RESCDAM

Development of Rescue Actions Based on Dam-Break Flood Analysis

Final Report
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APPENDICES

1 INTRODUCTION

1.1 General

The Grant Agreement No Subv 99/52623 was signed between the Commission and the Finnish Environment Institute on June 11, 1999. According to amendment no 1 (DG ENV 07/02/01, 801451) the operation ("Development of Rescue Actions Based on Dam-Break Flood Analysis project, RESCDAM") lasted for 22 months beginning June 1, 1999. Thus, the agreement period ended on March 31, 2001.The total project costs were € 861.332 the Commission's contribution being € 451.416. Other contributions came from the Finnish Ministry of Agriculture and Forestry, the Finnish Ministry of the Interior, the West Finland Regional Environment Centre, the Finnish Environment Institute and the partners mentioned below. The contact person in the Commission was Mr. Ernst Schulte (DG ENV Civil Protection and Environmental Accidents).

The RESCDAM project was co-ordinated by the Finnish Environment Institute.

The partners were: Enel.Hydro Polo Idraulico e Strutturale (Milan), EDF Electricité de France Laboratoire National d´Hydraulique et Environnement (Paris), the Laboratory of Water Resources at the Helsinki University of Technology, the Emergency Services College (Kuopio), Seinäjoki Fire Brigade (Seinäjoki), and the West Finland Regional Environment Centre (Vaasa, Seinäjoki).

The subcontractors of the project (consultants) were: Peter Reiter, M.Sc., PR Water Consulting Ltd. (Helsinki), Eero Slunga, Professor Emeritus (Espoo), Tomi Honkakunnas, Training Manager from the Provincial Rescue Association of Oulu and Heidi Lepistö, Dispatcher from the Emergency Response Centre of Southern Savo (Mikkeli).

The steering group of the project was:

Chairman: Markku Maunula, Senior Adviser, Ministry of Agriculture and Forestry
Members: Martti Kujanpää, Department Manager, West Finland Regional Environment Centre
Erkki Loukola, Chief Engineer, Finnish Environment Institute
Ilkka Manni, Division Manager, Finnish Environment Institute
Jyrki Paunila, Fire Chief, Seinäjoki Fire Brigade
Taito Vainio, Senior Adviser, Ministry of the Interior
Secretary: Timo Maijala, M.Sc., Finnish Environment Institute.

1.2 General objectives and plans of the project

The project work was divided into three sub-projects: 1) Risk Assessment (Analysis), 2) Dam Break Hazard Analysis and 3) Emergency/Rescue Action Planning. In addition to these sub-projects the International Seminar and Workshop was arranged on October 2-5, 2000 in Seinäjoki and a study visit to the Emergency Services College in Kuopio on October 1, 2000.

The main purpose of the RESCDAM project was to develop emergency action planning for dams. A dam break hazard (flood) analysis is a necessary aid for this. A risk assessment (analysis) was also included in the project work. The pilot project of RESCDAM was the embankment dam of the Kyrkösjärvi reservoir located in Seinäjoki in Western Finland. Because dams and especially consequences of a dam failure are quite similar in different countries, results and activities of the RESCDAM project should benefit EU and associated countries. Planned and realised measurable elements of the RESCDAM project results are presented in Chapter 7.

1.3 Authors of the final report

The authors of the final report are:
- Timo Maijala, Finnish Environment Institute (Chapters 1, 2, 4, 6 and 7)
- Mikko Huokuna, Finnish Environment Institute (Chapter 3)
- Tomi Honkakunnas, consultant (Chapter 5).

Appendices:
- Appendix 1 (sociological research); Katarzyna Kreft-Burman, Finnish Environment Institute
- Appendix 2 (physical models); Tuomo Karvonen, Antti Hepojoki, Jyrki Kotola, Hanna-Kaisa Huhta, Laboratory of Water Resources at Helsinki University of Technology
- Appendix 3 (risk analysis); Eero Slunga, consultant, Professor Emeritus
- Appendix 4 (loss of life); Peter Reiter, PR Water Consulting Ltd.
- Appendix 5 (models and their availability); Mikko Huokuna, Finnish Environment Institute
- Appendix 6 (digital terrain models); Jouni Sarkkila, Finnish Environment Institute
- Appendix 7 (Kyrkösjärvi reservoir and dam); Mikko Huokuna
- Appendix 8 (watershed models); Bertel Vehviläinen, Jarkko Koskela, Finnish Environment Institute
- Appendix 9 (dam breach hydrographs); Mikko Huokuna
- Appendix 10 (one-dimensional flow simulations); Mikko Huokuna
- Appendix 11 (two-dimensional flow modelling); EDF
- Appendix 12 (two-dimensional flow modelling); Enel.Hydro
- Appendix 13 (comparison of Enel.Hydro’s results); Mikko Huokuna
- Appendix 14 (report on analysis of the modelling results); Mikko Huokuna, Peter Reiter
- Appendices 15-23 (maps); Mikko Huokuna
- Appendix 24 (emergency action plan of Kyrkösjärvi dam); Tomi Honkakunnas, consultant, Jyrki Paunila, Seinäjoki Fire Brigade, Heidi Lepistö, consultant, Kari Syvänen, West Finland Regional Environment Centre
- Appendix 25 (updating the Finnish Dam Safety Code of Practice); Tomi Honkakunnas.

Contents of the multimedia CD-ROM was planned by Mikko Huokuna, Timo Maijala and Jouni Sarkkila from the Finnish Environment Institute and video filming by Jouni Sarkkila and Unto Tapio (West Finland Regional Environment Centre), photography by Jouni Sarkkila, Peter Reiter and Timo Maijala.

2 RISK ASSESSMENT

2.1 Introduction

The sub-project of RESCDAM - risk assessment - is based on four different studies as follows:

- Sociological research by Katarzyna Kreft-Burman, Finnish Environment Institute: Public response to dam safety issues - Kyrkösjärvi dam pilot project (Appendix 1).
- Physical laboratory tests and literature study by the Laboratory of Water Resources at the Helsinki University of Technology concerning human stability and permanence of houses in flowing water and roughness coefficients of forest and houses (Appendix 2).
- Literature and practical case study by Eero Slunga, consultant: Concept and bases of risk analysis for dams with an example application on Kyrkösjärvi dam (Appendix 3).
- Downstream risks of Kyrkösjärvi dam including infrastructure and property damage by the West Finland Regional Environment Centre, the municipality of Seinäjoki and relevant companies, and loss of life by Peter Reiter, PR Water Consulting Ltd. (Appendix 4).

2.2 Public response to dam safety issues - Kyrkösjärvi dam

2.2.1 General

The sociological research on the public response to dam safety issues was one part of the RESCDAM project. It played an important role in this project, in that the research was concentrated on the attitude of the public to the risk of a dam break at Kyrkösjärvi and on the possible reactions to a flood. By investigating the needs of the population in security matters, the research served as one of the tools in drafting the emergency action plan (EAP) for the eventuality of a dam break at Kyrkösjärvi and for better preparedness. The results of the questionnaire analysis is available in a paper entitled “Public Response to Dam Safety Issues – Kyrkösjärvi Dam Pilot Project” (Appendix 1) by Katarzyna Kreft-Burman, the Finnish Environment Institute.

2.2.2 Questionnaire for the population at risk

The first step of the research included preparing a questionnaire devoted to the problems of dam breaks in general and Seinäjoki in particular, as well as issues related to the alarm system. The purpose of the questionnaire was to introduce the dam break issues to the public and to investigate their perception of such a risk in Seinäjoki.

At the preparatory stage, care was taken to construct the questions in such a way as to find out the level of public awareness of the dam break risk problem without inducing panic. In order to avoid unnecessary fears and stress to the public, it was decided that the questionnaire was to be accompanied by a short letter of explanation signed by the Fire Chief of the Seinäjoki Fire Brigade. The letter underlined the fact that this questionnaire is part of a wider research project and that Kyrkösjärvi is only one example dam in the study.

The questionnaire was divided into three parts for personal data, dam safety issues and comments. One thousand copies were distributed to the households in a 2-hour dam break flood area. The questionnaire was sent by post along with the explanatory letter in late

October, 1999. A reply envelope with stamp, addressed to the Finnish Environment Institute was included. By the end of December, 1999, two hundred and eighty five response letters had arrived.

Several comments to this questionnaire revealed that dam break safety issues were a new and unexpected subject to the respondents. A few people stated that the fact that a dam could break had never crossed their minds. Nonetheless, the general risk perception among the public proved to be low.

The respondents emphasised the need for appropriate information on the dam safety issues. However, making a decision on the content and the amount of the information disseminated to the public, creates a problem for the authorities responsible for the public information campaign. On the basis of the sociological research, and the results of the international workshop on the RESCDAM project, a few conclusions were made on the subject of the public information campaign. Information presented to the public should be simple and easy to comprehend. It should stress the safety of a dam and simultaneously serve as a reminder that the EAP has been created to make the dam even safer. The problem of information overload and the long-term impact on the public should be tackled while designing the information campaign. Since people receive an enormous amount of diverse information daily, it is important to “pack” the information in such a way as to attract attention. Moreover, the impact of the information received will gradually diminish with time and some people will move away while others will settle as new arrivals in the community. One possible solution to this problem is to create web pages devoted to dam break issues and regularly inform the public where to look for updated information.

2.2.3 Recommendations for emergency action planning

A number of recommendations for the EAP were made on the basis of public response to the questionnaire. A compact guide for the population on how to act in the event of a dam break should be created. The guide should be in the form of a leaflet distributed to each household in the flood risk area. Another way of distributing the information would be to include it in the local phone-book.

Another recommendation concerns the creation of an effective alarm system. In case of a dam break, the quick and efficient alerting of the population is crucial role to their safety. The results of the questionnaire analysis reveal that the traditional alarm siren warning system may not be the best solution. There are a number of reasons for this. First, its relative inefficiency at night or when people are listening to radio or watching TV. People fear that they might be unable to hear the alarm siren. A second reason derives from the instructions on how to act when one hears the alarm, namely that people are supposed to go home to receive instructions by radio. The weakness of this arrangement in the event of a dam break is that a relatively long time elapses before the population finds out the actual reason of the alarm. Moreover, there is also a real danger that a flood may cut the power supply, and thereby cause disturbances in the reception of broadcasts.

Parts of the EAP should be presented to the local inhabitants during a public information meeting. They should be given the opportunity to comment and discuss the plan. Their suggestions should be taken into consideration in the process of further developing the EAP.

2.3 Human stability and permanence of buildings in flowing water and roughness coefficients

2.3.1 General

One part of RESCDAM was the research carried out at the Laboratory of Water Resources at the Helsinki University of Technology (Appendix 2).

There were three aims to this part of the project: 1) studying the stability and manoeuvrability of people in flowing water, 2) studying permanence of buildings in flowing water and 3) determining roughness coefficients of forest and buildings. Human stability and roughness coefficients of forest and buildings were studied using physical laboratory tests. Experiments on the human stability were conducted testing full scale test persons in a 130 m long model basin equipped with a test carriage in the Helsinki University of Technology Ship Laboratory. The roughness coefficient was studied in a 50 m fixed bed flume at the Laboratory of Water Resources using scale model forests and houses. The studies on the permanence of buildings in flowing water was based on literature.

