the affected public. This is reported in the paper by Paul Royet and Robert Chauvet of Cemagref in Aix-en-Provence. Cemagref is a public agricultural and environmental research institute[20].

The dam was Bimont Dam, a double curvature arch dam, for which studies had previously been undertaken indicating that the dam met current safety requirements for that type of dam in France. The immediate emergency area (submerged within 15 minutes) contains some 52,000 people. Inundation mapping was prepared and a pamphlet prepared showing the area, locations of assembly points and instructions including information about the sirens.

Public meetings were held to discuss the plans. Prior to the public meetings smaller meetings were held with elected representatives and local public leaders. Even though the risk of dam failure was well known to at least part of the population in this area, due to the nearby Malpasset 1959 failure, it was found that the information was well received by the public and the conclusion was that openness is to be recommended.

The Bimont Dam experience is worthy of careful consideration by other countries. The situation is quite specific in that the dam met the current guidelines, the population were familiar with risk in that there were already 43 other emergency plans in relation to nuclear and petrochemical plants in place within the geographical area. A further aspect in favour of the owners was that both the owners and technical authorities offices would be amongst the first to be affected in the event of a failure.

Other dam related projects being worked on by the “Hydraulics Works” Team at Cemagref are a data base for dams data, a data base for recording historic behaviour incidents to help analyse current dam behaviour and a FMECA analysis system.

There does appear to be a general recognition in France that for a complete dam safety program, surveillance must have a very high priority.

7. THE NETHERLANDS

New Waterway Storm Surge Barrier
Rotterdam
(Ministry of Transport, Public Works and Water Management)

7. THE NETHERLANDS

7.1 Regulation[21]

Regulation in relation dams in the Netherlands applies mainly to publicly owned flood protection infrastructure. The Netherlands has been amongst those countries at the forefront in the use of risk assessment for many years.

Without flood protection, about two thirds of the Netherlands is flood prone, from the sea or rivers. A quarter of the country is below mean sea level.

Following severe floods in 1953 in which over 1800 people died, the ‘Delta Commission’ was established and in 1958 set down the basis for safety standards to protect against high water. The Commission proposed what could be referred to as a risk based approach to consider the costs of dyke construction versus economic damages should the dyke fail for each dyke ring. However, because of technical difficulties, including the assignment of probabilities to the failure to dykes, a simplified approach based on prescribed water level, with a margin for wave conditions was adopted or, “overtopping probability”.

The standards vary from 1/10,000 to 1/1,250 annual exceedance probability (AEP), depending on the economic activities, the size of population in the protected area, and the nature of the threat (river or sea). The standards were adopted into legislation in 1996 with the Flood Protection Act. The policy is aimed at meeting standards by 2001.

At the same time, there is a move toward a new safety philosophy based on risk assessment, where safety is related to the risk of flooding in terms of the probability of flooding and consequences. The aim is to look at all contributing factors, including the integrity of the dykes in order to determine risk reduction strategies.

A research program, Marsroute of the Technical Advisory Committee for Water Retaining Structures (TAW), is working toward the development of reliable techniques to estimate failure probabilities for dyke systems. This work is well advanced at this time, with several sample calculations for dyke systems having been undertaken.

The indications are that substantially higher probabilities of failure than the “overtopping probability” are being calculated. The aim is to reach a position where flood risk can be compared to other societal risks and risk standards and thereby establish an acceptable level of safety.

7.2 Use of Risk Assessment[22]

Laws for the control of hazards have a long history, beginning in 1810 with Napoleon’s decree on industry operation permits. These permits distinguished between industries based on hazard or nuisance and thereby determined where those industries could be located, after the people lodged objections. An ordinance based on the decree was issued in 1814 and became in 1875 the Law on Factories. In 1896, the Labour Safety Law came into force and the Factory Law became the Nuisance Act. After renewal in 1934 the Labour Safety Law became the Conditions at Work Act in 1982.

In relation to the transport of dangerous goods, the Law on Transportation of Gunpowder was issued in 1815 in response to a barge explosion in 1807 killing 151 and wounding over 2,000 people. In 1876 a law on toxic materials was adopted that in 1963 became the Law on Dangerous Materials.

As discussed above, a form of risk approach to flood control was introduced in the early 1960's.

Major chemical industry accidents around the world in the 1970's led to legislation in many countries and the European Union. Some risk management concepts were introduced in public policies associated with nuclear power generation, but most were associated with chemical accidents. Notable were the vapour cloud explosions in Flixborough and Beek, the release of Dioxin in Seveso and the 3,000 deaths from the disaster in Bhopal.

In the Netherlands, safety concerns about LPG fuel sales and estimates of potential consequences resulted in 1978, in the introduction of planning controls within 150 m of filling stations. Subsequent regulation on industrial hazards have been shaped by the LPG regulations and follow a risk based approach.

7.3 Risk Criteria[22]

Dr. Ben Ale of the Institute of Public Health and Environment (RIVM), is recognised as a leader in the field of risk analysis. He was part of a team that prepared the basis of government policy for environmental risks. Dr. Ale has received the "Outstanding Achievement Award" from the Society for Risk Analysis and is a member of the Board of Directors of the International Association for the Probabilistic Safety Analysis and Management (IAPSAM).

In relation to risk criteria in the Netherlands, Dr Ale has explained that, "For individual risk an upper acceptability in new situations or new developments of 10^{-6}/year holds for establishments and for the transport of dangerous materials. In existing situations a sanitation limit of 10^{-5}/year is upheld. For Schiphol airport these limits are 10^{-5}/year and $5*10^{-5}$/year respectively. These last limits are under debate and thus subject to change."[23]

Ale also notes that a new general ordinance is in preparation, in which these risk limits are given full legal status. Further, "For societal risk an advisory limit is given for establishments and transport as is depicted in Figure (2). It should be noted that in spatial planning the limit for transport will only be observed within 200 m from the route. For air transport and other sources of risk no limit has been set."[23]

"Although the process as described in the Law on the Environment has a strict flavour, in practice a lot of discussion and negotiation precedes the granting or refusal of a licence."[24]

"On a national scale, comparison of risks can focus attention as to which risks are more threatening than others and which risks involve most people"[24] – Figure 3.

Dr. Ale notes that expert judgement is embedded in all activities pertaining to risk analysis and assessment and that if a result is obtained by judgement rather than rigorous scientific analysis it should be reported.

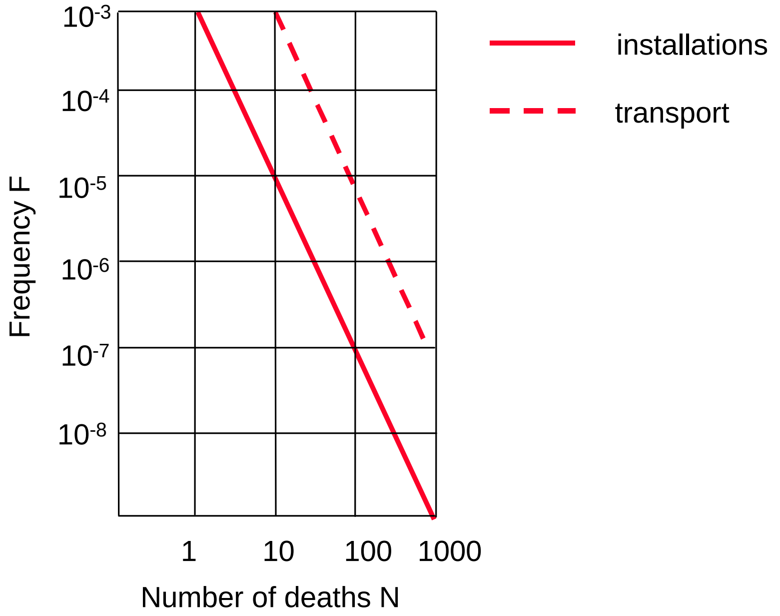

Figure 2
Advisory Societal Risk Limits in the Netherlands[22]

