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RISK ASSESSMENT – NEW TRENDS IN GERMANY

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INTRODUCTION

Dams have been a part of society for more than 5000 years. They are built for a number of purposes, e.g. flood control, drinking water supply, hydropower or even recreation. Just like all technical buildings they impose a potential risk to failure. Besides the natural hazard war time situations have to be taken into account. For example during World War II a number of dams have been destroyed. In Germany one of the biggest disaster was the failure of the Möhne Dam in 1943. Due to intensive bombing the dam failed while the reservoir was nearly full. The resulting flood wave caused 1200 death and destruction of the downstream settlements (figure 1).

The acceptance of potential risk of technical buildings is subject to change within society. While at the beginning of this century and in some cases even today society believes in the safety of technology, major disasters lead to a change in the acceptance of risk. Especially in the case of dams a frequent question is *'How safe are our dams?'*.

Basically two opinions can be viewed, the traditional and the risk orientated one. Traditionally dams are considered safe, because they have been build very carefully according to high technical standards, so there is no risk of failure. On the other hand all man made structures have a potential risk that has to be evaluated, assessed and managed.



Figure 1: The failure of Möhne Dam in 1943 (RUHRVERBAND, 1988)

In Germany the traditional opinion has been in favor. But the world wide discussion about dam safety has led to a change, so the risk of dams is no longer neglected. Consequently Risk Assessment has to be considered for German dams. This paper provides a brief overview on the state of the art of Risk Assessment. Based on the studied international approaches a Risk Assessment procedure for German dams has been developed. This procedure is applied to a test case, the Rursee. During the study it was found, that a lot of important data is missing for a complete Risk Assessment. The Risk of German dams is not known and has to be estimated. This estimated value could be taken into account only for a partial Risk Assessment. More detailed information on the German Risk Assessment and the test case for validation can be taken from the master thesis FALKENHAGEN (1999).

DEFINITION AND FRAMEWORK

For the Risk Management of dams or even other disciplines there are no definitions adopted officially. Therefore the development of internationally valid agreements is one major task of the Working Group on Risk Assessment of ICOLD. This paper is based on the definitions of ICOLD, but changes have to be made if national differences demand it.

The most important and also difficult problem is the definition of risk. According to ICOLD (1998) "Risk is the measure of the probability and severity of an adverse effect to life, health, property, or the environment. Risk is estimated by the mathematical expectation of the consequences of an adverse event occurring (e.g. the product of the probability of occurrence and the consequences) or, alternatively, by the triple of scenario, probability of occurrence and the consequences". Thus the risk depends on the probability of failure as well as on the consequences, even if the probability is very low.

Figure 2 summarizes the Process of Risk Management and illustrates the individual steps (Risk Analysis, Risk Assessment, Risk Management) as well as their integration in the Processes (Process of Risk Assessment, Process of Risk Management).

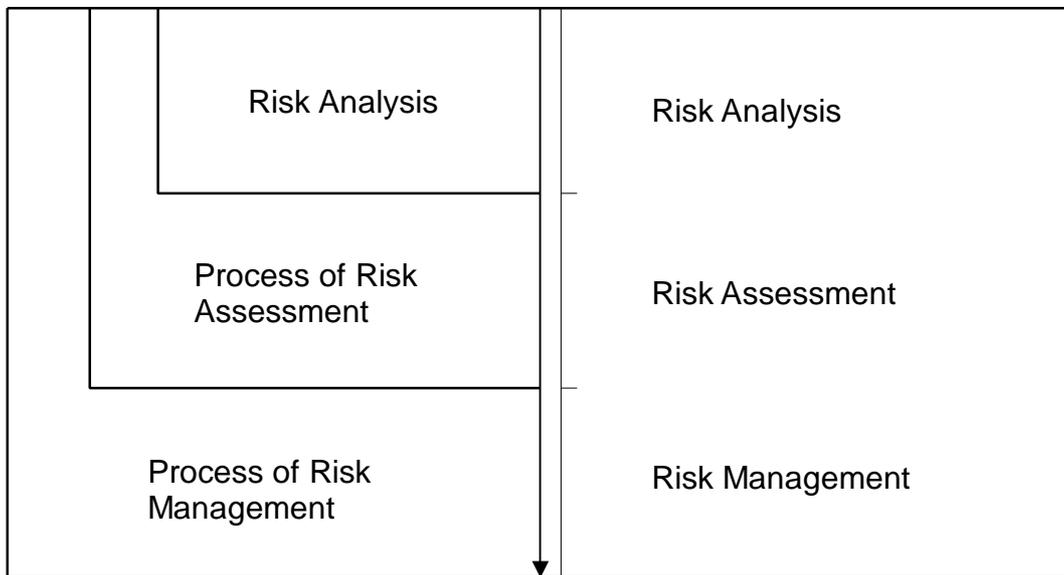


Figure 2: Process of Risk Management

The risk related terms such as Risk Analysis, Risk Assessment and Risk Management can basically be taken from figure 3. FELL & HARTFORD (1997) present the Process of Risk Management based on the Canadian Standard Association.