2.3.2 Human stability and manoeuvrability

The manoeuvrability of seven test persons, characterised by the coefficient: height times mass (mkg), was tested in the laboratory using velocities of 0,6 – 2,75 m/s and water depths of 0,3 – 1,1 m. The damage parameter flow velocity times depth (m^2/s) causing the loss of manoeuvrability or stability was determined and the relation between damage parameter and height times mass was studied. The results were compared to the earlier study by Abt et al. (1989), see References in Appendix 2. Based on the results of these two studies, approximate limits of adult human manoeuvrability and stability in flowing water are presented in Figures 50 and 51 in Appendix 2.

2.3.3 Permanence of buildings in flowing water

The permanence of buildings in flowing water was determined by studying literature (Black 1975; Clausen and Clark 1990; Lardieri 1975; Lorenzen et al. 1975; Sangrey et al. 1975; Smith 1989, 1991 & 1994), see References in Appendix 2. The findings of the earlier studies were combined and a recommendation for Finnish 1- and 2-storey buildings was made as follows (Table 3 in Appendix 2):

house type	**Partial damage**	**total damage**
wood-framed		
Unanchored	$vd \geq 2\ m^2/s$	$vd \geq 3\ m^2/s$
Anchored	$vd \geq 3\ m^2/s$	$vd \geq 7\ m^2/s$
Masonry, concrete & brick	$v \geq 2$ m/s & $vd \geq 3\ m^2/s$	$v \geq 2$ m/s & $vd \geq 7\ m^2/s$

damage parameter vd (m^2/s) = flow velocity(v) times water depth(d)

2.3.4 Manning's roughness coefficient for forest and buildings

Scale model experiments were conducted to define the roughness of forests and groups of buildings. The scale model forests and house groups were placed into a fixed bed flume. The difference in water table caused by the scale models was measured in different flow conditions, i.e. different water depths and velocities. The Manning-Strickler - coefficient was used to describe the roughness of the trees in the forest and houses in a built area. The bottom roughness was not included in the test results. Manning's coefficients were calculated and the results were converted into real scale using the Froude model law with scale numbers 5, 10 and 20 for the forests and 30, 40 and 50 for the house groups. The house groups were approached in two different ways. The relationship among Manning's roughness coefficient and parameters characterising the flow, the forest and the group of houses was produced. The results concerning forests are presented in Figures 23, 24 and 25 in Appendix 2. For the house groups, the roughness coefficients are presented in Chapter 3.4.3 of Appendix 2.

2.4 Concept and bases of risk analysis for dams

2.4.1 General

The study in Appendix 3 deals with the concept of risk assessment for dams, risk analysis, risk evaluation, risk management, systematic application of engineering judgement, causes and probabilities of dam incidents, risk analysis for Kyrkösjärvi dam, and finally conclusions and recommendations. The study "Concept and bases of risk analysis for dams, with an example application on Kyrkösjärvi dam" was written by Eero Slunga, Professor Emeritus (Helsinki University of Technology).

Risk assessment is the process of deciding whether existing risks are tolerable and present risk control measures are adequate and if not, whether alternative risk control measures are required. Risk assessment incorporates, as inputs, the outputs of the risk analysis and risk evaluation phases. Risk assessment involves judgements on the taking of risk and all parties must recognize that the adverse consequences might materialize and owners will be required to deal effectively with the consequences of a dam failure (see ICOLD 1999, Bibliography in Appendix 3).

The term risk implies a combination of the probability of an event occurring and the consequences of the event should it occur (risk = probability times consequences).

The primary steps of a risk assessment (Figure 1 in Appendix 3) consist of the following: risk analysis, risk evaluation, and risk management.

The main emphasis of this study is laid on the risk analysis of dams. The study is based on literature and Finnish experience. The risk analysis of Kyrkösjärvi dam was conducted as an application example.

The loss of life, economic, environmental, and social consequences associated with each identified failure model are an integral part of the definition of risk in order to properly compare alternatives. However, the primary interest in this study (Appendix 3) has been in evaluating the usability of the methodology and in evaluating the probability of failure without detailed assessment of consequences. The consequences of a dam failure have been assessed in Chapter 2.5 of this report.

The risk analysis of a dam consists of the use of the information available to estimate the risk to individuals or a population, to property or the environment. A risk analysis is generally done in the following order: scope definition, hazard identification, and risk estimate. A risk analysis involves the de-aggregation or partitioning of the dam system and sources of risk into fundamental parts.

2.4.2 Risk analysis of Kyrkösjärvi dam

The risk analysis of Kyrkösjärvi dam (Chapter 7 in Appendix 3) contains a dam description, identified weaknesses, a qualitative risk assessment (failure mode identification), quantitative risk assessment (probability of events), and risk evaluation.

According to the recommendations for acceptable risk to society in Figure 4 in Appendix 3, the accepted probability of failure on a specific event basis, in the case of Kyrkösjärvi could be of the order of $10^{-6}\ldots10^{-5}$ depending on the number of fatalities, when taking into account, that the analysis concerns an existing dam. The above-mentioned probability of overall failure and of severe flood, meet this requirement when the Renko inflow canal is closed or the earth dam is opened and the drainage is working. Taking into account that the core zone of the dam is wide and the core material is, to a certain extent at least, self-filtering, the probability of failure due to internal erosion and structural faults may also be said to meet this requirement just at the lowest acceptable level with the reservation of careful annual and regular inspections. The probability of failure due to earthquake or terrorist action and mischief is on an acceptable level. The Finnish Dam Safety Code does not give generally valid guidelines for acceptable risks. Every case must be evaluated separately.

If the criteria are applied on a total expected annual risk to human life ($1,4x10^{-4}$), the probability of failure meets the Limit value of Individual Risk for the person most at risk in the case of an existing dam according to the ANCOLD Working Group on Risk Assessment 1998 (see Chapter 3.3 in Appendix 3).

The accepted probability of failure as concerns economic risk depends on the nature of the activities in the dam area, but in general it is clearly higher than the failure probability in the cases of human life loss (Hoeg 1996; see Bibliography in Appendix 3). The proposal of Hoeg (Chapter 3.3 in Appendix 3) is of the order of $10^{-3}\ldots10^{-2}$, if no irreparable damage to the environment occurs.

In addition, one should take into account, that the emergency action plan includes the possibility to open the earth dam at sections 112 and 120 as an emergency measure. The height of the dam at those sections is only 1,0 - 1,5 m. According to Lemperiere (1999), see Bibliography in Appendix 3, it is also justified, on the basis of the above-mentioned measures together with careful annual and regular inspections, to divide the estimated probability of failure by 5 or 10.

The above aspects and criteria can be summarised as follows: the safety of Kyrkösjärvi dam may considered to be on an acceptable level provided that:
- The Renko inflow canal is closed and the height of the regulation dam is great enough to

prevent water to flow into the basin of Kyrkösjärvi in the event that a high flood occurs.
- The annual and regular inspection programme is adhered to.
- The observed damage to the dam structure due to external or internal erosion are repaired as soon as possible and the drainage system is kept in working order. Any repair measures have to be designed on the basis of observed defects. It is also important to prevent debris from blocking the out-flow.
- The natural thresholds at sections 76 and 104 are left open.
- During exceptionally high flood conditions (e.g. $>HQ_{1/100}$) or in other threatening conditions, preparations for the opening of the earth dam at sections 112 and 120 are undertaken.

Another recommended risk reducing measure is to have the power plant operating if possible, but in critical situations this measure alone is not enough to avoid a dam failure.

2.4.3 Conclusions and recommendations

Probabilistic risk analysis is a more rational basis for dam safety evaluation, and provides a deeper insight into the risks involved than the traditional standards-based approach. A full risk analysis provides a more comprehensive view of dam safety, in that it considers all load increasing conditions over the full range of loads. The analysis procedure itself should not be viewed as a replacement to traditional engineering judgement and expertise. Quite the contrary, this process depends heavily on the knowledge of experts. The attainment of an exact value of probability for dam failure is not a realistic expectation. The utility of this approach is to assess dam safety on relative basis. After having assessed the probability of failure for an existing dam, one can investigate - in a relative sense - the effects that various improvements or remedial measures will have (Graham & Bartsch 1995, McDonald 1998; see Bibliography in Appendix 3).

The concept of probabilistic risk analysis may be used for different purposes and at different levels, for example:
- At the dam design stage, to achieve a balanced design and to place the main design effort where the uncertainties and the consequences seem the greatest.
- As a basis for decision-making when selecting among different remedial actions and upgrading of old dams within the scope of restraints due to the time factor and to financial considerations.
- To relate dam engineering risk levels to acceptable risk levels established by society for other activities.

The scepticism toward the use of probabilistic risk analysis may result from too much emphasis on the third and most complex item above, while the benefits from applications, such as the first two, may be overlooked (Hoeg 1996; see Bibliography in Appendix 3). The application example of the risk analysis of Kyrkösjärvi dam may be included in the second of the above–mentioned items.

There is concern among practitioners, that risk analyses are too subjective, in that there are no clear-cut procedures for calculating some of the failure probabilities, and thus there is too much reliance on expert judgement. In fact there are still many areas, where further guidance is required. Recommendations for some of the areas that need to be addressed in more detail are listed below:

- Additional refinement of quantitative analyses.
- Development of internal erosion analysis methods to be used in a risk analysis format.
- Retrospective probability of failure under static load.
- Whether societal risk criteria should be applied on a total expected annual risk to life basis or on a specific event basis.
- The concept of average individual risk as opposed to population risk.
- Prediction of loss of life.
- Whether upgrading of dams should have criteria applied as stringent as those for new dams.
- Inconsistent international terminology.

2.5 Downstream risks of Kyrkösjärvi dam

2.5.1 General

Downstream risks (consequences of dam failure) have been estimated concerning property (infrastructure, buildings, agriculture) and loss of life. There are also environmental consequences and consequences to the society deriving from potential dam accident. Although environmental and social consequences might be very large, estimating of those in monetary value is impossible. The consequences to society would be significant when taking into consideration the effects on living, infrastructure and working.

2.5.2 Risk to property

According to the dam break hazard analysis of Kyrkösjärvi dam, the maximum breach flow will be about 2200 m^3/s and in the centre of Seinäjoki about 950 m^3/s in the worst possible calculated breach case (breach location A, base flow $HQ_{1/100}$ = 150 m^3/s, reservoir water level before breaching N_{43} + 81,75 m). In the centre of Seinäjoki the wave will reach the danger level in 2 h 30 min and the maximum level in 3 h 30 min (see Chapter 3). The maximum dam break flood will cover an area of about 10 km^2. A natural flood ($HQ_{1/250}$ = 160 m^3/s) for example, would cover an area of about 1,5 km^2 according to basic information concerning an assessment of the damage caused by a potential extreme flood in Finland, prepared by the Finnish Environment Institute in 2000.