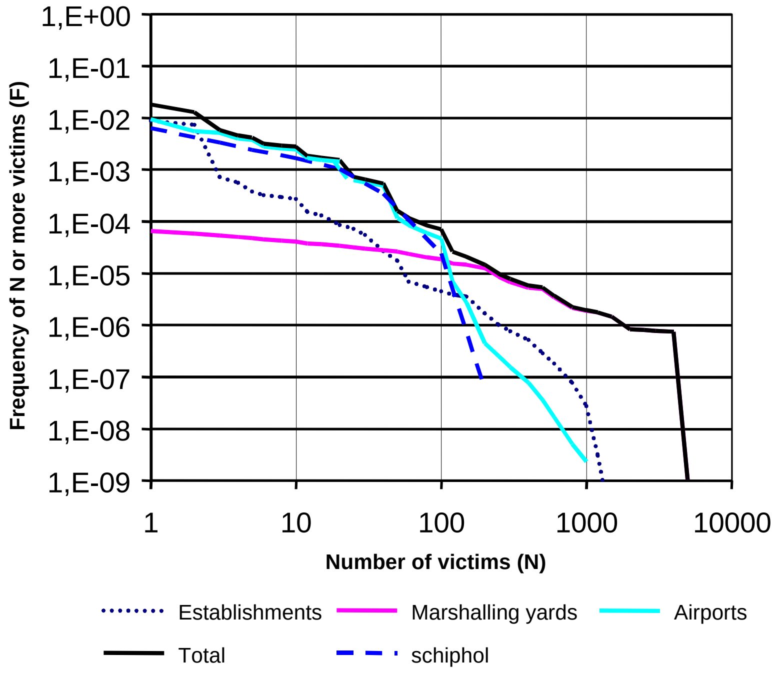

Figure 3
Societal Risks in the Netherlands (Yearly Environmental Report, RIVM 1999)[23]

He also comments that in relation to uncertainty, risk assessments and judgements are based on best estimates.

In another paper on standards for risks[25], Dr. Ale discusses the use of directional criteria, that is criteria that do not give explicit values but give a direction or intent, for example ALARA (as low as reasonably achievable) or ALARP (as low as reasonably practicable). Dr Ale notes that "in an increasingly competitive environment …….. any cost is damaging the competitive edge."[26] Owners may then say that any additional costs to exceed a standard are excessive and when this is combined with uncertainty about what is "safe" makes it cost effective to argue for not going beyond standards.

The ALARA and ALARP criteria also are under increased pressure to try and express all costs and benefits in monetary terms. "There are great advantages over this approach in the context of a market economy because it makes safety from a vague ethical concept into a good with a price worth paying."[26] The problem is that it is very difficult to place a value on life or injuries or environmental damage. Costs also can be difficult to value because of benefits can that also flow from those costs.

"In summary, it can be concluded that currently there is not yet a clear understanding of how to use cost benefit analysis in an organised way in risk management"[27].

These comments would appear to indicate some doubt about the practicality of the approach by the HSE in the UK, whereby cost benefit analysis is put forward as one method of measuring progress toward an ALARP condition.

7.4 Observations

It is clear that there is a solid foundation of use of QRA and acceptable risk criteria for public safety in the Netherlands.

In relation to flood defences this approach is being extended into a research program to enable a switch to a safety policy based on the risks of flooding per dyke ring area. This is a further development on the approach taken since the 1953 flood event of basing safety on flood return periods. Work to date has been focussed on calculating the probability of failure of dyke systems, but in the future calculations of damages will be added to the equation to determine risk (probability of the event and consequences) in each case. A process to evaluate acceptable risk will be required. It is expected that this process will mature over the next five to ten years. The Technical Advisory Committee say "This aimed for switch in safety policy with respect to flood defences will need to be intensively discussed at both a social and political level. The basic principle for the legislator in this process will be that the new safety approach will result in at least an equal level of safety."[28]

I understand that the Committee will have reported the calculated flooding probabilities to the Government by now. It will be interesting for those involved in risk management processes to follow how this very difficult question for the Dutch is managed over the next few years. The public discussion could well provide valuable insights into how communities perceive risk.

There is an obvious concern amongst those associated with risk assessment and control that risks be balanced in the community. An example of this is the current community debate in relation to the suggested concept of flooding some polders during high river flows to protect high consequence areas.

7.5 Risk Perception

In relation to the perception and decision processes based on risk assessment, Dr. Ale provided some insights into the issue in his paper regarding "Trustnet"[29]. The paper is based on a series of seminars held on the subject of risk communication and social trust. The paper points out the extreme complexity of decisions about the acceptability of hazardous activities, related to what are the benefits and if so to whom and where, uncertainty about the risks for catastrophic hazards, benefits and disbenefits not being applied to the same group, arguments between experts and others about hazards and risks.

Dr Ale points to a reduction in trust of experts who have tried to "educate" people about the difference in expert opinion and the views of the public. The need for openness by experts and a need to ensure that experts remain working in the realm of risk analysis (the calculations) and leave the risk assessment (what is acceptable) to policy makers is strongly made.

It may be that the public reaction to risk based information will not be adverse because people realise that there are risks in society and appreciate the information being in the open. The public reaction may not be as forgiving if the risks are covered up or lied about.

7.6 Risk Policy

There is some difficulty in the process of directing technical risk analysis approaches to risk assessment in the policy forum. An approach used in the Netherlands is to accept that the analysis outcomes, whilst representing the best possible information at the time, will probably be subject to change over time as the science improves. Therefore, the advice to Politicians, who must drive the criteria setting through the political process, is that the policy should include provisions for review in five years to check how well the policy has worked and to review further developments in the scientific and social context.

Policy developers consider that it is essential to involve all people with an interest and ensure that those who must pay if works are required agree with the risk-based methods on which the policy would be based.

Policy developers also recognise that whilst there can be large confidence limits on assessments, it is difficult for the political process to deal with that type of information and therefore, the most probable estimates are used in developing policy.

7.7 Rotterdam Flood Barrier[30]

The flood barrier in the new waterway at Rotterdam is an interesting case of risk based design. The barrier is the final element of the "Delta Plan" works that were recommended following the great flood disaster of 1953. The Delta Plan proposed measures to prevent a repetition of such a disaster in the future. The dykes in Zeeland and Zuid-Holland were to be raised to the so-called ‘delta height’.

In the subsequent decades, all but two of the open sea arms in the Dutch delta area were closed by means of dams. In the Hollandsche Ijssel river a moving storm surge barrier was constructed. The port of Rotterdam had to remain open to shipping and so a program of dyke construction was put in place. However, due to public protest about the effect of construction on urban areas, costs escalations and Government economies the concept of a moving storm surge barrier was revived.

The New Waterway at Rotterdam connects that harbour to the sea and the canal also serves as the main water outlet of the Rhine and Maas rivers. Since Rotterdam is the largest cargo handling harbour in the world, the structure could not hamper shipping. The structure required at least 360 m horizontal clearance and a minimum water depth of 17 metres. The chosen design consists of two semi circular steel gates, each attached by two trusses to a steel ball joint.

The criteria required for the structure required that the probability of structural failure is at most 10^{-6} per year (10^{-4} in the design life of 100 years). Standard design procedures, which for individual members, provide close to the required target for a life of 50 years, were modified to meet the probability requirement. Research was undertaken to supply structural engineers with partial safety factors, in such a way that the target reliabilities were met.

In addition to 10^{-6} probability of structural failure of the barrier, a maximum probability of failure to close the barrier of 10^{-3} per demand and a maximum probability of failure to open the barrier of 10^{-4} per demand were required. It is estimated that the barrier will be deployed on average, once every 10 years, but due to the expected sea level rise will be once every 5 years at the end of the 100 year design life.

When required, due to storm forecasts, the waterway is closed to shipping and the barrier floated into position and flooded with water to sink to the sill. When the storm surge has passed, the water is pumped out and the structure floated to allow it to be rotated back to its storage position.

The cost of the entire project consisting of the storm surge barrier, the Europoort defence system and the final dyke reinforcements in the tidal river area came to 1.4 billion guilders (US $0.6B). This is approximately 400 million guilders (US $170M) less than that estimated to complete the dyke reinforcements program and decades faster to build.

8. NORWAY

Rodungen Dam
(Statkraft)

8. NORWAY

8.1 Regulation[31]

Dams regulation in Norway is undertaken by the Norwegian Water Resources and Energy Directorate (NVE) through their Safety Department.