The Risk is evaluated either qualitative or quantitative in the Risk Analysis. For the quantitative estimation of Risk the probability as well as the amount of loss has to be determined. On the other hand, if the statistical basis is insufficient, experts and risk analysts can estimate and determine the Risk. The Risk Analysis is part of the Process of Risk Assessment as well as the Risk Assessment itself.

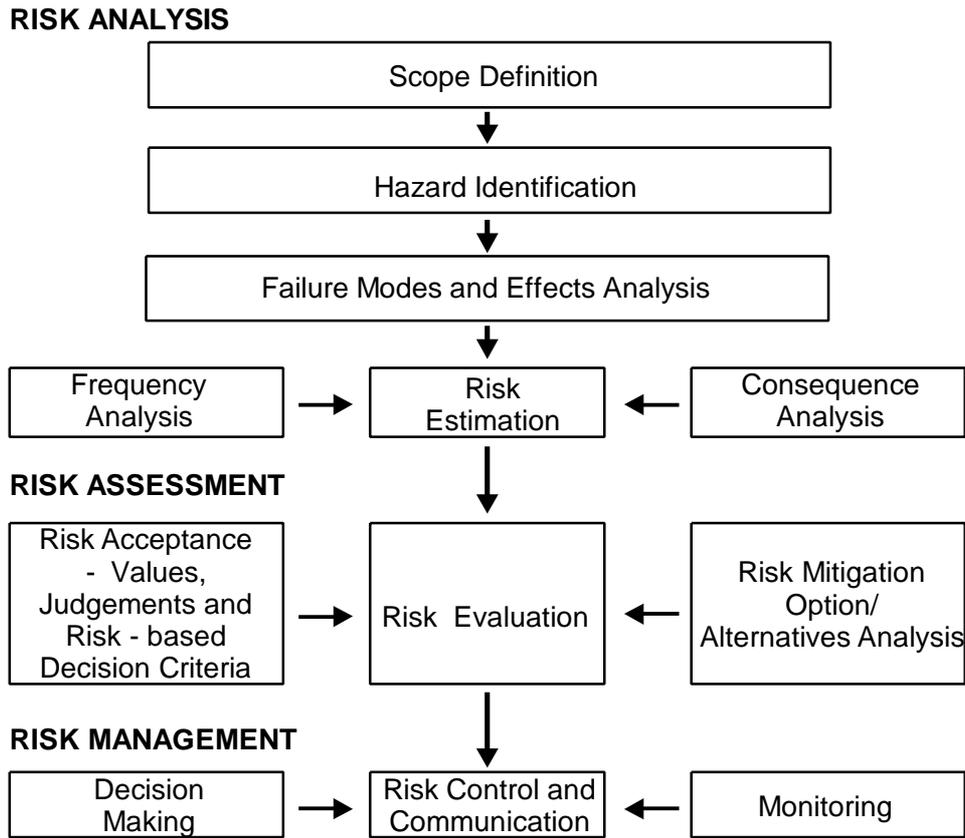


Figure 3: Risk Management Process (adapted from FELL & HARTFORD, 1997)

After the Risk Analysis the Risk is evaluated and thus the priorities for the Risk Management are determined. The Risk Assessment divides into three parts:

Risk Acceptance Risk Mitigation Risk Evaluation

One of the most difficulties lies in Risk Acceptance. The economic, environmental and cultural loss have to be taken into account. Especially the loss of life is a very important issue and the acceptance depends not only on society but also on population. For example Australia and Canada have poorly populated areas where dams might not always impose a risk to the population, while Germany is densely populated, so the loss of life is an issue for almost every dam.

ANCOLD (1998) or USBR (in RIBLER, 1998) have developed F-N Diagrams (F: Probability of failure, N: Number of fatalities) as criteria for Risk Acceptance (figure 4). Figure 4 proves that there are no homogeneous Risk Acceptance Criteria. For comparability reasons the original diagrams are placed in diagrams with the same scale. Not only the limits of the original diagrams differ but also the ranges of acceptable Risk. While Australia includes up to 10.000 losses of live if the probability of failure is low, the US have a limit of 200 losses. Risks are tolerable within certain limits and have to be reduced until they are acceptable by ALARP (As Low As Reasonable Practicable) Principle.