The following evaluation of damage estimated in euros is based on an estimate by the West Finland Regional Environment Centre, the municipality of Seinäjoki and relevant companies.

The most severe damage from the flood wave would be caused to buildings such as residences, industrial and business buildings, offices and stores. The total number of buildings covered by the flood in the above-mentioned case is about 1 400 and the total damage is estimated at 60 million euros. The basic data for calculations includes real repairing costs caused by natural floods in Finland. According to calculations, the buildings are located as follows: in the flood area with a water depth in excess of 1,0 m about 500 buildings, a water depth 0,5-1,0 m about 400 buildings and a water depth lower than 0,5 m 500 buildings. In comparison, only some 25 industrial buildings and some 25 dwellings would be affected by water in a natural flood as stated above ($HQ_{1/250}$).

A dam breach flood would also affect 13 bridges, the telecommunications network, the power grid, the water supply and sewage system, the street and road systems, the railway station and traffic and agriculture.

The above-mentioned damage and expenses with unpredictable costs have been estimated to reach a total of some 160 million euros.

2.5.3 Risk to population

The method introduced by Reiter in Appendix 4 is based on the method by Wayne J. Graham "A Procedure for Estimating Loss of Life Caused by Dam Failure, DSO-99-06", U.S. Department of Interior, Bureau of Reclamation (see RESCDAM seminar paper by Graham or http://www.usbr.gov/research/dam_safety/documents/dso-99-06.pdf). Dam break flood modelling results, flood severity impact (SEV), living environment impact (LOC) and vulnerability impact (VUL) are used to specify areas of high, medium and low risk for loss of life. It is obvious that the method in Appendix 4 should be tested with such earlier cases where data on the flood event as well as distribution of the population and its main parameters (SEV, LOC and VUL) are known.

The population living in the project area (see Figure 1 in Appendix 4) is 11 500 people, but a significant percentage of this number live in areas near the flood inundation boundaries. In addition to the local population, there are as many as 12 000 people in the project area daily for work, school and shopping and a further 12 000 –19 000 visitors participating in two cultural events in summer, each lasting several days.

Depending on the severity of the dam break flood event (severity dependent on site and base-flow) only a certain part of the population will be confronted directly with the flood, i.e. population at risk (PAR). In the worst evaluated case they comprise some 60 % or about 6 900 people and in a case of lesser impact 10 % or about 1 200 people. The distribution of outsiders in the area and the percentage being confronted with the flood is assumed to be similar to that of the local population.

The loss of life (LOL) evaluation was prepared with different impacts on population at risk (PAR), different dam break cases and different warning and emergency/rescue scenarios in mind. The analysis took into consideration the variations of PAR, as well as the most probable dam break risk at different sites and under different base-flow conditions within a specified time scenario (hours in a day, workday and weekend, and seasons) of one reference year. Short time LOL values may rise significantly (cultural events), but their effect on the mean annual LOL is minor due to their short time-span of occurrence over the year. Different weighting of warning and emergency/rescue preparedness cases were considered when finally evaluating the mean annual LOL as follows:

- current situation (dam break flood analysis + low level EAP) …. LOL = 14-23
- after RESCDAM project defined improvements ……….……… LOL = 8.

There are two ways to conduct an evaluation of the loss of life potential caused by a dam failure. One way is to use observations on life-loss associated with dam failures in the past and deal with the problem on statistical base. The other way is to model the expected flood event and its impact to the population at risk. New research on the capabilities of people to manage, or the opposite, when confronted with the flood at their homes and on field, as well as the common availability of public population registers, can be used to widen the analysis. The original task for a LOL analysis was to prepare information on the risk to third parties downstream of dams for the use of decision makers. A more specific LOL analysis, as prepared for the RESCDAM project, allows specifying areas of greater risk, which are not exclusively near the dam. This information can be used in emergency planning for cases of dam failures.

3 DAM BREAK HAZARD ANALYSES

3.1 Introduction

3.1.1 General introduction

Dam break hazard analyses (DBHA) provide information on the consequences of a possible dam break for risk estimation and rescue planning purposes. Numerical models are used in DBHA to determine the flow through a dam breach and to simulate flood propagation in the downstream valley.

Kyrkösjärvi reservoir and its embankment dam, located in the town of Seinäjoki, Western Finland, was chosen as the area for the pilot project to the RESCDAM project. A numerical model for the simulation of dam breach formation was used to determine the dam breach flow hydrographs. The propagation of the flood wave in different breach scenarios was calculated with a 1-dimensional flow model and two 2-dimensional models. The effect of different approaches to model urban areas on flood propagation were also studied in the project.

The 2-dimensional flood analyses and the study of the effect of urban areas on flood propagation were made by the project partners, EDF Electricité de France (Paris) and Enel.Hydro Polo Idraulico e Strutturale (Milan). According to the preliminary sensitivity analyses, the most dangerous breach location (location A) and the $HQ_{1/100}$ flood condition and mean flow condition (MQ) were chosen for DBHA calculations, which were made by the partners EDF and Enel.Hydro. The analyses for two other breach locations (locations B and C) were done using a 1-dimensional flow model. It was also decided that 1d-model is used to produce a downstream boundary condition for 2-dimensional models. Later it was observed that the original modelling area is too small and simulations were extended to include the northern area of Seinäjoki (the area encompassed by the railway). The simulations were first made using 1d-model by the Finnish Environment Institute and it provided a rating curve for the flow over the railway for the project partners. In the simulations, the flow is divided to several streams and the modelling of that area is extremely difficult, and thus it was decided to calculate the most important cases using the whole area with a 2-dimensional flow model. That work was done by the Finnish Environment Institute by using Telemac-2d model.

Geometry input data for the DBHA was obtained from an accurate digital terrain model which was available for the project. The results of DBHA were provided as flood maps, tables, water level hydrographs and animations for rescue planning. The Geographical Information System (GIS) was used to produce flood maps and the information about buildings and people living in a flood risk area.

3.1.2 Hydraulic flow models for DBHA

To know the effects of dam break, we have to know how dams may break and how a flood will propagate. Numerical and physical models are used to answer these questions. The development of a dam break is a complicated problem that contains a lot of uncertainties. Compared to the breach development process the propagation of a flood wave can be modelled more "accurately". However, the propagation of the dam break flood wave is an extreme phenomenon and there is very little valid observation data available. Today, physical models are not only used to study the behaviour of the prototype but also to produce the necessary verification data for numerical models.

Mathematical, or more accurately speaking numerical, modelling methods have been in use for more than a hundred years. Nevertheless, it took until we had access to digital computers before models could be set-up and operated at a level of complexity, accuracy and reliability where the results are accurate enough for hazard and risk assessment, as well as for emergency/rescue action planning. In parallel with the rapid development of computer technology within the last 20 years, dam break and flood simulations have stepped from the use of simplified models to one-dimensional channel network models and finally to extensive two-dimensional models.

While earlier the state of the art was presented by simplifying the models to allow functional and feasible operation on the computers of "yesterday", today's state of the art procedure is to develop complex terrain models and superimpose them with flood computation parameters. The trend is to minimise the expert work in favour of computer resources.

There are many different modelling techniques used in DBHA. Some information on models and their availability is given in Appendix 5. As emergency and rescue action planning and practical arrangements are the main task of the RESCDAM project, only a general overview on the availability of numerical flow models and on their capabilities will be provided in that Appendix. The reader is advised to gain more information from ICOLD Bulletin 111, Dambreak Flood Analysis (1998). For the latest development in dam break flood modelling, we refer to a report on the EU supported CADAM project, published in 2000.

3.1.3 Input data for DBHA

Any output of a dam break hazard analysis is related to the accuracy and amount of input data. We cannot expect to have accurate results if our data is poor. In "Dambreak Modelling - Guidelines and Best Practice" (CADAM project) the required data is characterised as:

- reservoir data (including catchment hydrology and river flood conditions)
- structure data
- topographic data
- sediment and debris data.

Reservoir data includes stage-area and stage-volume relationships and the bathymetric data for the reservoir. Catchment hydrology data may for example be reservoir inflow and river flow data including natural flood observations. Structural data consists of data for dams and other structures. Topographic data is needed for the whole area which may be flooded by a dam break flood. Terrain model technology provides excellent tools for handling of topography data. In Appendix 6 there is a presentation of the use of the terrain model technology in the RESCDAM project.

3.1.4 Output of DBHA

The results of DBHA should provide information for emergency action planning, land use planning and other purposes in a form that is appropriate to the end user. A Geographical Information System (GIS) provides efficient tools to transfer the information in digital form and to analyse the results. By using GIS flood inundation maps and other related information can be produced in different scales depending on the scale of the base map which is used in the presentation. In the RESCDAM project maps were produced for flood inundation (max inundation and the inundation 0,5 h, 1 h, 2 h and 3 h after the initiation of the failure), for flow velocity, for damage parameter (water depth times flow velocity) and for flow depth. The scale used for printed maps in the RESCDAM project was generally 1:20 000 but the scale 1:10 000 was also used.

Water level hydrographs and tables for certain locations may be important for emergency action planning. From hydrographs the arrival time of flood wave and the speed of the rising of water level can be obtained. In the RESCDAM project water level hydrographs were printed out for several locations.

The output of DBHA for emergency/rescue action planning in the RESCDAM project is presented in Chapter 3.10.

3.2 Kyrkösjärvi reservoir and dam

The Kyrkösjärvi reservoir, located in Seinäjoki, Western Finland, is an off-river channel reservoir using the water from the river Seinäjoki, a major tributary to the river Kyrönjoki (see Figure 1). This reservoir and its embankment dam were chosen as the area of the pilot project in the RESCDAM project. There are several reasons for this choice. The reservoir is in multipurpose use (flood control, hydropower production, water supply, cooling water for a peat power plant and recreational use) and it is therefore very important to the local population. The area has also been recently surveyed and high accuracy digital maps and a digital terrain models were available. The reservoir is located in the town limits, with urban areas at risk. The Seinäjoki Fire Brigade is responsible for the Kyrkösjärvi reservoir as well as for other reservoirs and dams in the area and is therefore highly motivated to develop their organisational responsibilities.

The dam was designed in 1977 and taken into use on February 6, 1981. The reservoir is used as flood storage for the river Seinäjoki, which flows through the town area. There is a hydropower plant in the northern part of the reservoir and, at the eastern bank of the reservoir a peat power plant which uses the water from the reservoir for cooling water. The volume of the reservoir is $15{,}8 \times 10^6$ m^3 at the flood HW-level 81,25 m and $22{,}3 \times 10^6$ m^3 at the emergency HW-level 82,25 m (HW + safety margin).