Regulations were introduced in 1981 and are valid for dams with a water depths greater than 4 metres and those which impound a reservoir of $0.5*10^6$ m^3 or more. The original regulations were directed mainly toward dam construction. In the years since, additional guidelines have been introduced which recognise the shift from construction to operation and maintenance, changed technologies and the risk that the level of expertise in dams could fall with the arrival of new owners to the industry. The experiences of the offshore oil industry in managing risks was also a consideration. The “dam safety project”, a joint effort of NVE and the Norwegian Electricity Federation (EnFO), was also a recognition of the changed emphasis and the final nine volume report dealt in detail with issues relating to existing dams.

The dams subject to regulation are divided into categories based on consequence of failure. Class 1 (high hazard) if more than 20 residential houses are affected (about 260 dams), Class 2 (significant hazard) if between 1 and 20 houses (about 540 dams) and Class 3 (low hazard) if no houses are affected (about 1700 dams). The classification also includes consideration of the loss of resource and dam infrastructure, the residential classification is carried out using inundation mapping undertaken by the dam owner.

Each dam owner is required to have an engineer approved by the regulator to act as the Chartered Dam Engineer. The Chartered Dam Engineer must meet certain educational requirements and further specific training depending upon the classes of dams owned by the organisation and is responsible for dam safety within the organisation.

Under the guidelines, dam owners are required to have internal quality control systems to ensure the satisfactory safety inspection and surveillance of its dams. In this way the regulator acts as an auditor of the owners’ dam safety program and the emphasis is on the dam owners to take responsibility for dam safety.

NVE now also requires dam owners to have contingency plans for abnormal events, including the need for frequent emergency plan exercises.

At the time, I was aware that new dam safety regulations are proposed for Norway, but had not yet been introduced. It is understood that the new regulations will provide for the use of risk assessments either as a requirement of NVE or by the choice of the owner as part of safety evaluations.

The NVE issued Guidelines for Risk Analysis for Dams in 1997. The Guidelines refer to the use of risk assessment for prioritisation of remedial works, selection of the remedial option and as a tool for emergency planning measures. The guidelines when issued, included reference only to probability assessments.

8.2 Use of Risk Assessment

Several risk analyses for dams have been undertaken. Most have focussed on the dam failure probabilities and although a model has been developed for estimating consequences, it appears that the profession are concentrating on refining the assessment of failure probabilities prior to moving to detailed consequence assessments and developing risk criteria.

At least two case studies of the analysis of failure probabilities for Norwegian dams were to be presented at the ICOLD 2000 Beijing conference.

Dr. K. Hoeg (past President of ICOLD) in a 1998 paper[32] put forward some considerations relating to the use of risk analysis. He pointed out that the new performance regulations being developed in Norway "state that alternative solutions are acceptable as long as analyses show that the resulting risk level is no higher than that implied by the regulations."[33]

Dr Hoeg also considered that "The main purpose of carrying out a risk analysis is to provide decision support"[34] and "Risk analysis provides a framework for systematic application of engineering judgement and available statistics in decision making"[35]. He believes that factors of safety do not provide a transparent level of safety and that probabilistic risk analyses can assist in exposing uncertainties. Even though a failure mode may be missed in analysis, this can also occur with deterministic solutions. The key is to "improve our understanding of dam/foundation behaviour and failure mechanisms, resist complacency, and improve quality assurance and control."[36]

Dr Hoeg also states that the use of the concept of acceptable risk (risk criteria) is controversial.

8.3 Observations

Several papers have been published about risk analysis (effectively probability of failure analyses) of Norwegian dams. In a paper by T. Aamdal[37], there are included comments on the process by independent consulting firm Veritas, who have experience in the offshore oil industry. Interestingly, the comments tend to be suggesting the use of more rigour in the methodology, amongst other things pointing to "statistics, analysis and computations" and "sensitivity analysis".

9. SWEDEN

Ajaure Dam
River Ume Alv
(Vattenfall)

9. SWEDEN

9.1 Regulations[38]

In Swedish law, owners have the main responsibility for dam safety. Government permission is required for dams to be constructed. Although it is not required by law, each major dam owner usually has an internal dam safety organisation for the operation and maintenance of existing dams. Owners are therefore operating in a non-regulatory environment.

For example, Vattenfall AB, the major hydropower operator in Sweden and responsible for 50% of Swedish dams, has an internal commission for the safety of dams.

Individual towns are responsible for emergency planning for accidents whilst County Councils have responsibility for major events such as dam failure.

9.2 Use of Risk Assessment

The Swedish Government has considered the establishment of regulations for dam safety on several occasions, including recently, at which time it was indicated that regulation may be required.

In response, dam owners set up their own guidelines – the RIDAS guidelines of 1997. The RIDAS guidelines are due to be reviewed in 2001. More recently, the Government has stated that dam owners are wholly responsible for the safety of dams and for the consequences of dam failure. This has placed even greater emphasis on owners to fully understand the risks within their portfolios.

Risk analysis is being considered as a methodology to prioritise the remediation of dam safety deficiencies. In this regard, Vattenfall, with consultant SwedPower, have been working with both quantitative and FMECA type analyses to evaluate what methodologies would be suitable for their purposes.

9.3 Observations

An interesting dam safety issue in Sweden relates to the stability of embankment dams. Particularly those constructed with glacial till (moraine) core material. There are 27 embankment dams higher than 15 metres in Sweden that have developed sinkholes. This is equivalent to 20% of Sweden's large earth and rockfill dams.[39]

In some cases remedial works have been undertaken whilst in others enhanced surveillance is in place to monitor developments. In this regard, Vattenfall/SwedPower are investing in joint research into improved seepage monitoring techniques in addition to that being done within the European Union.

10. UNITED STATES

Eastside Reservoir (West Dam)
Riverside County California
(Metropolitan Water District of Southern California)

10. UNITED STATES

10.1 Regulation

The Federal Dam Safety Program in the United States has developed from a background of dam failures. Following the 1972 failure of Buffalo Creek dam in West Virginia when 125 people died, Congress passed the National Dam Inspection Act. The Act authorised the inventory and inspection of US dams.

However, inspection did not commence before the Teton dam failure in 1976, in which 14 people died. Federal Agencies acted to develop technical guidelines and standards for dam safety. Then, in April 1977 the Kelly Barnes dam failed, killing 39 people. A Federal Interagency committee prepared dam safety guidelines and the inspection of high hazard non-Federal dams was commenced.

In October 1979, President Carter directed Federal Agencies to adopt the dam safety guidelines and report on progress to the newly formed Federal Emergency Management Agency (FEMA), which was to take the lead in dam safety.

FEMA works closely with the Federal dam owning agencies through the Interagency Committee on Dam Safety (ICODS) and also with the Association of State Dam Safety Officials (ASDSO), the United States Committee on Large Dams (USCOLD) and the American Society of Civil Engineers (ASCE). The partnership had to extend beyond the Federal arena since 95% of the 80,000 dams in the US are owned by the States, local government or are in private hands.

Areas that have been worked in by FEMA and the other partners are:

- Training Aids for Dam Safety (TADS). Sponsored by ICODS and managed by the Bureau of Reclamation.

- The National Inventory of Dams, commenced in 1989. Funded through the Corps of Engineers and managed by FEMA with close co-operation of the States.

- Sponsored dam safety public awareness workshops, managed by ASDSO. Owners, operators and public officials attend these workshops. ICODS has also encouraged local government emergency management exercises to include dam failure scenarios.

10.2 Use of Risk Assessment

Attitudes to the use of risk assessment vary widely from no formal use whatsoever to adoption as a normal dam safety process. However, risk assessment is certainly on the national agenda, and the subject of debate throughout the country.

At the moment, the Bureau of Reclamation, Washington and Montana States are the only users of societal risk criteria as an integral part of a dam safety program that were identified during the study. Some States use a basic level of risk analysis as a tool for prioritising regulatory efforts, but normally fall back to standards based approaches for long-term remediation, apart from isolated cases where the consequences of failure at the dam are low.

10.3 US Bureau of Reclamation

The Bureau of Reclamation (commonly known as "Reclamation") is responsible for a portfolio of over 350 dams, forming a significant part of the water resources infrastructure of the western United States. As such, Reclamation is amongst the world's largest dam management agencies and the activities and views of the organisation in relation to risk analysis and assessment must be carefully considered, particularly as Reclamation is actively using these methodologies.