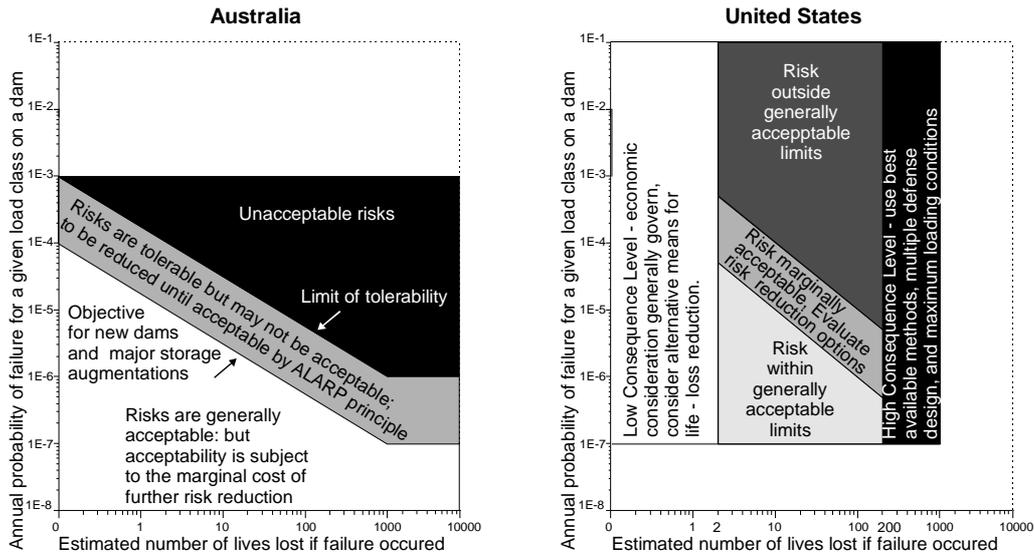


Figure 4: Risk Acceptance Criteria in Australia (left) and the US (right)

The acceptance of loss of life is very individual and depends on society. This is why Risk Acceptance is still discussed and a final general solution has not been found so far. If the Risk is not acceptable it has to be mitigated. Risk Mitigation comprised the reduction of probability of failure or the consequence. Possible approaches for Risk Mitigation are emergency planning, monitoring and surveillance, operation or constructional improvements. The Residual Risk has to be evaluated. The final part of the Process of Risk Management is the Risk Management itself. It is decision making for managing Risk, and the implementation, enforcement and reevaluation of its effectiveness. Monitoring can be part of Risk Management.

INTERNATIONAL TRENDS ON RISK ASSESSMENT

The Process of Risk Assessment is very unique and individual with a world wide variety of approaches. ICOLD has a committee working on Guidelines on Risk Assessment while the ICOLD-European Club is concerned with special European questions on Risk Assessment. In addition 1997 a workshop on 'Risk based dam evaluation' was held in Trondheim, Norway. The new trends are summarized in the Workshop Report Part 1 (1998) and Part 2 (1998), FRY (1998) and RIßLER (1998).

From all studied countries Australia is the only country with Guidelines on Risk Assessment. Canada has Dam Safety Guidelines which include guidelines on Risk Analysis as well as Risk Assessment. Most of the other countries include parts of the Risk Management Process within their dam safety guidelines, but the details vary. BOWLES et. al (1999) describe the situation in the US while OOSTHUIZEN & ELGES (1998) gives a detailed view on the experience with Risk Assessment in South Africa.

In Europe the state of the art on Risk Assessment shows a wide variety. Basically three groups can be distinguished (FRY, 1998). The first group recommends Risk Assessment for dams. For example Norway has regulations where Risk Analysis is proposed and established. Additionally reliable Risk Assessment techniques can be taken from coastal areas; e.g. the Netherlands have established risk oriented models and criteria for dikes. The countries comprising the second group established Risk Assessment on a research level. Sweden for example uses Risk Assessment as a tool for the 'most important weakness', but not for general application. A third group has established Risk Assessment for other industries, e.g. nuclear industry but is not ready to apply it for dam safety. Parts of the Risk Assessment Process are included in each countries' Dam Safety Guidelines. Germany belongs to the third group, with well adapted Risk Assessment approaches for the nuclear industry but only partial consideration in the case of dam safety.