Seinäjoki river is a tributary of Kyrönjoki river (catchment area 4 900 km^2). The catchment area of Seinäjoki river upstream of Kyrkösjärvi reservoir is 813 km^2. Water from Seinäjoki river flows to the reservoir through a canal which begins at Renko weir (Figure 1). The discharge through the canal between the Renko weir and the reservoir are at low reservoir levels or high river levels 45 m^3/s and at low water level differences, at least 25 m^3/s. The discharge from the reservoir through the turbines of the hydropower plant may reach 21 m^3/s plus 3 m^3/s past turbines and through a discharge valve 2 m^3/s.

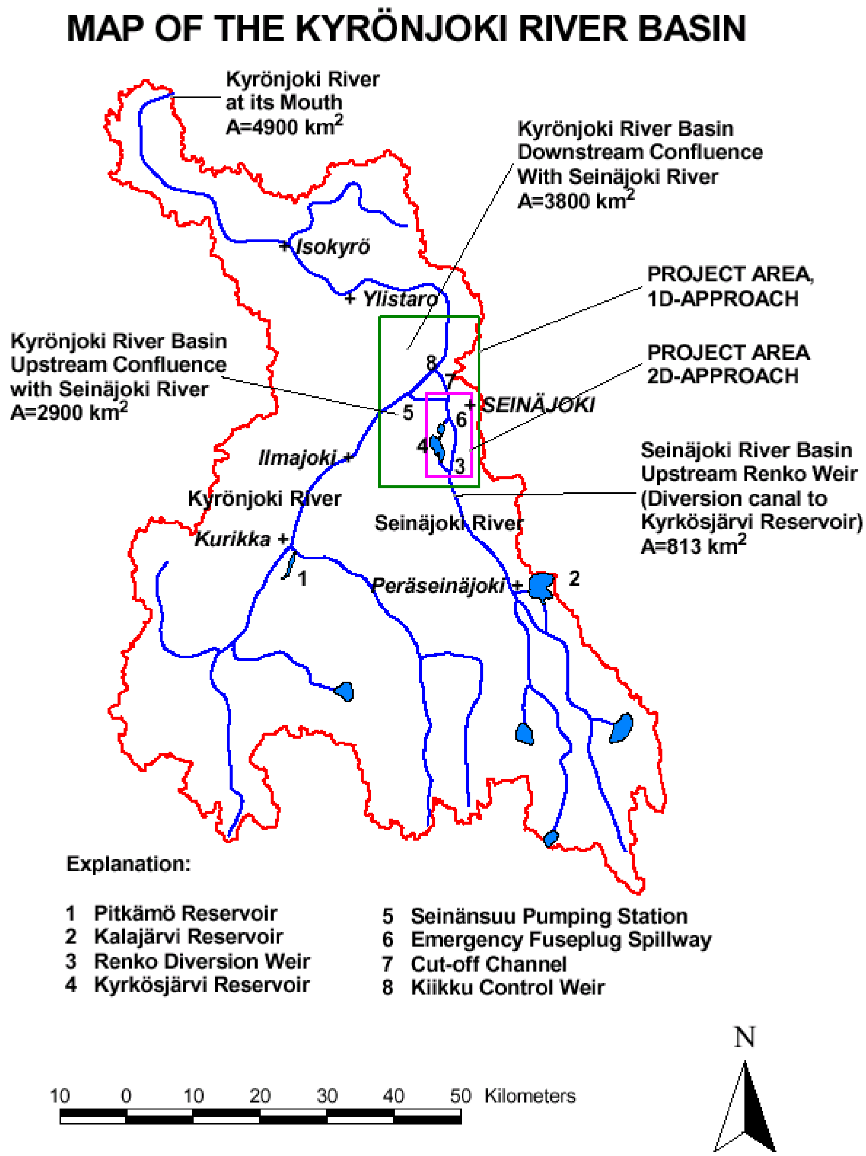

Figure 1. Map of the Kyrönjoki river basin.

Kyrkösjärvi dam is a homogeneous embankment dam (Figure 2). The length of the dam is 12,5 km, one third of which is lower than three metres. The maximum height of the dam is less than ten metres. The core material of the dam is glacial till.

More detailed information on the Kyrkösjärvi reservoir and dam and the available data for the DBHA is given in Appendix 7.

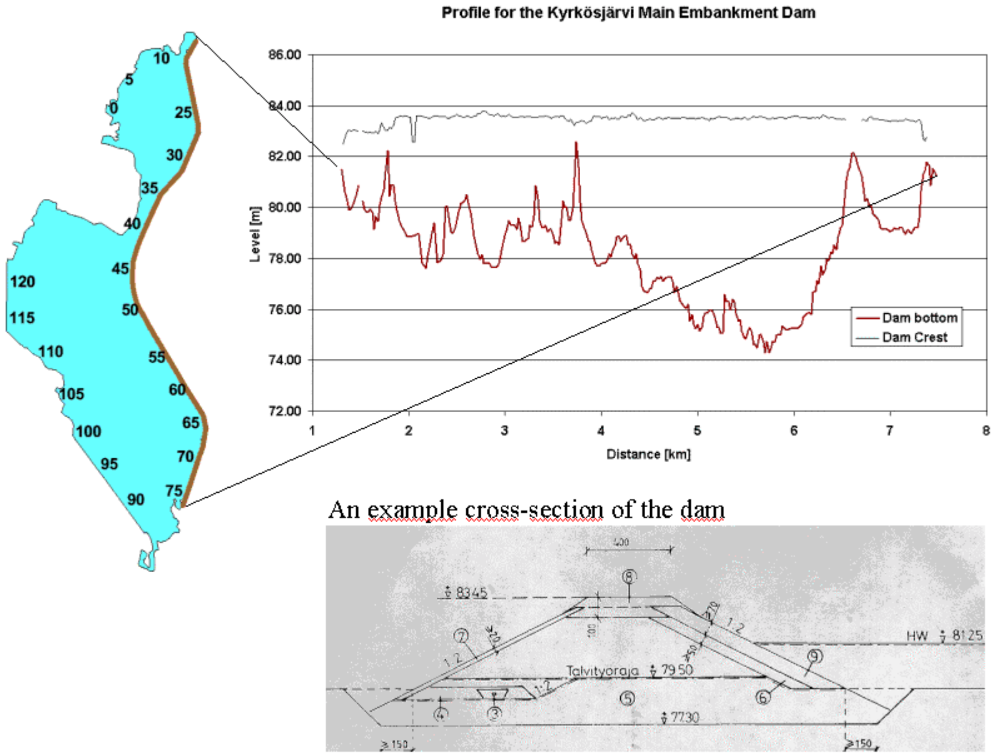

Figure 2. Kyrkösjärvi embankment dam.

3.3 Hydrological analysis

The hydrological analysis in the RESCDAM project is based on the HBV-hydrological model.The Kyrönjoki watershed model is a semi-distributed model with 22 sub-basins. Each sub-basin has separate precipitation, temperature and potential evaporation as input. The Kyrönjoki model has a flood-area-model which simulates water exchange between river and flood plains. The flood-area-model is simulated with shorter time steps than the main model. At every reach of river with embankments and weir, the model calculates the water level in the river and discharge through the weir over the embankment into the flood plain. This part of the model is important during the flood season. This simple hydraulic model is verified against the results from a complete hydraulic model in order to keep up the accuracy of the simulation.

The Kyrönjoki watershed model is a conceptual model used for operational forecasting at the Finnish Environment Institute (Vehviläinen 1994). The watershed model is based on a conceptual distributed runoff model, water balance model for lake, river routing model (Muskingum and cascade reservoirs) and flood area models. The input variables for the model are daily precipitation, temperature and potential evaporation (Class A pan).

As input for Kyrkösjärvi dam break simulation three flood situations have been simulated. Floods with a return period of 20, 100 and 10 000 years have been created or determined with the operational hydrological catchment model. The method used to determine a 10 000 year flood is based on precipitation with a return period of 10 000 years.

More detailed information on the hydrological analysis of Kyrkösjärvi reservoir is given in Appendix 8.

According to analysis the flow values at Renko dam, located upstream of the dam, are 150 m^3/s for the $HQ_{1/100}$ –case and 74 m^3/s for the $HQ_{1/20}$ –case.

3.4 Determination of the breach hydrographs

Determination of flow through a dam breach has lot of uncertainties. In the RESCDAM project a numerical model for erosion of an embankment dam has been used for the determination of the discharge hydrograph. The results of the erosion model has been compared with those of other methods.

In the studies the breach is assumed to happen at three locations with two hydrological conditions which are. $HQ_{1/100}$ flood and mean flow (MQ). The assumed dam breach locations are presented in the Figure 3.

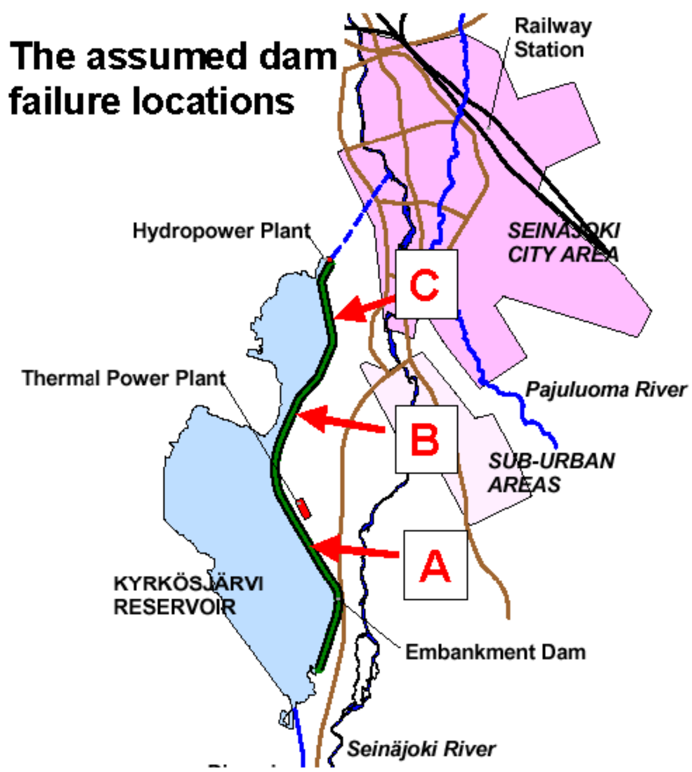

Figure 3. The locations of the assumed dam failure sites.

Location A in Figure 3 is the most dangerous location for a possible dam failure at Kyrkösjärvi dam. The dam is highest at this location (distance km 5,7 at Figure 2) and because of the topography of the valley downstream of the dam, the Seinäjoki downtown area could be badly flooded if the dam breaks at location A.

The determination of the breach hydrographs was done with an erosion model which is presented in Appendix 9. The comparison of the results of the erosion model with the other methods shows that the hydrographs used in the RESCDAM project are very conservative and both the peak discharge and the breach formation speed may be overestimated. However, according to the flood simulations presented in Appendix 9, the flooding caused by a breach hydrograph which was determined by assuming a much smaller erosion rate, was not much different compared to the flooding caused by a breach hydrograph calculated with the erosion model. Because of that, and because there is still a lot of uncertainties in the dam failure mechanism, the breach hydrographs calculated with the erosion model were decided to be used for flood analyses in the RESCDAM project. The breach hydrographs for the failure location A in $HQ_{1/100}$ and MQ cases are presented in Figure 4.