A degree of understanding of Reclamation's position in relation to risk analysis and risk assessment can be gained from its methodology document[40]. The fundamental basis appears to be that risk analysis and assessment are considered a means to the improved management of risks that are an inherent part of dam management, whilst recognising the limited availability of resources to remediate those risks. Reclamation states that "Tightening budget constraints suggest it is appropriate to use risk determinations as a tool to direct funding to those issues presenting the greatest risks."[41]

The Federal Government authorising legislation for the dam safety program states:

> *"In order to preserve the structural safety of Bureau of Reclamation dams and related facilities, the Secretary of the Interior is authorised to perform such modifications as he determines to be reasonably required."*[42]

Responding to the congressional mandate, Reclamation has refined the goal as follows:

> *"The objective of the Safety of Dams Program is to ensure that Reclamation structures do not present unacceptable risks to public safety, property, and welfare. This requires identifying structures which pose unacceptable risks and taking corrective actions to reduce or eliminate these risks in an efficient and cost effective manner. Reclamation policy is to provide safe structures, but this does not imply a risk free environment. A safe dam is one which performs its intended functions without imposing unacceptable risks to the public by its presence."*[43]

The mention of "unacceptable risks" suggests that there are guidelines used to determine if risks are unacceptable. This is the case and Reclamation uses a two-tier system to measure calculated risks against.

Although the two-tier system is used as a guide, it would be incorrect to postulate that this is the only criterion used to determine dam safety actions. Risk assessment is used to assist on the evaluation of public safety, economic, resource and social concerns within the overall dam safety decision making process. Other factors that may be considered are operational, economic, public involvement, water use, and legal requirements.

Reclamation defines risk as:

Risk = Pr(load) * Pr(adverse response, given load) * consequences(given response)[44]

("Pr" means Probability)

The term "risk analysis" is used in reference to the process of calculating risk and "risk assessment" in reference to the process of considering the analysis and other factors in making a decision.

Risk analysis benefits are described as including the ability to compare risks resulting from varying loading conditions at and between dams, an improved understanding of dam behaviour, as a guide for further investigations, as being able to assess the effectiveness of risk mitigation measures and as a way to effectively allocate resources. The aim is to ensure that dams representing the greatest risk receive priority for funding and/or evaluation.[44]

Reclamation categorises risk analysis into two types known as baseline and risk reduction. A baseline risk analysis can be a portfolio level analysis, a basic analysis performed by a senior engineer as part of a six yearly comprehensive facility review or a project team risk analysis.

The project team type of risk analysis is the most detailed and requires the preparation of event trees with associated probabilities and consequence estimates. Areas of uncertainty can be identified for decision-makers and information gaps, which if filled would significantly improve estimates.

The risk reduction analysis consists of two parts. The first part consists of identifying the highest component contributors to risk and then devising alternatives to reduce risk, either structural or non-structural. The second part is evaluating the alternatives for effectiveness of risk reduction.

In "Guidelines for Achieving Public Protection in Dam Safety Decision Making"[45], Reclamation expresses particular views in support of the risk analysis process. It is pointed out that there is a joint requirement within the organisation to ensure public safety for large and more frequent events in the most cost effective way whilst always recognising that employing the most stringent standards still results in some risk of failure.

The risk analysis process is described in two stages, the first in determining the need for risk reduction and the next as evaluating alternative risk reduction strategies. With the aim of allowing staff to present public safety information to assist in allocating limited available resources.

In addition to the Reclamation's mission and the Reclamation Safety of Dams Act of 1978, the Federal Guidelines for Dam Safety 1979, are included as giving organisational guidance on dam safety decision making. In particular the following extract:

> "*The agencies should individually and cooperatively support research and development of risk based analysis and methodologies as related to the safety of dams. This research should be directed especially to the fields of hydrology, earthquake hazard, and potential for dam failure. Existing agency work in these fields should be continued and expanded more specifically into developing risk concepts useful in evaluating safety issues.*"[46]

The guidelines are focussed on loss of life risks as the fundamental issue for public agencies with responsibility for dams. In relation to risk based and standards based decision making, Reclamation considers that risk assessment is a way of "formalising and documenting" the judgement process which is part of decision making. Since standards are a way of incorporating judgement into a set of design rules, there must be a level of conservatism to allow for uncertainties. In some cases therefore, an inefficient outcome may be determined in some cases and lead to a significantly different levels of public protection at different dams. However, it is also recognised that where high probabilities of loads and high consequences are the case, then it is necessary to employ the best available technology and built in redundancy to ensure public protection since the estimation of the very low failure probabilities may not be feasible.

Reclamation uses a two-tier system for the public protection guidelines. The first deals with loss of life considerations, whilst the second deals with public trust. The graphical representation of those guidelines is shown below:

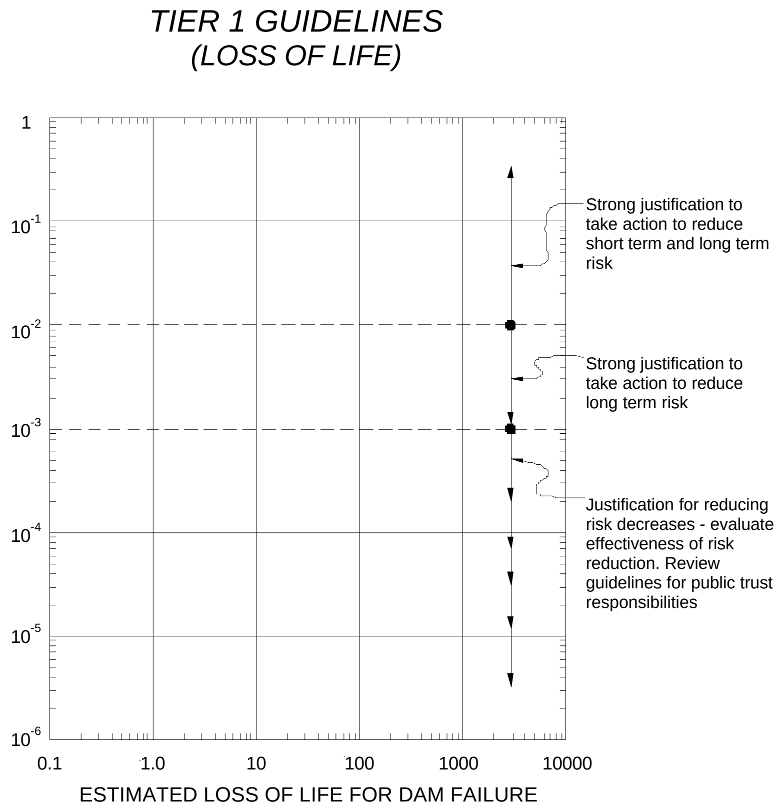

Figure 4
USBR Tier 1 Guidelines[45]

The guidelines should be referred to by those interested in the particular details since they are not reproduced in full here. However, whilst Reclamation does not describe precisely how the guidelines were developed, there are several indicators. For low loss of life situations, it considers that an annual loss of life probability of 0.001 could expose individuals to risks similar to that from background risks such as car accidents or disease and that the Tier 2 guideline should address this situation. The Tier 1 guideline includes the actual loss of life estimate so that decision-makers are aware of high life loss situations with significant public aversion.

In considering the annualised life loss of 0.001, it can be seen that for every multiplication of consequences, the same factored reduction is required in the probability of failure.

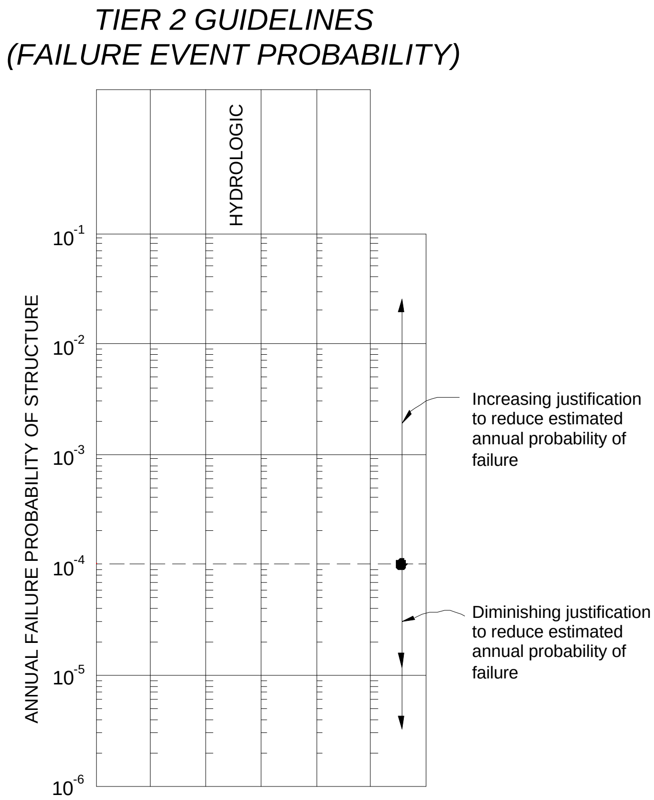

Figure 5
USBR Tier 2 Guidelines[45]

The Tier 2 guideline relates to public trust whereby Reclamation recommend that each individual dam has a maximum combined annual probability of failure of 1 in 10,000. This is to ensure a reasonably low probability of failure of a dam within the Reclamation portfolio within the next 50 years.