The results of the world wide study show differences between the individual countries in many aspects of Risk Assessment and in the application of Risk Assessment. At first sight this is due to the different progress in development of Risk Assessment or the confidence with the technique. On closer inspection some fundamental explanations can be found.

It is apparent that one Risk Analysis cannot be universally applicable for all demands on dam safety. The obvious deviations in the Risk Analysis result from the different approaches to dam safety questions. The approaches and models can vary, depending on the type of dam, the cases of failure and the downstream situation. Some differences in approach refer to the behavior of the dam. For example the main aspect for concrete dams could be the structural reliability (Austria, Switzerland). Internal erosion (US, Norway, Sweden) requires a different approach, e.g. embankment dams. The operation of the spillway has its own reliability techniques as well, where human reliability and monitoring are taken into account (Netherlands, Germany). Other important differences in the approach to Risk Assessment are situated in the determination of the consequences. The uncertainties in the advance warning time can be the most important aspects (Australia, Canada, US, South Africa). They are less important for other countries, particularly for those countries with uniform geography and well established warning systems (Switzerland). Thus the determination of Risk has to take into account a number of unique factors.

Social, cultural and institutional habits indicate large differences, even if the concept of Risk and Risk Assessment is actually recognized. That can either promote or limit the use of Risk Analysis and Risk Assessment. One example are the Netherlands, where risk concepts are legally adapted and recognized in connection with flood control and dikes. Other countries (Switzerland, France, Great Britain) stay with conventional procedures for dam safety concepts which are based on well proved standards. Others (Canada, Australia, US, Norway) have some examples of applications on risk basis, but they proceed in a very complex way.

Another important aspect for the practice of Risk Assessment are the objectives and needs within one country. In some cases qualitative techniques (Great Britain) or the partial use of quantitative methods (Austria) are sufficient for the requirements of the respective countries. Higher requests have immediately led to the development of more complex structures with risk-oriented decision criteria (Canada, Australia). Many of the guidelines and recommendations (US, Australia, South Africa) serve for the understanding of the behavior of dams in order to meet direct measures of the risk mitigation at low costs.

RISK ASSESSMENT IN GERMANY

In Germany 272 (World Map, 1997) dams are higher than 15 m. Dams are built according to DIN 19700 Standards. Each German State has its own State Law of Water defining dams as subject to regulation by height and volume, e.g. for North-Rhine-Westfalia $h = 5$ m and $V = 100.000$ m³, so more dams as in the ICOLD register are existing. The technical standards that have to be applied are regulated in the State Law of Water.

On a research level Germany developed procedures for Risk Analysis including qualitative and quantitative evaluation of failures. In 1980 the German Federal Ministry for Research and Technology initiated a feasibility study for probabilistic oriented safety. The potentials and limits were discussed during the 1989 German Symposium on Dams (IDEL & RIßLER, 1989). Ever since risk based approaches to dam safety were rarely studied in Germany.

The traditional opinion on dam safety has been in favor in Germany. Germany puts a lot of effort into high standards for the construction and maintenance of dams. Consequently the possibility of failure has been neglected, so flood or emergency plans do not exist for any German dam. The only part of the Risk Management Process which is covered in Germany are the high standards in monitoring and surveillance.

The world wide discussion about Risk based dam safety leads to a new approach for German dams as well. Because of the cultural and legal difference it is impossible to use directly a Risk Assessment procedure from another country. The Risk Assessment procedure that is presented in figure 5 has been developed by the authors on the bases of other known procedures as well as taking into account the German questions.

Risk Assessment is part of the Process of Risk Management. The Risk, that was estimated in the Risk Analysis is evaluated in the Risk Assessment procedure. This was also presented in figure 2 and all Risk Assessment Processes have those fundamentals in common. Usually the Risk has to be determined either quantitative or qualitative before starting Risk Assessment. A lot of studies have been done for the quantitative determination of Risk and

especially on the modes of failure and effects. But also a qualitative estimation is quite common. While monitoring is part of Risk Management or Risk Mitigation in a lot of countries, it is part of the Risk Analysis in Germany and can be taken into account for the risk estimation. In Germany monitoring is well established for all dams and also enforced by law so it can be considered as a known value in dam safety.