For breach locations B and C, the erosion model was combined with the 1-dimensional flow model to get the dynamic effect of the shallow area in the lake to be taken into account. Because of the shallow area in the lake between locations A and B, the possible outflow for locations C and B is much smaller than for location A. The breach hydrographs for locations B and C are so close to each other that the same hydrographs were used for both locations. The breach hydrographs for locations B and C are presented in Figure 5.

More detailed information on the determination of the breach hydrographs in the RESCDAM project is given in Appendix 9.

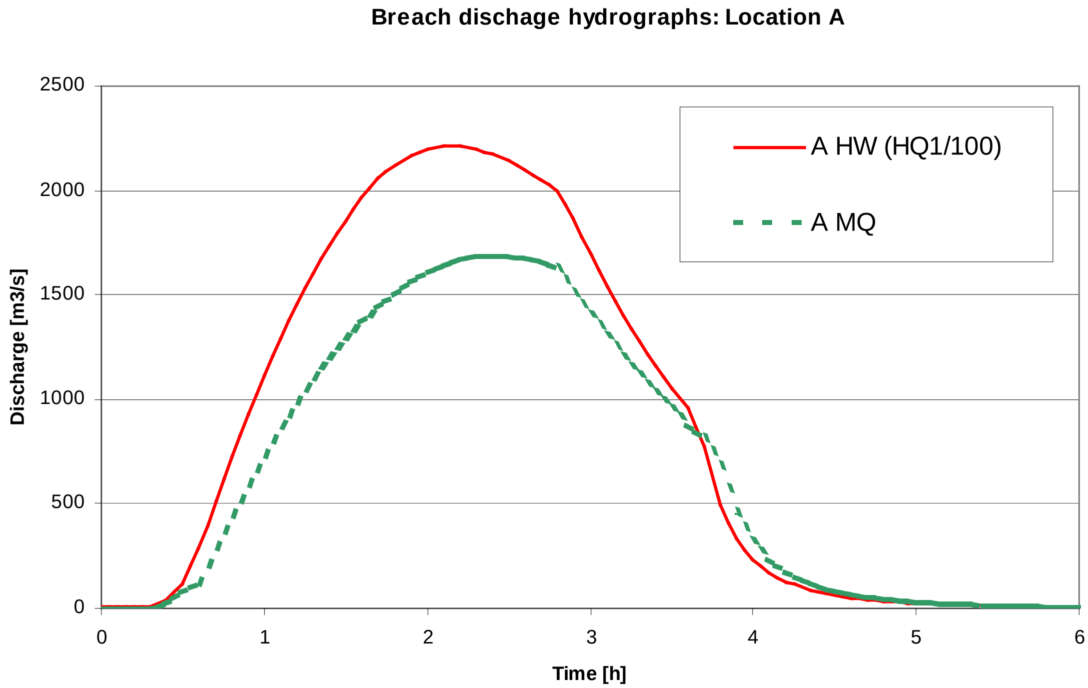

Figure 4. Breach hydrographs for location A in the $HQ_{1/100}$ and MQ cases.

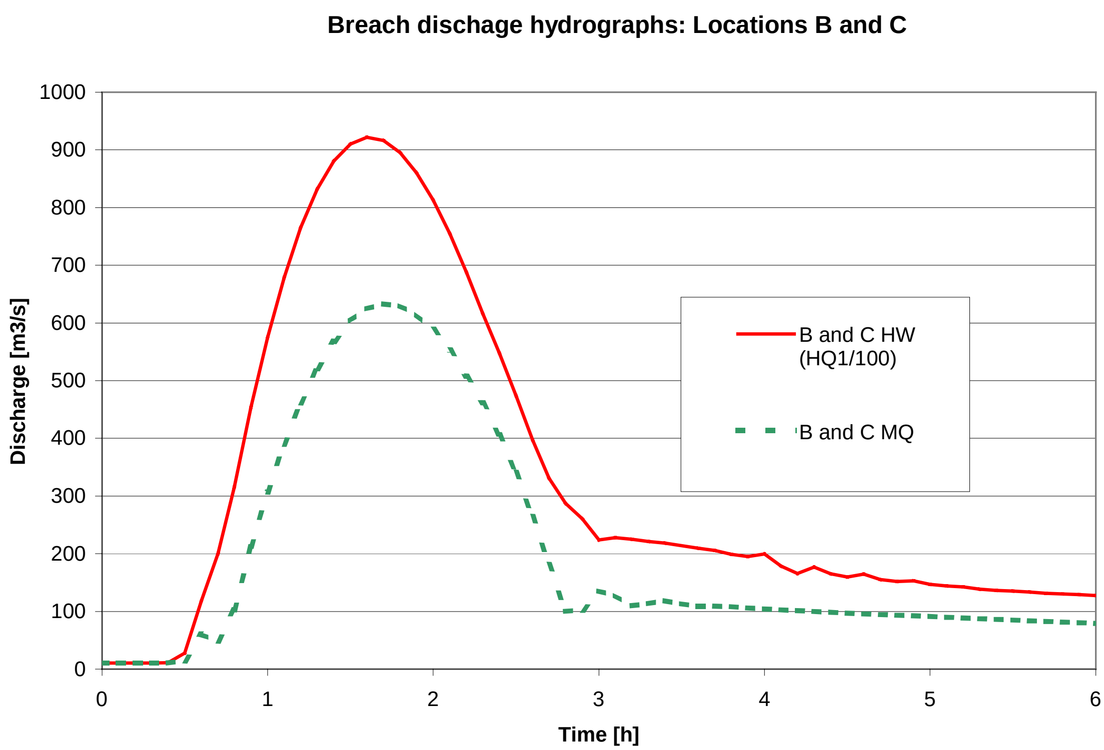

Figure 5. Breach hydrographs for locations B and C in the $HQ_{1/100}$ and MQ cases.

3.5 One-dimensional flow modelling

The 1-d modelling for the dam break hazard analyses in the RESCDAM project has been done by using DYX.10 flow model. The model is based on four point implicit difference scheme and uses the solution algorithm developed by Danny L. Fread for DAMBRK model. During 1980's Fread's algorithm was developed further in Finland for river networks.

The 1-d flow model for the Kyrkösjärvi DBHA covers the area from Renko dam (upstream of Kyrkösjärvi reservoir) to Kylänpää (about 30 km downstream of the reservoir). The map of the 1-d model area is presented in Figure 6. The cross-sections used in the model were taken either from a terrain model or they were measured cross-sections. There were 735 cross-sections, 22 reaches and 35 junctions in the Kyrkösjärvi 1-d DBHA model (breach location A). Some of the reaches were fictive channels (flood plains, connecting channels etc). The reaches used in the model can be seen in Figure 6.

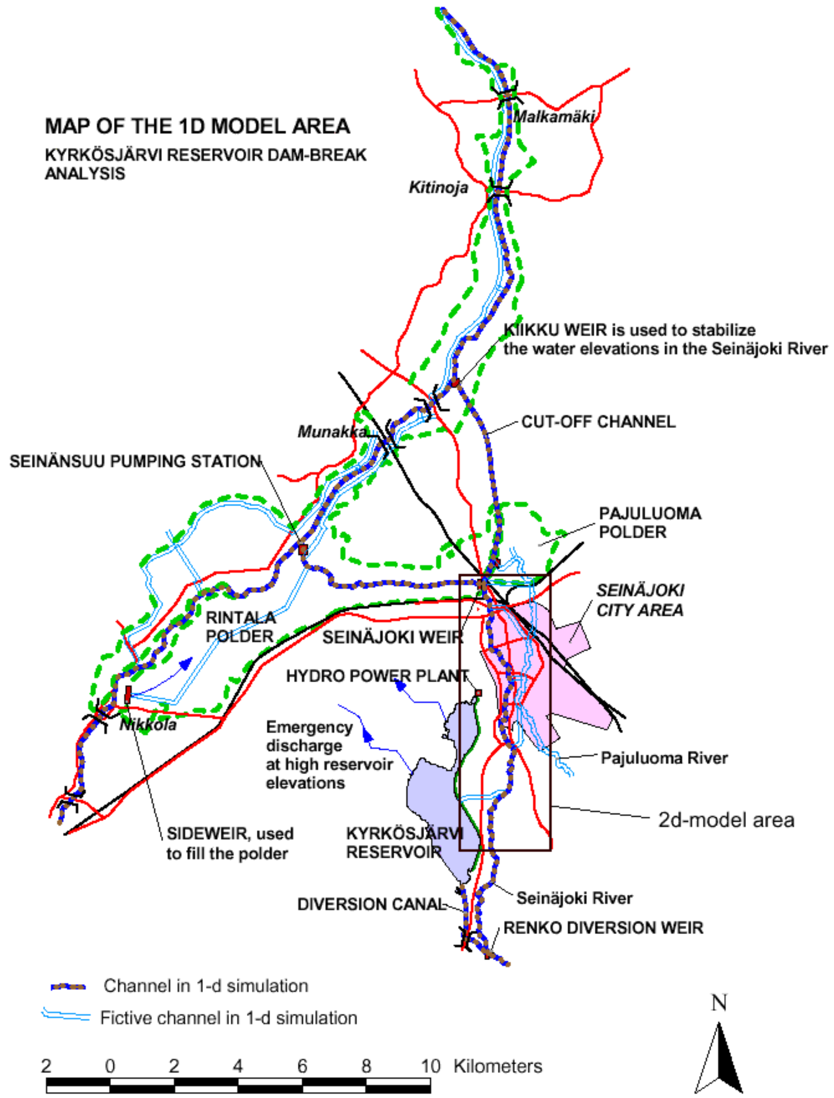

Figure 6. Map of the 1-d model area and the reaches used in the calculation.

The flow simulations in which the breach was assumed to happen at location A or at location C were modelled with the 1-d flow model. So the breach cases studied with the 1-d model were:

- Breach location A: base flow MQ (same as RUN 1 for 2-d models).
- Breach location A: base flow $HQ_{1/100}$ (same as RUN 2 for 2-d models).
- Breach location C: base flow MQ.
- Breach location C: base flow $HQ_{1/100}$.

The breach hydrographs which were used in the simulations were defined by using the breach erosion model (Chapter 3.4 and Appendix 9). The hydrographs were the same than those used in the 2-dimensional flow modelling.

A constant roughness coefficient (Manning n = 0,060) was used in all simulation cases.

1-d model was also used to run sensitivity analyses of the effect of the size of the breach hydrograph on the water level downstream of the dam.

A more detailed description of the 1-d flow modelling in the RESCDAM project is given in Appendix 10.