The guidelines include examples for cost effectiveness calculations and sample plots.

10.3.1 Reports by the US Bureau of Reclamation

(i) Achieving Public Protection with Dam Safety Risk Assessment Practices[47]

The risk approach of Reclamation comes partly from the remediation of many obvious high risks during the years following the Safety of Dams Act in 1978. This left a very large portfolio of dams without a clear way to prioritise future works or investigations.

There has been a move to greater efforts in detection of problems through enhanced monitoring. Also to dam safety emergency plans incorporating site-specific indicators along with periodic examination of the dams. In addition, the risk assessment process has been developed as an additional tool to help in understanding safe performance of dams and evaluating the more complex situations now being faced.

The paper includes a statement in relation to how "risk assessment approaches are intended to be an additional tool that leads to improved decisions by helping to accomplish the following objectives:

- Recognises that all dams have some risk of failure
- Considers all factors contributing to risk
- Identifies the most significant factors influencing risk and uncertainty, which facilitates efficient targeting of additional data and analyses
- Identifies a full range of alternatives to manage risk, including monitoring and other non-structural methods
- Focuses funding and resources toward risk-reduction actions that achieve balanced risk between dams and between failure modes on individual dams
- Establishes stakeholder credibility and due diligence for risk-reduction actions"[48]

Reclamation sees risk assessment as a way of quantifying the engineering judgement necessary when considering the safety of existing dams where so many uncertainties are present. An example is given about the consideration of an embankment dam slumping under MCE loading. If the judgement is that the dam is "safe" then a decision-maker will wish to know what are the chances of the judgement being wrong, particularly if the consequences of a failure are large. Conversely, if the dam is judged as being in danger ("not safe"), then how does this risk compare to other dams.

In relation to standards based approaches, it is pointed out that there are areas of inconsistency. For example, due to regional variations in the probability of large floods and earthquakes the use standards can result in varying levels of risk for the same standard. Or the use of factors of safety that vary for different aspects of the dam, or the issue of the time of exposure to unusual loads, or that some standards do not take into account the consequences of failure.

The use of the phrase "public protection guidelines" rather than "acceptable risk" is deliberate, to put the focus on the protection of lives rather than develop the view, even if erroneously, that no risk reduction is required if risks are below the criteria. The use of guidelines also allows for the consideration of influences beyond the risk assessment framework.

(ii) Considerations for Estimating Structural Response Probabilities in Dam Safety Risk Analysis[49]

This report outlines the technical basis for the techniques used by Reclamation to estimate structural response probabilities. In particular, in providing the basis for the quantification of engineering judgement as subjective, degree-of-belief probability, necessary to undertake the risk assessment process for dams.

The report explains the differences between the relative frequency approach to probability and the subjective, degree of belief approach. Most people are familiar with relative frequency, where the frequency of occurrence of an event is drawn from repeated trials. This approach has some limitations in relation to dams because of the unique nature of individual dams and the issue of single event occurrences such as geologic features. Degree-of-belief probability is described as not having a singular value, but as varying depending upon the quality of the available information, technology and judgement of the estimator. Weather forecasting is cited as an example of a degree-of-belief approach that incorporates frequency information.

Reclamation considers that the use of statistically characterised data and subjective judgement can be incorporated legitimately.

Given that judgement and therefore the probability derived from it can vary with time, “In this context, a more applicable goal is the sensible and responsible use of such a probability: sensible by applying it with an understanding of the factors that affect it, and responsible by expressing it with due recognition of its intrinsically non-unique character.”[50]

Reclamation uses two techniques for estimating structural response probabilities, either normalised frequency or decomposition. Normalised frequency involves adjusting failure frequency data to a revised value based on the particular circumstances applying at the dam in question.

Decomposition, which is the more general approach, relies on breaking the failure sequence into small components. The individual component probabilities can be estimated using several methods – statistical (reservoir level, electrical and mechanical), degree-of-belief, reliability (say material properties), regression (say from laboratory data).

Reclamation have developed specific techniques to try and ensure that the process of degree-of-belief probability estimation is as robust and transparent as it can be, with well defined and recorded roles for all participants.

10.3.2 Comments on US Bureau of Reclamation

There is no doubt that Reclamation use risk analysis processes as a fundamental part of its dam safety decision-making (risk assessment). Following discussions with key personnel, it was concluded that Reclamation uses risk processes for more than the prioritisation of its works program. If the outcome of risk assessments result in risks that Reclamation determine to be low enough as to not warrant action (in the absence of other influences), even if a standards approach would determine otherwise, then works are not undertaken and dam safety money is invested elsewhere.

This does not mean that work will not be taken at some time in the future (“never say never”), but it appears that there will be no action unless the risk situation or guidelines change.

The Public Protection Guidelines document does not include background on how the Tier 1 guideline was constructed, nor any indication as to whether the public had input into the guidelines. However, it is understood that whilst there was no public input into the guidelines, Reclamation do have public input once it is determined that risk reduction works are warranted. The likelihood of loading, dam response and consequences are all provided to the public to highlight critical conditions that require remedial works, but not in comparison to any risk threshold.

10.4 Washington State

10.4.1 Use of Risk Assessment[51]

The State Regulator for dams, Washington State Dam Safety Office (DSO) uses risk concepts as part of their dam safety program. The methodology was developed to meet the competing needs of providing consistent dam safety across the State whilst working with limited resources. Risk processes were seen as being useful, but QRA for every project was not feasible. An approach was developed that uses risk concepts and procedures in a standards-based framework.

A concern of the DSO was that applying strict standards design events would result in an unbalanced level of public protection across the State. The primary driver here is that the probability for probable maximum precipitation (PMP) and maximum credible earthquake (MCE) estimates vary considerably with geographic location. For example the AEP of the PMP can vary from 10^{-6} to 10^{-9}. There was also recognition that the use of PMP and MCE as design loading standards does not result in zero risk, nor does it recognise differences in consequences between sites.

A process known as the Design Step Format is used to take account of the desire to achieve balanced protection across the State and incorporate the extent of consequences into design. The format is shown in Figure 6.

To include public protection into the design step process, benchmarking was undertaken against levels of safety provided by other engineering disciplines, Government regulations and risks that the public are exposed to ordinary life. Use was also made of "back calculations" of codes used by the Department of Energy in setting performance goals for its facilities. This resulted in life loss numbers being set to design steps through each design step probability. If plotted on a societal risk curve the results are conservative in comparison to similar guidelines prepared by other organisations.

Design Step	Exceedance Probability	Consequence Rating Points
1	1 in 500	<275
2	1 in 1,000	275-325
3	1 in 3,000	326-375
4	1 in 10,000	376-425
5	1 in 30,000	426-475
6	1 in 100,000	476-525
7	1 in 300,000	526-575
8	1 in 1,000,000	>575

Figure 6
Washington State Design Step Format[51]
(Note that there is a tenfold increase in protection for every two step increase.)

In order to select the design step level, a consequence rating system was developed to take into account consequence categories (Figure 7).