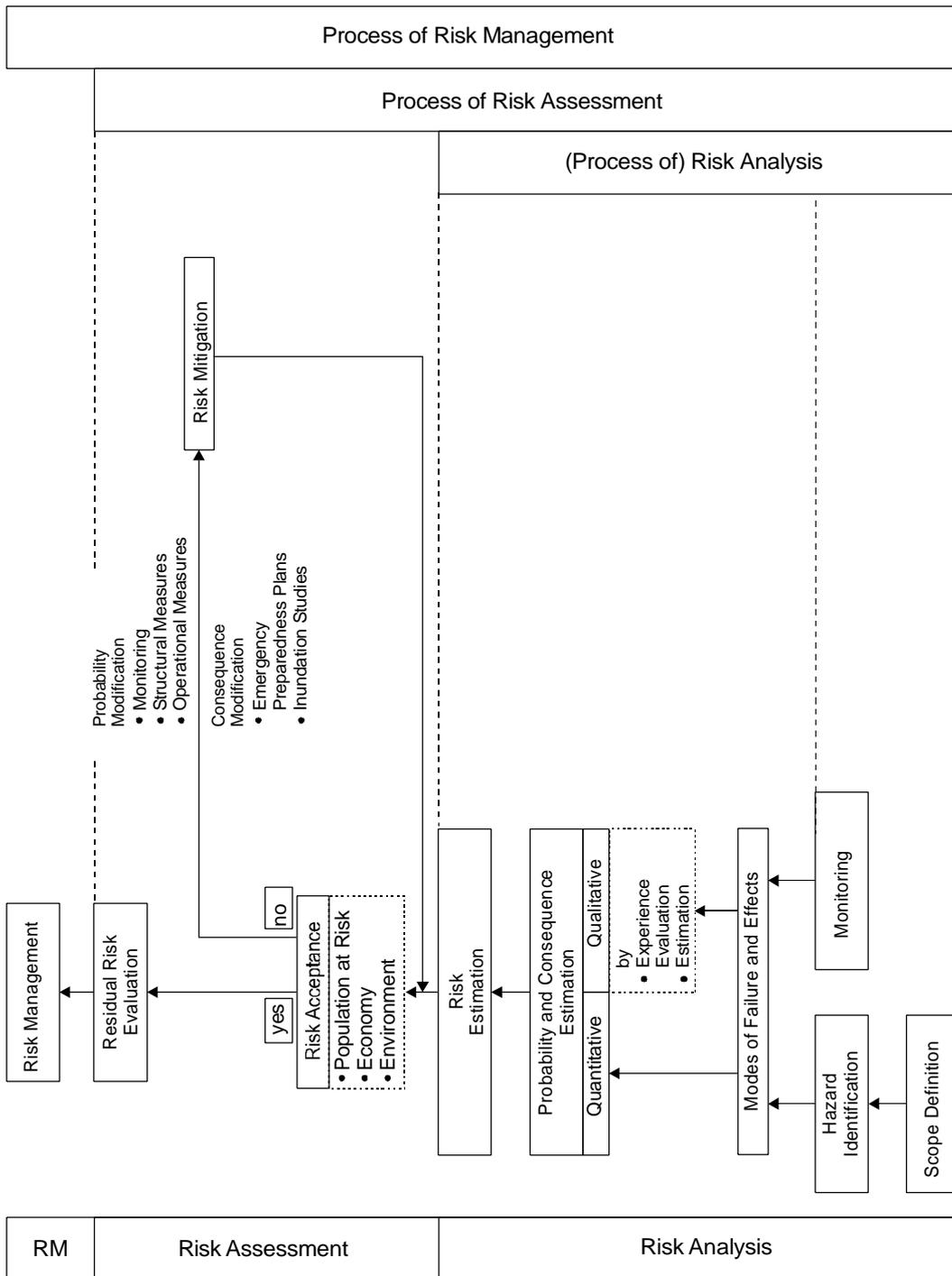


Figure 5: Risk Assessment Procedure for German Dams

The first step in Risk Assessment is the Risk Acceptance. This decision cannot be made only by engineers, but economist and sociologists have to be included. One possibility to check a Risk for acceptance are F-N-diagrams. Especially for the loss of live they can help to provide a first estimation. The US or Australian diagrams (fig. 4) cannot be applied in Germany because the acceptance of loss of live is very low. Therefore Figure 6 presents a possible diagram for Germany.