3.6 Two-dimensional flow modelling by EDF

Electricité de France (EDF) used Telemac-2d flow model, a 2-dimensional finite element model, in the simulation. There were 81 161 elements and 41 086 points used in the Kyrkösjärvi model. The finite element mesh is shown in Figure 7. The mesh size ranges from approximately 8 m to 20 m. The river beds, the bridges, the roads, and the have railways been highly refined to accurately model flood propagation In regular areas such as roads, reservoir dykes, and river beds, regular grid application has been used. For other features such as railways, embankments, and constraint lines have been imposed. All these features are quite visible on the mesh.

A separate report on their modelling work in RESCDAM project is given by EDF in Appendix 11**.** The results are also presented in Chapter 3.9 (comparison of results). The porosity approach developed by EDF to model urban areas is presented in Hervouet´s seminar paper.

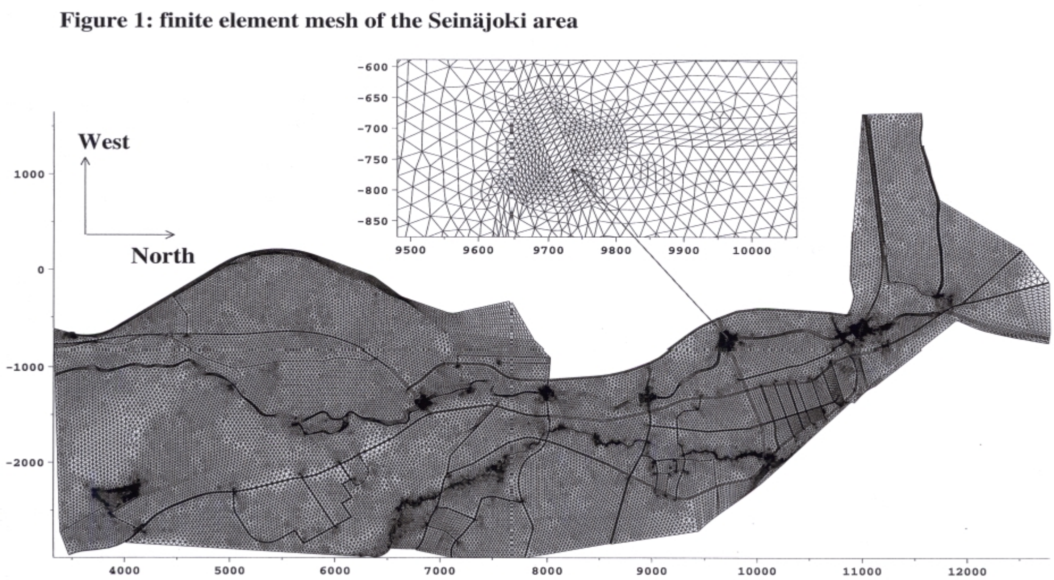

Figure 7. The Telemac-2D finite element mesh used in the Kyrkösjärvi simulations by EDF.

3.7 Two-dimensional flow modelling by Enel.Hydro

Enel.Hydro used FLOOD2D model, a 2-dimensional finite volume model, in the simulation. FLOOD2D has been developed by Enel.Hydro. The model is based on the integration of the Saint Venant equations for 2-dimensional flow and it neglects the convective terms in the momentum conservation equations.

The 2-dimensional model was applied to the area below the dam including the town area of Seinäjoki. Two sets of topography were used:

- rectangular mesh (grid size10m) without buildings and
- rectangular mesh (grid size 10m) with buildings.

The model has a total number of 446 961 grid points. Depending on the base flow condition, approximately 55 000 – 70 000 cells of the model were flooded during the computations.

A separate report on their modelling work in RESCDAM project is given by Enel.Hydro in Appendix 12**.** The results are also presented in Chapter 3.9 (comparison of results). The results of modelling urban areas with geometry approach used by Enel.Hydro is presented in Chapter 3.8 and in Appendix 13.

3.8 Urban areas and floating debris

During RESCDAM project the partners EDF and Enel.Hydro developed methods to calculate flood wave propagation an urban area. Enel.Hydro used the geometry approach and houses were taken into account in model geometry. EDF used the porosity approach.

There is a separate paper by EDF presenting the results of the porosity approach on calculation results (Hervouet´s seminar paper: Modelling urban areas in dam break flood wave numerical simulations).

Enel.Hydro applied the geometry method for the whole calculation area. In the FLOOD2D model by Enel.Hydro the geometry was represented by a grid consisting of rectangles of 10x10 metres. Enel.Hydro made the calculations for MQ and $HQ_{1/100}$-cases (breach location A) by using a geometry with buildings and without buildings. A comparison of those results is presented in Appendix 13. Generally, the calculated water levels were higher in the cases where buildings where taken in to account (maximum difference about 0,5 m). The propagation of a flood wave was generally a bit slower when the buildings were taken in to account. However, the effect on propagation speed was not very significant. The effect of buildings on damage parameter was not very significant in the case of Seinäjoki DBHA and can not be seen as very important for the planning of emergency actions. However, in some other cases the effect may be greater.

The effect of urban areas and floating debris in dam break modelling is presented in a RESCDAM seminar paper by Reiter (Considerations on urban areas and floating debris in dam break flood modelling).

3.9 Analyses of the results

The following analyses were decided to be done by the partners EDF and Enel.Hydro during the RESCDAM project:

RUN 1	Base flow in Seinäjoki River 150 m^3/s ($HQ_{1/100}$) + breach hydrograph for max reservoir level, roughness varies between Stricler 15 (Manning's n = 0,06666) and 40 (Manning's n = 0,025).
RUN 2	Base flow and breach hydrograph as in RUN 1, roughness is constant for the entire modelling area with Strickler 15 (Manning's n = 0,06666).
RUN 3	MQ base flow + breach hydrograph, constant Manning n varying in the entire modelling area according to land formation and vegetation and according to the experience of EDF and Enel.Hydro.
RUN 4	$HQ_{1/100}$ base flow + breach hydrograph, other conditions as in RUN 3.
RUN 5	Conditions of RUN 3 modified according to the partners choice of modelling buildings (EDF: porosity, Enel.Hydro: geometry).
RUN 6	Conditions of RUN 4 modified according to the partners choice of modelling buildings (EDF: porosity, Enel.Hydro: geometry).

The breach location was assumed to be location A for all these analyses. Runs number 5 and 6 were done for the whole area only by Enel.Hydro, while EDF used a smaller sample area.

In the RESCDAM project, the reason behind using different models to simulate the same case was not to compare the computational algorithms. The reason was to get an idea how much the results differ depending on the models and the modellers using their own approaches. The comparison of different models and solution algorithms have recently been done in the CADAM project.

The partners get the land use data in the 10 m x 10 m grid which was derived from the terrain model data. The computation area was divided into 6 land use areas and the modellers used their own judgement for choosing the friction factors for different areas.

In an separate report (Appendix 14) the results of calculations made by Enel.Hydro and EDF are compared together with the results of 1-d simulations. The water level comparison is done on different locations downstream of the dam. The progression of the dam break flood is also compared on maps.

According to the comparison the results calculated by EDF and Enel.Hydro seems to be relatively close. There is a greater difference between the two dimensional models and the 1-dimensional model. The 1-dimensional simulations were made only for constant Manning's n (n = 0,06) and this may be the explanation for some of the differences. However, in the case of very complicated topography, such as the Seinäjoki case, the use of a 2-dimensional model seems to be more reasonable. The use of a 1-dimensional model needs a lot of experience since the cross-sections have to be put at the right locations. The use of a 2-dimensional models is more straightforward.

3.10 Results for emergency actions

During the RESCDAM project it was observed that the original modelling area is too small and simulations were extended to include the northern area of Seinäjoki (the area behind the railway). The simulations were first made using a 1d-model by the Finnish Environment Institute and that provided a rating curve for the flow over the railway for use by the partners. Later the Finnish Environment Institute made the calculations for the whole area using a Telemac-2d model by extending the mesh generated by EDF to the area behind the railway. The six simulation cases were calculated by the Finnish Environment Institute using Telemac-2d:

- $HQ_{1/100}$ breach locations A, B and C
- MQ breach locations A, B and C.

The roughness coefficient was constant n = 0,060 for all these cases.

In the beginning of the project, the 1-d modelling results and the results calculated by EDF and Enel.Hydro were used in the emergency action planning. The "final" results for the emergency action planning were the results calculated by the Finnish Environment Institute by using Telemac-2d model.

The results of DBHA for rescue actions consists of inundation maps, water depth maps, hazard parameter maps as well as water level and velocity hydrographs and tables. Animations were also produced to demonstrate the consequences. In the RESCDAM project the results were transferred to a GIS system and different results could be analysed together with the database information of buildings and inhabitants. That information could be used to get damage and loss of life estimates.

The following maps are presented as Appendices (a for screen viewing, b for A3 printout):

Breach location A

- $HQ_{1/100}$ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 15a and Appendix 15b
- $HQ_{1/100}$ maximum flow velocities: Appendix 16a and Appendix 16b
- $HQ_{1/100}$ maximum flow depth: Appendix 17a and Appendix 17b
- $HQ_{1/100}$ maximum damage parameter (velocity x depth): Appendix 18a and Appendix 18b
- MQ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 19a and Appendix 19b.

Breach location B

- $HQ_{1/100}$ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 20a and Appendix 20b
- MQ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 21a and Appendix 21b.

Breach location C

- $HQ_{1/100}$ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 22a and Appendix 22b
- MQ maximum flood inundation and flood inundation for 0,5 h, 1 h, 2 h and 3 h after the initiation of the dam break: Appendix 23a and Appendix 23b .

3.11 Conclusions

Dam break hazard analyses (DBHA) provide information on the consequences of a possible dam failure for emergency action planning and risk analysis (downstream risk to population, property and environment). Numerical models are used for DBHA to determine the flow through a dam breach and to simulate flood propagation in the downstream valley.

To determine flow hydrographs through the dam breach opening is crucial to the results of a DBHA. In the RESCDAM project a numerical erosion model for the breach of an embankment dam has been used to define the flow hydrographs. There are a lot of uncertainties in the determination of a breach hydrograph and sensitivity analyses have to be used to ensure the results.

In the RESCDAM project several modelling approaches have been used in flow modelling. A one-dimensional flow model and two different two-dimensional models have been used in the calculations. The results shows that with careful modelling and accurate data the results of different modelling approaches may be relatively close each other. However, there is a lot of uncertainties in the modelling and specially in the one-dimensional flow modelling where the user of the model can have a significant effect on the results by selecting the locations of cross-sections carelessly. The debris flow, clogging of bridges and other structures and erosion of flooded areas also cause uncertainties in the flood simulation and those uncertainties must be taken into account.

In the RESCDAM project, special methods have been tested to model the flow in urban areas. The results of EDF, where a porosity approach was used, and Enel.Hydro, where a geometry approach was used, are promising and provide a good basis for further development. In the case of Kyrkösjärvi DBHA, the special treatment of urban areas in flow modelling did not seem to have any significant effect on the values of damage parameters and can not be seen as very important for emergency action planning. However, in some other cases the effect may be greater.