Consequence Categories	Consequence Rating Points	Indicator Parameter	Considerations
Capital Value of Project	0-150 0-75	Dam Height Project Benefits	Capital Value of Dam Revenue Generation or Value of Reservoir Contents
Potential for Loss of Life	0-75 0-300 0-100	Catastrophic Index Population at Risk Adequacy of Warning	Ratio of Dam Breach Peak Discharge to 100 Year Flood Population at Risk Potential for Future Development Likely Adequacy of Warning in Event of Dam Failure
Potential for Property Damage	0-250	Items Damaged or Services Disrupted	Residential and Commercial Property Roads, Bridges, Transportation Facilities Lifeline Facilities Community Services Environmental Degradation from Reservoir Contents (Tailings, Wastes)

Figure 7
Washington State
Numerical Rating Format for Assessing Consequences of Dam Failure[51]

Utility curves and rating tables are used to implement the system. For example, a utility curve is used to determine consequence-rating points from the population at risk. The points system has been calibrated to ensure that the life loss guideline is met in relation to annual exceedence probability (AEP) for loss of life.

Design loading levels are derived from magnitude frequency relationships. In relation to flood loading, a conservative approach is taken for new dams, whilst parameters closer to the mean are used for existing dams.

Seismic loading is more problematic for the DSO, since recent work has identified Mw 9 earthquakes with relatively short return periods. This could double the acceleration levels used for dams design on the west coast. However the probabilistic method is still used, albeit at mean values of acceleration. The DSO considers that further advances in the science will result in lower variance to estimates. When available, previous studies will be revisited.

For static loads such as seepage, redundant design procedures are used for new dams and qualitative assessment is used to estimate the probability of failure for existing dams.

The DSO considers that since the approach was implemented in 1990, it has been successful in providing an adequate level of protection against failure between projects across the State and to prioritise compliance efforts. 40 of the 46 dams identified under the National Dam Inspection Program prior to 1990 have been repaired and 78 of an additional 101 dams identified as unsafe since 1985 have been repaired.

10.4.2 Comments on Washington State Procedures

The methodology used by Washington State is based on a simplified risk assessment system. It implicitly includes societal risk guidelines and attempts to provide a consistent level of safety for similar dams in terms of the consequences of failure across the State. The methodology is also used to prioritise the efforts of the DSO.

The State does not provide any funding to owners for upgrades, but does undertake most of the investigative studies. They have found that this has been a useful tool in dealing with owners as the owners can use the data in supporting cases for upgrading works.

The DSO arranges for briefing sessions with the affected populations where there are severe deficiencies at an upstream dam. Emergency action plans are required for all dams at which there potential for loss of life. The owner is responsible to prepare the plan and get a sign off by the County authorities for the plan.

The guidelines for the design step format are not directly referred to in the legislation, but the legislation provides for the establishment of guidelines for dam safety. The acceptance or otherwise of guidelines is at the State Government Department level.

The State of Montana also has elements of a risk-based approach to dam safety. At least flood capacity is determined by loss of life estimates at each site. The methodology was developed in conjunction with public meetings and a stakeholder reference group.

Both Washington and Montana States have their dam safety decision making criteria available on the Internet.

10.5 Utah

10.5.1 Use of Risk Assessment

A risk-based process is used to prioritise the efforts of the Utah State Dam Regulator, the Dam Safety Section, but not to determine the extent of remedial works.

The prioritisation process is a point scoring system based on Utah dam failure statistics[52]. Dam elements are rated from 1 to 5, then multiplied by a factor to give a score for that element. Scores are added, then multiplied by the "humans at risk" score to give the "Total Risk Score"

The elements and factors used are shown in Figure 8:

Dam Element	Score	Factor	Total Failure (0 to 155)	Humans at Risk (1 to 5)	Total Risk (0 to 775)
Spillway	1 to 5	10			
Guard Gate	1 to 5	2			
Piping	1 to 5	10			
Slope	1 to 5	4			
Seismic	1 to 5	5			

Figure 8
Utah State Dam Safety Priority System[52]

10.5.2 Comments on Utah State Procedures

Utah State has 180 dams classified as high hazard. It is required that emergency action plans be developed for all high hazard dams and owners are encouraged to test the plans.

The State also provides grants for at least 80% of the cost to upgrade dams owned by mutual irrigation companies.

10.6 Utah State University and RAC Engineers and Economists

Dr David Bowles, Professor of Civil and Environmental Engineering at Utah State University together with RAC Engineers and Economists have played and continue to play a significant role in the development of risk based approaches to dam safety.

They have undertaken considerable work within the United States and Australia over many years, in particular in applying the Portfolio Risk Assessment process and are currently working with the Corps of Engineers in demonstration projects using risk analysis.

In their 1997 paper[53], Bowles et al point out the benefit of risk management in enhancing dams management. "When properly implemented, it can result in a more rapid and more cost effective achievement of risk reduction at aging dams. This approach (risk enhanced approach) seeks to a) develop a thorough understanding of the dam safety risks, and b) explore the options and provide a basis for managing these risks in the context of the owner's business."[54]

The paper points out the benefits of risk identification, exploring options, justifying and prioritisation of actions.

10.7 World Bank

From 1991 to 1999, the World Bank provided assistance for a Dam Safety Assurance and Rehabilitation Project in India. The objectives of the Project were to improve the safety of selected dams in the project states through remedial works, installation of basic safety facilities and strengthening the institutions of the Borrower and the project states responsible for assuring dam safety. This was the first World Bank project directed entirely at dam safety. ICOLD standards were followed for the project.

The scope of the project covered four states (Madhya Pradesh, Orissa, Rajasthan and Tamil Nadu) and remedial works on 33 dams.

Whilst initial works were not prioritised on a risk basis, draft risk guidelines were prepared under the project and are being finalised through the Indian National Committee on Dam Safety. Perhaps not surprisingly, given the varying worldwide views on risk assessment, there are some varying views within the Indian dams community regarding the use of risk assessment, even in a prioritisation role.

10.8 US Army Corps of Engineers

The US Army Corps of Engineers (the Corps) have responsibility for a total of 569 dams in the United States. Of these dams, 407 are embankment dams and 162 concrete. Of the embankment dams, 356 are high hazard, 36 significant and 15 low hazard.

A fundamental role of the Corps in relation to dams is to provide flood control works to save lives. The nature of flood control dams results in a peculiar dam safety situation. That is that a high proportion of the Corps embankment dams have not experienced “first filling” to spillway flows. From a total of 243 high hazard ungated dams, only 41 have ever spilled and record high pool levels have only been over relatively short durations[55].

The Corps is engaged in a five-year research program into the use of risk analysis for dam safety. Current views are that the use of risk analysis seems promising for prioritisation of works and that it may be used to support conventional decision making. At least one demonstration analysis has been completed and I believe that another is underway.

Risk analysis is used for decision making for navigation structures where loss of life is not an issue. The program is primarily focussed on mechanical and structural components and is used to provide economic justification of projects and apportion costs between stakeholders.

A paper on risk analysis for hydrologic risk prepared for the Corps[56] contains some detailed commentary in relation to the use of risk assessment. The report recognises the challenge of providing levels of safety for large dams that recognise the trade-off between costs and benefits. Also, that “Every dam safety decision is an implicit decision about the allocation of resources in society”[57] and “Neither the deterministic method nor the probabilistic method really attempts to efficiently allocate resources in the dam retrofit situation.”[58]

In the paper, recognition is given to the “rational and responsible position”[59] of using quantitative risk assessment to balance risk reduction costs with consequence reduction. However, there is not a recommendation to replace traditional methods with risk assessment, but to use risk assessment as an aide in the decision making process. It appears that the authors recognise the benefits of risk assessment and believe that there should be a “move from the use of implicit risk associated with such a deterministic or selected worst-case design standard to a policy determined by a reasonable and explicit risk target”[60], but consider that further development is required.

10.9 California

Dam safety regulation in California is strongly standards based. Following the failure of St Francis dam in 1928, legislation was strengthened, providing for supervision over non-federal dams in the State. Following failure of the Baldwin Hills dam in 1963, the legislation was amended to include offstream storages. The legislation provides for new dam or existing dam modification approvals, supervision of works and operation and maintenance.

Dams covered by the regulations are those 7.6 metres or more in height and have a capacity of $60*10^3$ m^3 or more.

An interesting application of risk assessment was applied to the Eastside Reservoir Project. The project consisted of the construction of three dams to form a pumped storage for urban supplies with a capacity of $990*10^6$ m^3 for the Metropolitan Water District of Southern California. The dams of the project represent the largest earth and rock fill reservoir project in the United States, with a total embankment volume of over $84*10^6 m^3$. The project cost US $2 billion.