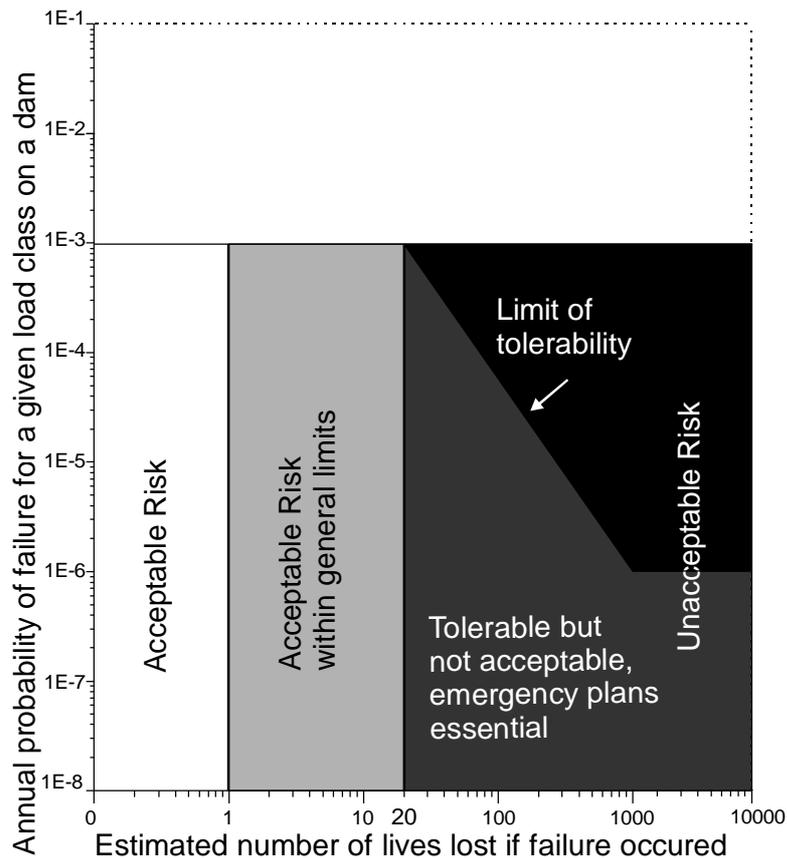


Figure 6: F-N-diagram for Germany

First of all it can be noticed that a Risk is only acceptable if no one dies. Taking into account the insurance measure for catastrophe vs. misfortune, a failure with less than 20 dead persons is acceptable within general limits. All other Risks are unacceptable. This does not take into account the probability of failure. Only within the area of tolerable but not acceptable Risk the probability of failure is considered. In this case emergency planning is essential and should be sufficient for risk mitigation. The range of the probability of failure is limited to 10^{-3} because of the capacity of the spillway, according to DIN 19700.

The limit of tolerability curve is subject to change for individual dams. The range of the number of fatalities depends on the number of endangered population and should be increased if necessary. The trend of the 'limit of tolerability' curve can only vary in the value where the slope changes. This value

depends for example on the number of people that can be evacuated in a limited time. The horizontal line is fixed to 10^{-6} according to IDEL (1986) for the totally unlikely Risk.

If the Risk can be accepted maybe including limited risk mitigation the residual Risk can be evaluated and managed. If the Risk is unacceptable it has to be mitigated. Since the Risk is the product of consequences and probability of failure these values can be reduced. Possible measures are extended monitoring, structural or operational changes, emergency planning, etc, which are still missing in Germany. For German Risk Assessment it is very important that the mitigated Risk has to be checked for acceptance again. The procedure has to be repeated until the accepted Risk can be evaluated and managed.

It is very important to notice, that all procedures (Risk Analysis, Risk Assessment, Risk Management) stand alone. Thus Risk Assessment can be done without a detailed Risk Analysis, if only the worst case – e.g. complete failure – is considered. Of course different failure modes and inundation studies have to be considered especially for risk mitigation. But Risk Assessment can be done without a detailed determination of Risk.

VALIDATION OF THE GERMAN RISK ASSESSMENT

For the validation of the German Risk Assessment Procedure the Rursee was chosen as a test case (figure 7). It is the second largest German reservoir with $V = 184.6 \text{ hm}^3$. The dam has a height of 68.5m and was build between 1934 and 1938 with an upgrading between 1955 and 1959. It has been built and maintained according to the North-Rhine-Westfalian Law of Water, for details see RETTEMEIER & KÖNGETER (1998).



Figure 7: Dam of the Rursee

The Risk of the Rursee is unknown, so before proceeding with the Risk Assessment the Risk has to be estimated. Since the main focus is the Risk Assessment, a qualitative approach was chosen. This is why the estimated Risk is an appraised value and should not be used for other studies. It was estimated only to proceed in this study and has to be proven in further research.