The concrete results of the DBHA for emergency action planning consist of inundation maps, water depth maps, damage parameter (flow velocity times water depth) maps as well as water level and velocity hydrographs and tables. The results of DBHA should be presented in such a way that they can be used efficiently in the emergency/rescue action planning and risk analysis. The use of the Geographical Information System (GIS) is essential for that purpose. In the RESCDAM project, the DBHA results were transferred to a GIS system where the results were analysed together with other GIS data. The flood animations, that were used extensively in the RESCDAM project, seem to be very useful tools in presenting the flood simulation results to people without any special knowledge on the subject.

There are several topics in dam break hazard analysis that require additional research. According to the DBHA of the RESCDAM project, the following topics are of primary importance:

- Determining a dam breach formation (flow hydrograph).
- Determining roughness coefficients used in flow simulations.
- The effect of debris flow and urban areas in a DBHA.

REFERENCES

ICOLD. 1998. Dambreak Flood Analysis. ICOLD Bulletin 111, 1998.

Loukola, E., Huokuna, M. 1998. A numerical erosion model for embankment dams failure and its use for risk assessment. Proceedings of the CADAM Workshop on Dam Breach Formation and Development. Munich.

Morris, M.,W., and Galland, J., C. 2000. Dambreak Modelling - Guidelines and Best Practice. CADAM project.

Vehviläinen, B. 1994. The watershed simulation and forecasting system in the National Board of Waters and Environment. Publications of the Water and Environment Research Institute No 17. National Board of Waters and the Environment. Helsinki.

4 INTERNATIONAL SEMINAR AND WORKSHOP

4.1 Introduction

In keeping with the general objectives of the RESCDAM project, an international seminar and a workshop were organised in Finland on October 1-5, 2000. The results of the RESCDAM project had created a basis for the seminar and workshop activities. The activities included a visit to the Emergency Services College, Kuopio (October 1, 33 participants), the seminar (October 2-4, 76 participants) and the workshop (October 4-5, 51 participants). There were 32 foreign participants in the seminar, 8 of whom came from outside Europe. Participants came from the following countries: Austria, Canada, Denmark, Egypt, Finland, France, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the USA. In addition, Mr. Ernst Schulte from the European Commission, unit " Civil Protection and Environmental Accidents", participated in the seminar.

The visit to the Emergency Services College, Kuopio on October 1, 2000 gathered a group of twenty foreigners and more than ten Finnish participants. The visitors were introduced to college activities and rescue arrangements in Finland, the exercise and training area of the college and saw two rescue demonstrations. One of the exercises dealt with rescue operations after a traffic accident, the other with a water accident.

4.2 Seminar

The seminar was held in Seinäjoki on October 2-4, 2000. The detailed programme of the seminar and workshop and seminar papers can be viewed separately (click here).

The seminar dealt with:

- Introductions to emergency services and dam safety arrangements in Finland and introduction to the RESCDAM project.
- Lectures: A Simple Procedure for Estimating Loss of Life from Dam Failure (W. Graham, USA), Towards Improved Life Loss Estimation Methods: Lessons from Case Histories (D. Bowles, USA), Risk and Reservoirs in the UK (M. Morris,UK), Dam Risk Management at Downstream Valleys: The Portuguese Integrated NATO Project (A. Betâmio de Almeida, Portugal), Digital terrain modelling for flood analysis and impact assessment in emergency action planning (J. Sarkkila, Finland).
- Sessions 1-4: risk assessment, mathematical and physical modelling to simulate a dam break flood, emergency and rescue arrangements, pilot project Kyrkösjärvi dam and other practical case studies.

The questionnaire before the seminar to EU countries and associated countries made by the Finnish Environment Institute produced eight replies (see seminar papers). The questionnaire dealt with legislation and guidelines, monitoring and inspection, dam break flood analysis, warning and alarm systems and emergency action planning. According to the replies, dam safety practices vary considerably in different countries. The practice concerning dam safety legislation, for instance, may be specific dam safety legislation, water legislation, environmental legislation, emergency management legislation, or there may be no specific legislation. Each country does, however, have a system of its own concerning dam safety and emergency/rescue arrangements.

4.3 Workshop

The workshop took place on October 4-5, 2000. Participants were divided into four groups according to their professional experience, i.e. dam owners, emergency services, administrators and researchers.

4.3.1 Group work 1 - Emergency action planning

The components of a feasible action plan for dam emergencies were thoroughly discussed. Several aspects were taken into consideration, i.e. the content of such a plan, responsibilities of different interested parties, action in different phases of an emergency, implementation of the plan, information dissemination, and organising training.

The participants expressed the opinion that the aim of the emergency plan is the safety of the upstream and the downstream population. The emergency action plan (EAP) should contain both emergency preparedness and emergency response. A risk assessment should be completed to identify critical links and points. Thorough knowledge of the dam is required before a plan can be developed. Not all dams are identical, nor should the emergency plans be identical: a dam with a higher risk should have a more detailed or refined plan.

It was suggested that the components of the plan were to include, among other things, the roles and responsibilities of the owner's staff and a definition of warning levels based on severity and defined according to quantitative or semi-quantitative observations. The EAP should define the procedures based on warning level. Such information as names, titles, phone numbers, alternative contact, etc. of response personnel should be included in the plan.

There were different approaches to the question of responsibility for creating the EAP and how many plans are actually needed for one dam. Some participants suggested that only one EAP document should be created and the responsibility of the owner is the notification of the downstream agencies and providing key information to enable effective planning by the agencies. The contingency action planned by the dam owner should be integrated into the final EAP. Other participants expressed the opinion that there should be two EAPs, i.e. a plan of the dam owner and a plan of downstream authorities with co-ordination between them.

An opinion was also expressed to the effect that there should be a number of emergency plans: one for the owner, those for the downstream agencies and one for overall co-ordinating authorities.

All participants agreed that a dam break scenario was a useful tool for the planning of emergency action. However, some of the participants suggested only a maximum case to be used for the development of the EAP, whereas others preferred at least two - dry and flood - cases to be taken into consideration. Nonetheless, it was agreed that the simplified cases should be used due to the problems with handling complex data in an emergency situation.

Action in different stages of emergency

All four groups agreed that early warning of a dam break threat is of great importance. In many countries dams are located close to an urban infrastructure with a large population at risk. Therefore, time is an important factor for the success of rescue action. Early warning systems should be supported by automatic monitoring connected to the alarm system. It was also stressed, however, that the efficiency of early warning should not be taken for granted.

Many useful remarks were made concerning evacuation and rescue activities:

- There is no legal requirement to make people leave their homes.
- The limited capacity of the rescue teams makes it impossible to evacuate everybody.
- The preferred situation is when people evacuate themselves with the support of emergency services organisations; "carry-to-safety" evacuations is not a good solution.
- Different opinions on whether elderly people, disabled people, homes for the elderly, schools, hospitals or prisons should be of a special concern in the EAP. Special considerations based on legal requirements vs. limited capacity of emergency personnel in a short period of time.
- It is recommended that flood zones be defined on the basis of a shelter possibility, e.g. safe at home but unsafe on the road. Zones which must be evacuated should be defined.
- Potential control - co-ordination - command problems in a crisis situation should be taken into consideration in advance.
- The time needed for performing certain actions, for instance evacuation, should be estimated and checked. Table-top exercises were suggested.

Implementation and training

Although the participants had varying opinions on who was responsible for preparing the EAP, they seemed to agree that it should be implemented by a local authority - the fire brigade, the police, a civil protection organisation or similar. It was not recommended to have state or provincial authorities in charge.

Training is an important part of developing the EAP. It gives planners an opportunity to identify weak points. Different exercises ranging from table-top exercises to functional exercises indoor and complete outdoor exercises were recommended. Concerning full scale outdoor exercises, the working groups recommended that the public should not be involved in the training action.

Updating

It was generally agreed that updating the EAP is an integral part of the dam safety improvement. Regular updates of the EAP can be performed during regular dam safety inspections – with a time interval of 3-5 years.

4.3.2 Group work 2 - Public information campaign

Making the public aware of a dam break risk is a delicate matter and should be approached with care. Workshop participants suggested that dam safety information should be consistent and honest. In order to improve the chances of a successful implementation of the EAP in the case of a dam break, the public should be told about its functions and the responsibilities of different interested parties. Dam owners and emergency service organisations should work together while introducing the EAP to the public. As a rule, the general public should not be underestimated as a recipient of information.

To avoid panic or unnecessary stress while conducting public information campaign, it was recommended to stress the positive sides of a dam and its overall safety. A proposal was made to the effect, that creating an EAP might be explained either as a way of handling a small risk of a failure or as a way to make a safe dam even more safe. It is important that people realize that a dam break flood is not a wall of water. One of the purposes of conducting information campaign is to give the public peace of mind as far as the dam is concerned.

When and how to conduct a public information campaign

Who should participate: population at risk if a dam breaks, businesses in the area concerned, the media, representative of the municipality, the dam owner, the official in charge of emergency services, the water authorities in charge of river basin operations.

Information distributed to the public should concentrate on a dam and its benefits, the low risk, the EAP created to counter the risk.

Stages of information dissemination: before the emergency, while preparing the EAP, after it is ready, after it is tested during an exercise/emergency, after emergency.

The potential problem of information overload has to be addressed: how to get the message through, pictures and demo-animations effective and easy to understand, information should be kept simple.

Responsibilities of different interested parties:

- A dam owner should provide technical information on the dam and its safety monitoring. All the risks, even the small ones, are to be addressed.
- Emergency services organisations should inform people about the alarm systems, places to evacuate to, how to behave. People should be reminded that it is vital to their safety to respond to a warning.
- The campaign should be led by local, well known people. However, high rank officials representing the dam owner and the municipal authorities should be present so as to make the public take the campaign seriously.

Campaign effectiveness:

- Determine whether the information was received correctly.
- Perform an exercise, let the public be informed in advance and observe the reactions after the alarm signal.
- Involve the media in the exercise.
- Distribute questionnaire to check the level of public awareness on dam safety matters.

4.4 Achievements of the seminar and workshop

- The seminar and workshop gave a possibility for dam owners, water officials, risk experts and emergency/rescue officials to meet, to have discussions and to find subjects of mutual interest.
- The lectures provided an excellent background on dam safety issues.
- The seminar provided an opportunity to compare the practices in this field of the European and the North American countries.
- An interest for future co-operation was expressed by the participants from Europe as well

as those from the USA and Canada.

- Practical comments expressed during the workshop were important since they gave confirmation of the Finnish Code of Practice as well as stimulating improvement. The contributions proved to be very valuable for the RESCDAM project development.

5 EMERGENCY ACTION PLANNING

5.1 Introduction

The main purpose of the RESCDAM project was to develop emergency action planning in the event of a dam failure. The topics of the emergency action planning are approached from the point of view of rescue authorities. Rescue services consist of the following (see Act on Rescue Services in Appendix 25):

- The prevention of fires and other accidents unless otherwise provided for in another Act or Decree.
- Rescue activities referring to the emergency measures to be taken in the event or under threat of accidents in order to protect and rescue people, property and the environment, to limit the damage and to minimise the negative consequences.
- Civil defence as concerns the protection of people and property, the safeguarding of the operations of agencies, institutions and production plants important to the operations of society.