The methodology was undertaken by Woodward-Clyde consultants and published in 1996[61]. The methodology was based on a logic tree approach where “the occurrence of the event is decomposed into component events whose probability have a better chance of being estimated using analysis, available data, or judgement of a panel of recognised experts.”[62] The method was seen as providing an improved understanding of system performance of the dam as well as an estimate of probability of failure of the dams.

The analysis resulted in an Estimated Range of Mean Annual Probability of Failure for the two main embankments of 10^{-7} to 10^{-9}. It was considered that the results were consistent with the conservative design adopted, the controlled filling period, detailed testing and monitoring and the small ratio of drainage area to surface area. Whilst the degree of influence of expert judgement on the result was recognised, it was felt that since the results were one to three orders of magnitude lower than threshold levels of “acceptable risk”, they provide assurance that the risks would be sufficiently low even if the subjective probabilities were to increase.

11. CANADA

Cheakamus Dam
(British Columbia Hydro and Power Authority)

11. CANADA

11.1 Regulations

New dam safety regulations have recently been introduced. They are based on downstream consequence estimates considering loss of life, economic and social loss and environmental and cultural losses. Under this system dams are classified as rating either very high, high, low or very low. These ratings are then used to specify particular requirements for each rating classification. For example, for the requirement for emergency plans, operation and maintenance manuals and dam safety reviews.

The regulations are non-technical in that specific standards are not stated.

11.2 British Columbia Hydro and Power Authority

British Columbia Hydro and Power Authority (BC Hydro) is the third largest electric utility in Canada and a Crown corporation of the Province of British Columbia. More than 90% of the electricity generated by BC Hydro is hydroelectricity with a system capacity of 10,000 MW from 30 generating sites. Six generating facilities on two major river systems, the Columbia and Peace, generate 75% of total capacity. Revenue for the year ending 31 March 1999 was CDN$3,000M.

BC Hydro have responsibility for 61 dams at 42 sites. Over CDN$150M has been expended on dam safety improvements since the mid 1980's.

11.2.1 Use of Risk Processes by BC Hydro

There has been significant development in dam risk management processes at BC Hydro since 1997. The development includes a changed approach to risk assessment, resulting in the "Proposed BC Hydro Tolerable Risk to Life Criteria", which were never adopted by the organisation, becoming obsolete. Those criteria should therefore no longer be quoted.

The new dam safety decision-making framework includes consideration of:
- Conformance to authoritative good practice.
- Regulatory requirements.
- Corporate values.
- Social expectations.
- Quantified risk.

BC Hydro believe that risk regulation for dams is not as developed as risk regulation in other hazardous industrial activities and that the framework takes account of this, whilst also ensuring that the process is consistent with established principles of industrial safety management.

In relation to quantified risk analysis, there is a consideration that in most cases, quantification of the probability of failure will include subjective estimates. Therefore, it concludes that it becomes necessary to ensure the meaning of the estimated values is clearly understood and that this understanding directs how the results of the analysis can be appropriately used.

Regarding risk assessment, there is an increased emphasis toward individual risk. Whilst still considering societal risk, the 'risk to individuals' receives much greater emphasis than previously. Measurement against risk criteria - either individual, societal or economic - follows an approach of the risks being "unacceptable" above specified limits and to be reduced to an ALARP condition below those limits, rather than being "tolerable".

For measurement of an ALARP condition, the concept of 'gross disproportion' is employed. In the UK, the Health and Safety Executive (HSE) says that this is achieved where there is a 'gross disproportion' between the effort to control risks further and the risk reduction that would be achieved.

BC Hydro's re-formulated approach to catastrophic risks posed by dams, although independently developed, aligns with the principles set down by the HSE in its discussion document 'Reducing Risks, Protecting People'[3]

In this way efforts are directed at "striking a balance between the need to protect against the risks and the needs of society for the benefits generated by the dams"[63], with recognition that an owner cannot meet this balance without consultation with the relevant stakeholders.

BC Hydro have a risk based scheme for prioritising "investigations of actual or potential deficiencies identified through routine surveillance and/or periodic dam safety reviews" called "PREP"[64]. A summary of the approach is given below. However, those wishing to gain a full understanding of the methods are referred to the paper and, of course, to BC Hydro to ensure that any fine-tuning undertaken by the organisation is known.

Non-conformance ratings for actual performance deficiencies are assigned on the basis of a 10 point system for normal load deficiencies and 5 point for unlikely load deficiencies. For perceived performance deficiencies ratings are assigned on a 1 to 5 point basis for normal loading and between 0.5 to 1.0 for unlikely loading, if the dam safety engineer expects the deficiency to be confirmed on investigation. If the dam safety engineer considers that the deficiency will not be confirmed, scores of 0.1 to 0.5 are allocated if it is unlikely to be demonstrated one way or the other, and 0 to 0.1 if it is likely to confirmed not to be a deficiency. Procedural deficiencies are assigned a rating between 0.0 and 0.5.

"Performance deficiencies" are based on performance comparison to the requirements of the Canadian Dam Safety Guidelines. "Procedural deficiencies refer to inadequacies in the testing, emergency preparedness plans or other similar dam safety activities" under the same guidelines.

The non-conformance ratings are finally summed and multiplied by $10^{\text{consequnce category}}$ to produce an importance coefficient.

BC Hydro is trialling the methodology and intend to adjust it as necessary as more experience is gained and it can be benchmarked over time.

The interface between prioritisation and periodic Dam Safety Reviews is the FMEA/FMECA (Failure Mode and Effect/Criticality Analysis) studies that the organisation has introduced into the Dam Safety Review process. These studies provide information in relation to identification of potential deficiencies and provide assistance to the dam safety engineer in judging the rating of those deficiencies.

The FMEA process is seen by BC Hydro as forming "a sound basis for qualitative and semi-quantitative analysis of risk" and as having the "key benefits of transparency and auditability".[65] It is also seen, when developed further to a FMECA as "providing a sound basis for prioritising corrective or remedial actions"[65]. However, it must be kept in mind that the organisation considers this type of analysis requires a considerable effort to be undertaken properly for these purposes and is not a "quick and dirty" analysis – "Since the analysis is required to first identify all significant potential failure modes and then identify all compensating provisions, FMEA/FMECA often requires a great deal of time and a very significant resource commitment."[65]

With FMEA, the dam is typically divided into components and the function/s of each component identified. On a worksheet basis, the potential failure modes for each component are identified. The evaluation of results may lead to identification of deficiencies that require remedial works, or identify a need for further investigations or monitoring through new or improved instrumentation.[66] The organisation is particularly interested in applying strategic monitoring and surveillance to more fully understand dam performance and then to use that information to set performance bounds on measurements as a risk management strategy at least in the short term whilst long term strategies are developed.

Criticality is introduced by assigning ratings for failure mode initiation, progression and consequences. "At different levels of criticality, decisions are required to distinguish between those levels of risk that require: immediate action to mitigate risk, a phased approach to understanding and managing risk, dealing with issues as and when the opportunity arises and finally, accepting the risk and not taking any further action."[66]

Also, "Application of these principles is entirely consistent with traditional dam safety practice – Careful application of the process results in entirely defensible risk based dam safety decisions – all dam safety investigations are some form of risk analysis – all dam safety decisions are some form of risk assessment."[66]

11.2.2 Comments on BC Hydro Risk Processes

It was concluded that BC Hydro intends to use a three level approach to risk analysis. The first is FMEA/FMECA to prioritise dam safety remedial works or to identify the need for further information, the second is in prioritising dam safety investigations ("PREP"), the and the third is to undertake detailed probabilistic analysis if further detailed understanding of a particular issue is required.

12. CONCLUSIONS

12.1 Introduction

Risk analysis is a methodology aimed both at estimating the probabilities of component or system failure events and the magnitude of the resulting consequences. “Risk” then being defined as the product of the probability and the consequence. Risk Analysis is employed in several Countries for the purpose of assisting in decision-making for the safety of industries with potential affects on public safety. The early development of techniques for analysing risks to public safety was led in the main by the United Kingdom, the Netherlands and Hong Kong. These developments were directed toward the chemical, nuclear and offshore oil industries and focussed on the risks posed by low probability, high consequence events.

Risk assessment is the process of assessing what actions are necessary to address the outcomes from a risk analysis. For this purpose, criteria defining what levels of risk may be acceptable can be used. For events leading to loss of life, reference is made to individual and societal risk guidelines.