At first the probability of failure has to be estimated. FRY (1998) determines the probability of failure to 10^{-8} /year/dam since about 25 people died due to dam failure in the last 30 years. This value does not take the individuality of dams into account. RISLER (1998) describes the probability of failure for German dams according to "mit an Sicherheit grenzender Wahrscheinlichkeit ausgeschlossen" (with a degree of probability verging on certainty unlikely). IDEL (1986) reports a relation between verbal probability and an exact value (table 1). Thus the probability of failure for German dams in general would be 10^{-5} , which is chosen for the Rursee as well.

Verbal Probability	Quantitative Probability
Totally unlikely	$<10^{-6}$
With a degree of probability verging on certainty unlikely	10^{-5}
Unlikely	10^{-4}
Not impossible	10^{-3}
Possible	10^{-2}
Likely	$1-10^{-1}$

Table 1: Probability of failure verbally and quantitative (IDEL, 1986)

The consequences are the next step in Risk estimation. They cannot be estimated without a inundation study. Unfortunately for Germany inundation studies do not exist. For a first approximation a theoretical French dam break method was chosen. This method was developed by 'Centre Technique du Génie Rural des Eaux et des Forêts' (C.T.G.R.E.F., 1977) and has an estimated error of 40%. It is very useful for a first approach but should be treated very cautious. In this case an instant and total failure due to flooding with no warning time was chosen. Since only one effect was considered the estimated Risk is only a partial Risk, so only a partial Risk Assessment could be done.

Figure 8 presents the location of the Rursee and the downstream area which was studied.