12.2 Risk Analysis for Dams

Typically, those practitioners favouring the use of risk analysis as an aide to normal dam safety practice point to the benefits of improved understanding of dam behaviour and its assistance in providing a basis for the prioritisation of dam safety efforts at or between dams.

Over the past decade, activity in the development and use of risk analysis techniques for the dams industry has accelerated and become more widespread. The status of risk analysis for dams in the Countries visited follows.

In the United Kingdom some dam owners are using a qualitative or semi-quantitative failure modes and effects type of risk analysis (FMEA), sometimes including the criticality of failure events (FMECA). These analyses are used to prioritise investigations and works. Quantitative risk assessment (QRA) is not used.

In France, some work is being undertaken in trialling the various methodologies, but the regulatory scene is set to a standards based approach.

In the Netherlands, QRA techniques are being developed for the consideration of dyke safety and have been used for the design of at least one major flood control structure at Rotterdam.

In Norway, several QRA’s have been undertaken, in the main without detailed consideration of consequences. New regulations are being introduced which will allow the consideration of risk assessment as part of dam safety analyses, providing that the resulting risk level is no higher than that implied by the regulations.

In Sweden, both FMECA and QRA techniques are being trialled.

In the United States the scene is mixed. There are two main self-regulating Federal dam owning Agencies, the United States Bureau of Reclamation (USBR) and the Corps of Engineers. Reclamation use QRA as a key decision making tool, whilst the Corps are trialling QRA. The main Federal regulators, the Federal Energy Regulatory Commission, relies on a standards based approach.

State regulation within the Untied States is mainly directed toward a standards approach. However, Washington State uses a simplified QRA process, and Montana have recently moved to a risk based approach in relation to spillway size.

In a recent World Bank dam safety project in India, draft risk guidelines were prepared and are being finalised through the National Committee on Dam Safety.

In Canada, BC Hydro is using FMEA, FMECA and QRA, where necessary, to support their dam safety program.

In Australia, all forms of risk assessment are being used to assist in gaining an improved understanding of dam safety.

12.3 Risk Criteria for Dams

To assist in decision making, the risk determined from analyses can be measured against criteria indicating what are considered to be reasonably acceptable levels of risk. For loss of life considerations, societal and individual risk criteria are used.

Within the world dams industry, the development and use of societal and individual risk criteria is somewhat controversial.

Of organisations from the Countries visited, only the USBR explicitly use risk criteria to establish acceptable levels of dam safety. Washington State's regulations implicitly include acceptable risk concepts and Montana State have included the concept in their new regulations for spillway size.

The main arguments raised against the use of loss of life criteria for dam safety can be summarised to three issues.

Firstly, the wide confidence limits on probability and consequence estimates result in too much uncertainty to allow sensible measurement against criteria. Secondly, because "judged" probabilities are required for some elements of the analysis, it is not acceptable to compare the resulting calculated risk to acceptable risk to life criteria. Thirdly, the conflicting philosophy of whom should decide what is an "acceptable" risk.

A further argument from some relates to the degree of sophistication of the risk analysis processes used within the dams industry at the moment and whether it compares well to the practices used in other high consequence, low probability industries that compare analysis results to acceptable risk criteria.

However, the degree to which the same arguments apply to the past and current use of loss of life criteria in other industries is open to question.

Proponents of the use of risk criteria point to society’s limited resources to deal with risk reduction and the need to apply those resources in a logical and equitable way. It does not appear to be reasonable, for example, to accept a certain level of risk from a chemical or nuclear facility on the basis that the benefit is worth the risk and then to apply standards which may provide a much greater level of safety for a nearby dam. The question becomes one of how much is society prepared to pay for dam safety.

Others say that the argument relating to “who decides what’s acceptable” could be applied equally to current standards. That is, if standards are to be used, shouldn’t those who are exposed to the residual risk, and it is generally agreed that there is some residual risk, decide if that is acceptable?

Since there remains residual risk after the implementation of standards based on hazard category, the process could be described as the application of a form of risk assessment. Whether the process used to determine the hazard categories is a “reasonable” way to distribute risk and is acceptable to the public exposed to the risk is not usually questioned. It does not seem reasonable to question the use of risk criteria on the grounds of due process, but not to question the standards that are being followed. Standards could be questioned either in terms of the magnitude of the inherent risk, the concept of “acceptable risk” that is implicitly included or whether the standard has been established using reasonable process.

An issue not often raised is the differing levels of public safety that can occur across a jurisdiction through the application of standards. This is based on the geographic variance in the probabilities of probable maximum precipitation and seismic hazard. The application of standards based on these events can result in varying levels of risk across a geographic area. Furthermore, whereas the incremental consequences from an earthquake-induced failure are commonly in excess of those from a flood-induced failure, the probabilities of the flood events used in design are typically one to two orders of magnitude less than the earthquake probabilities.

12.4 Summing Up

Over the past few decades, major dam failures, at least in the developed countries have been rare. This has had an influence in dams occupying an apparently low, or no risk compartment in the minds of the public and politicians. Whereas the development of risk processes for other industries over the past few decades has been driven by either catastrophic accidents or public dread of a process, dam safety has not been exposed to the same combination of pressures. Certainly failures have occurred, but the political outcomes have been directed toward regulation and the use of standards, without questioning of the level of residual risk that remains once standards are applied. There appears to be poor public understanding of the potential consequences of a dam failure, as there is in general of the potential energy in elevated stored water.

Where the costs of dam safety are not obvious to the public and owners can generate funding for upgrading works without substantially affecting the price of the product created from the stored water, there is a tendency for regulators to insist on a standards approach and not contemplate risk processes, since there is no particular driver to take any other approach. However, the situation is more problematic for owners of water supply dams, particularly rural water supplies, where dam upgrade costs can have a dramatic affect on the price of water supplied from the dam. The political influences, usually dormant within the industry until the costs are known and the argument of who should pay is raised, are quite rightly, suddenly active and asking, “Is this a reasonable investment compared to the other competing priorities in society?”

The current efforts in research and development in the use of risk analysis and assessment appears to be undertaken, with a couple of exceptions, by a relatively small number of dedicated, but underfunded, experts and interested owners. Whilst there is a growing recognition of the cost of dam safety, without a complementary recognition of the risk posed by large dams in comparison to other high consequence, low probability industries, it is unlikely that the funding situation will improve.

As new dam construction has slowed in the developed countries, efforts to review the safety status of existing dams has grown. This is resulting in a large body of dam safety information becoming available over a relatively short period of time. As the accumulated cost estimate to undertake standards based remedial works continues to grow, there will be increasing pressure from stakeholders and Government to justify the expenditure. It is unlikely that reference to standards alone will be acceptable, unless the basis for those standards can be justified.

Finally, in the absence of any other methodology, risk analysis, whether through qualitative or quantitative methods, provides a valuable tool for understanding dam behaviour, assisting in the definition of strategic surveillance, identifying interim risk reduction measures and for the prioritisation of investigations and works to reduce risk.

The current arguments against the use of risk criteria determining what is appropriate for the ultimate safety level for a dam are recognised. However, efforts to improve these procedures are needed so that policy makers can be provided with the technical information necessary to reach objective decisions about the investment of societies limited resources toward dam safety.

Ultimately, the issue of what is safe enough for society at a particular dam, will be determined by society and their representatives, taking into account many factors of which the risk posed by a dam is one element. Therefore the rigorous application of a pass or no pass criterion is not an issue. What is at issue is a means by which an understanding of risk can be communicated in a meaningful way and how the risk compares with other risk exposures.

13. RECOMMENDATIONS

1. Risk analysis processes continue to be developed and used as a tool to improve the understanding of dam behaviour, identifying surveillance requirements and to prioritise investigations and risk reduction works.

2. Quantitative risk analysis processes currently developed for dams be benchmarked against those processes used in industries where the outcomes of such analyses are compared to risk criteria as part of the risk assessment process.

3. The outcomes of quantitative risk analysis benchmarking be used to determine what further research and development may be required for quantitative risk analysis for dams to be used as part of the process to establish acceptable safety levels for dams.

4. Regulators, in conjunction with owners, work with Government to advance the concept of acceptable risk criteria, encourage investment in development and engage stakeholders in the process of risk assessment.

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