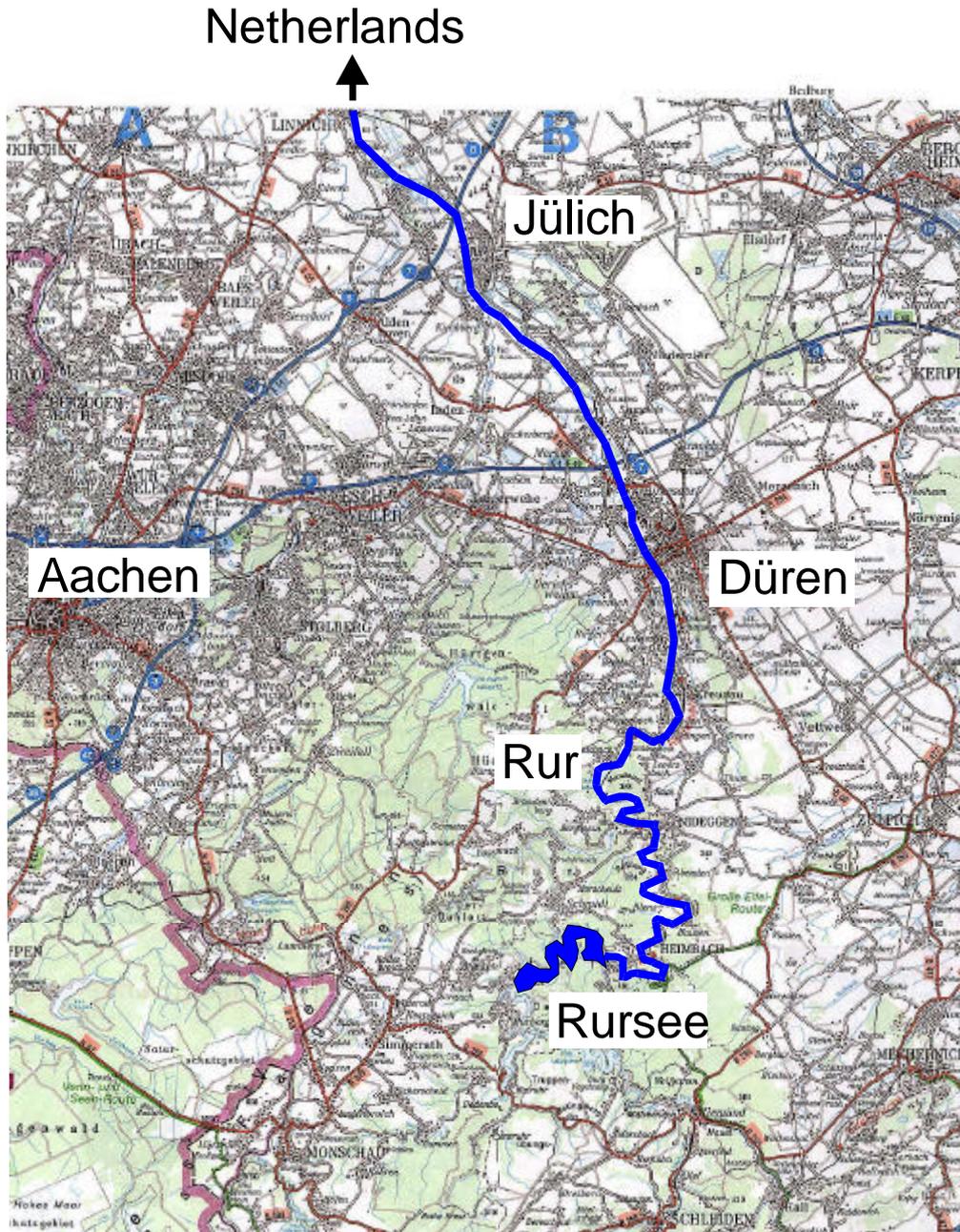


Figure 8 presents the location of the Rursee and the downstream area

The fatal affected population was roughly determined to 5.000 mainly from the City of Düren and Jülich. Since not enough information was available on the exact economic value of the region only the number of dead persons was taken into account to estimate the economic loss. For one person dying in a traffic accident 0.8 million € is the estimated value of economic loss for society in Germany (including education, work etc.) adding up to a total of 4 billion € in this case. This value is not a measure for cost-live relation.

Summarizing the probability of failure which is very low and the consequences which are very high both for the fatal effected population and the economic loss the qualitative Risk can be estimated 'very high'.

Even though the estimated Risk is a partial Risk taking only one effect into account the Risk Assessment can be done. First of all the Risk has to be checked for acceptance. Using figure 6 with a probability of failure of 10^{-5} and a fatal effected population of 5.000 persons the Risk is unacceptable. An evaluation of acceptance of the economic loss was not done. Following the next step in figure 5 risk mitigation is necessary. Possible measures are extended monitoring, structural or operational changes, emergency preparedness plans. Since monitoring and structural states in Germany have a very high standard additional improvements will be very expensive. The less cost intensive changes can be done either operational or most efficiently with emergency planning. After considering and executing those mitigation measures the reduced Risk has to be checked for acceptance and can be evaluated and managed if it is acceptable.

CONCLUSION AND OUTLOOK

The world wide discussion about Risk Assessment as a tool in dam safety leads to new developments in Germany. On the basis of known Risk Assessment procedures a new procedure was developed for German dams. Some important differences can be noticed. Monitoring and surveillance can be part of the risk mitigation as well as risk management. In Germany it is part of the Risk Analysis, because of its status and very high standard within dam safety. The Process of Risk Management divides into Risk Analysis and Risk Assessment. They can be treated separately so Risk Assessment can be done, even if the Risk Analysis does not include all the failure modes and effects. An estimated Risk, e.g. the worst case can be used for the Risk Assessment.

Risk Assessment comprises the acceptance, the mitigation and the evaluation of Risk. The acceptance of Risk is a very important issue and a lot of research economically as well as sociologically has to be done before it can be adapted in Germany. Even though the Risk can be very high a lot of risk mitigation measures are known. Especially in Germany a very useful tool are emergency plans. They are not adapted so inundation studies have to be done before they could be established.

The validation study proved that the developed Risk Assessment is valid for German dams. For a complete Risk Assessment a lot of information is still missing. So before Risk Assessment can be applied for German dams a lot of research has to be done especially for inundation studies and the acceptance of risk.

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SUMMERY

This paper provides a brief overview on the state of the art of Risk Assessment. Based on studied international approaches a Risk Assessment procedure for German dams has been developed. The Process of Risk Management divides into Risk Analysis and Risk Assessment which can be treated separately. The Risk Assessment comprises the acceptance, the mitigation and the evaluation of Risk. The developed procedure is applied to a test case, the Rursee. During the study it was found, that a lot of important data is missing for a complete Risk Assessment. Still the validation study proved that the developed Risk Assessment is valid for German dams.

RESUMÉ

Ce rapport donne une vue d'ensemble sur la situation actuelle de l'évaluation des risque en Allemagne. Basée sur l'analyse des approches internationales différentes, une procédure d'évaluation de risque pour les barrages en Allemagne est développé. Le procès de management de risque se divise en analyse et l'évaluation de risque qui peuvent être traité séparément. L'évaluation de risque se compose de l'acceptance, de la réduction et de l'évaluation des risques. Cette procédure developé dans cet rapport est appliqué à une étude de cas, le Rursee. En cours de l'étude on a remarqué qu'il manque encore beaucoup d'information pour une évaluation de risque complète. De tout façon, l'étude de cas prouve la validité pour les barrages allemandes.