For P dams, an emergency action plan shall be drawn up jointly by the dam owner or holder and the rescue authorities. A hazard assessment (a dam break flood analysis) is always the basis for an emergency action plan. A dam is classified, according to the Finnish Dam Safety Code of Practice, as a P dam if, in the event of an accident, it may manifestly endanger human life or health or seriously endanger the environment or property (see Chapter 3.1 in the Dam Safety Code of Practice).

The team for emergency and rescue action planning in the RESCDAM project was: Tomi Honkakunnas, Training Manager from the Provincial Rescue Association of Oulu, Jyrki Paunila, Fire Chief from Seinäjoki Fire Brigade, Heidi Lepistö, Dispatcher from the Emergency Response Centre of Southern Savo and Kari Syvänen, Engineer from the West Finland Regional Environment Centre.

Dam safety is an issue for a few people only, such as dam owners or dam holders, the rescue and environmental authorities. Only a few of these people have been faced with a serious dam failure or dam emergency situation. In case of an extensive accident, situation management is almost impossible without advance planning.

The execution of emergency and rescue operations is often based on experimental knowledge. Certain kinds of accident, like building and forest fires, have occurred for centuries. The method that was successful during the last fire fight operation is also used to fight the next similar fire. Methods are developed and improved with increasing experience and knowledge.

Experimental information about dam emergencies is not available as readily as it is with more frequently occurring emergencies. Rescue operations must be based on theoretical knowledge about the character of the accident and conditions. At the same time experience from other types of emergencies must be adapted. Lack of experience is also a problem when considering the emergency action plan of a dam. It is difficult to prepare an emergency action plan for an event that can only be imagined.

However, in the rescue services, there is not much research into dam safety. The RESCDAM project offered an opportunity to acquire information about the planning of rescue and emergency services in other countries and to develop emergency planning for water course dams in Finland. Within the scope of this project, the sufficiency of dam safety guidelines controlling emergency action plans of dams, was also assessed.

The RESCDAM project also included the thesis in the Emergency Services College concerning the warning and evacuation of the population and rescue operations in a dam failure situation (Honkakunnas & Lepistö 2000). Findings of the thesis have been used for the emergency action plan of Kyrkösjärvi dam (Appendix 24) and for recommendations to update the current Finnish Dam Safety Code of Practice (Appendix 25).

5.2 Organising the warning and evacuation of the population and rescue operations in a dam failure situation

Dam failure is an extremely demanding accident situation to everyone involved. A strong water flow, varying water depth, floating debris, damaged road network and power supply etc. makes the situation especially difficult for rescue operations. Thus the population in the danger area must be evacuated before the arrival of a flood wave.

The essential part of warning the population is to get the population to take the action necessary. People must be convinced of the reality of the danger and they must be advised to act according to the instructions of rescue authorities. A mere warning is often not enough. People in danger need instructions on how to save themselves from a threatening situation. Their actions must be monitored and corrected if necessary.

Two main groups of action related to alerting a large population are demonstrated in Figure 8. They are action taken by authorities and dam owner, and action taken by individuals and the community. Prompt warning and evacuation of the population cannot be successful without the population in danger also acting. Nothing happens, if people are not informed about the seriousness of the accident.

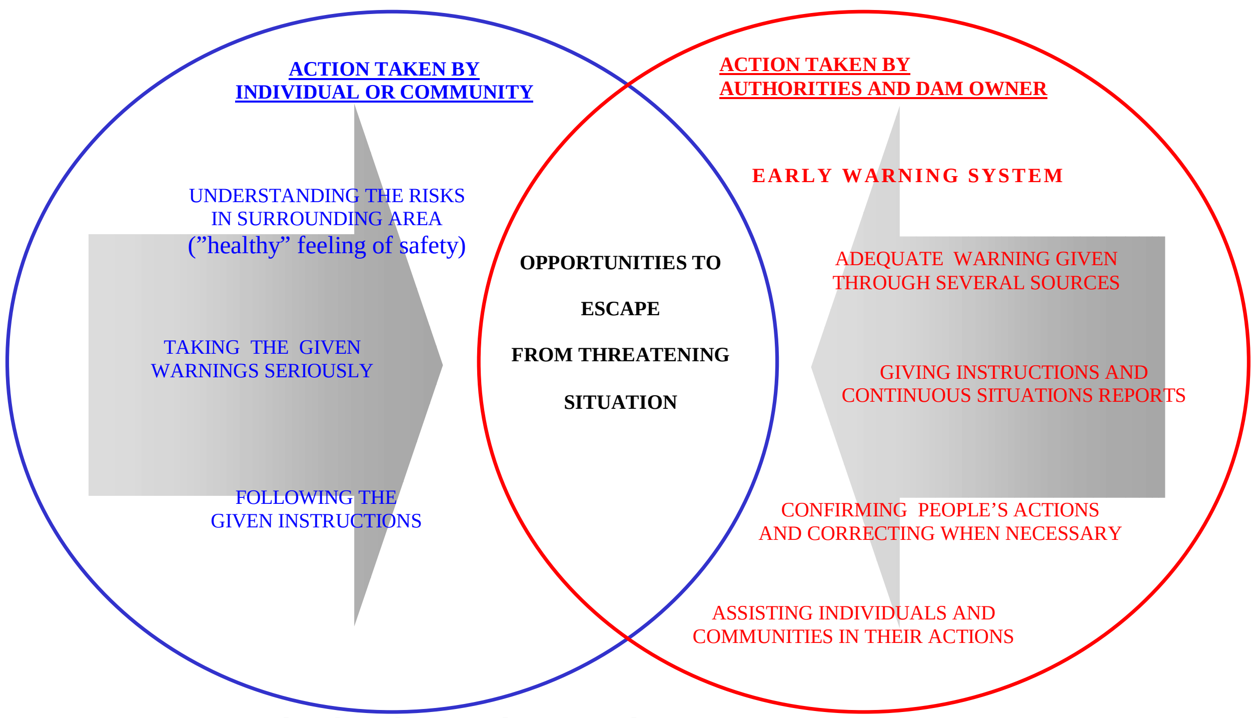

Figure 8. Action related to alerting a large population.

If people are adequately warned about the accident without sufficient instructions, they normally cannot take action the way rescue authorities anticipate. The actions of a population in a danger area, as well as actions of the dam owner and rescue authorities will fail, if dam failure is detected too late.

5.2.1 Emergency information

Definitely the most important factor affecting the warning, evacuation and rescuing of the local population is the time period between dam failure and notification of the failure and commencement of the rescue operation. If a dam failure alarm is given late, the conditions for making emergency repairs to the dam are poor and the probability of human casualties increases. At the same time the benefit from the public alarm system installed to the dam danger area is lost. The notification speed of the dam failure has been observed to have a direct correlation to the loss of human life (Douglas et al. 1999**,** Lemperiere 1999). The safety monitoring of the dam must correspond to the risk factors of the dam. The greater the failure risk of the dam, the greater the demands on dam safety monitoring functions.

5.2.2 Warning of population

The credibility of following warning methods and achieving the necessary action was assessed (Honkakunnas & Lepistö 2000):

- public warning signals (sirens)
- emergency bulletin on the radio
- loudspeaker vehicles of rescue units
- telephone and mobile phone (group calls)
- warning people indoors from house to house.

Public warning signals are best suited to urban areas, because an alarm can be given quickly and a large population can be reached. The working state of equipment is generally secured using backup batteries, to make sure the system is independent from an external power supply. Spoken messages and instructions can also be given using modern electronic equipment (see Chapter 5.2 in Appendix 24).

One problem with public warning signals is the credibility factor – do people believe that the danger is real. In addition to a public alarm signal, attention must be paid to the visibility of the warning. The effect of the alarm is emphasised by loudspeaker equipment mounted on rescue units. This way people receive a visual confirmation of the given warning. In addition to this, there is a practice in Finland, that a public warning signal includes an emergency bulletin on the radio (see Emergency bulletin in Appendix 24). This bulletin can be broadcast on all radio channels (within 10-15 minutes). The radio bulletin includes information on the reason for the warning and instructions required by the situation. Rescue units circulating in the residential areas with emergency bulletins on the radio make it possible to warn people indoors.

A public warning signal and rescue units announcing the warning do not require much personnel and do not strain the personnel of an emergency response centre. A greatly increased number of calls to the emergency number 112 after a public warning signal may cause problems. Calls may block the telephone traffic of an emergency response centre even though the public is instructed not to use the telephone.

The telephone is also a suitable warning method in sparsely populated areas. Households in the danger area are called systematically and people are informed about the threatening situation and the action required. Since this method is cumbersome, there may be problems if a large number of households is to be warned. The warning process takes a long time and requires a great number of personnel. In cases like this, the warning should go out through group calls. Using group calls, several households can be warned with one telephone call. Accuracy of contact information is essential when using the telephone.

People indoors are reached by phone, as are people outdoors if mobile phones are in use. Reaching people outdoors requires public alarm signals and loudspeakers mounted on rescue units.

If telephones or rescue units are used in a warning capacity, a warning operation is initiated in the order of urgency determined by the flood wave caused by dam failure. Operational efficiency is improved, if the danger area of the dam is divided into numbered areas of responsibility according to the same urgency order (see Plan map of rescue services in Appendix 24).

5.2.3 People's reaction to warnings

Warning the population is often something of a problem. The actual warning process and the technical solutions required, is simple (the main problem being money), but it has been difficult to assess human behaviour beforehand. Based on findings during the RESCDAM project and general experience in Finland the following behaviour patterns are discernible (Eränen 1994, Honkakunnas & Lepistö 2000):

- As a rule people believe that their environment is safe.
- People often fail to react to given warnings.
- Before acting, people assess the reality of the threat and the danger to themselves in the face of an emergency.
- People tend to seek information to confirm their assessment. The source of information might be a friend, a neighbour, the authorities etc.
- Peoples decisions depend on their social status (age, family, employment etc.).
- People act as a social group.
- In addition to warnings, people need instructions.

5.2.4 Advance informing on the risk of dam failure

The success of a warning operation is partly dependent on the fact that the population is aware of living in a dam danger area. If a lot of people, whose safety the rescue services cannot guarantee in case of an emergency, are living in a dam danger area, an independent initiative is also required for escaping the danger area. The population must be aware of the possible personal danger so that they can protect themselves and act on their own in case of an emergency. The necessary information can be distributed through an advance information bulletin (see Safety bulletin in Appendix 24). This bulletin is based on a risk factor determination. In addition to the action of rescue services, some action on the part of the population in the danger area, is also required to control the risk and to avoid casualties. People are given the opportunity to prepare for an emergency and to form an image about the protection instructions given by rescue authorities and about their own actions in case of a dam failure as described in the bulletin.

This bulletin has a special purpose due to the nature of a dam failure. In case of a chemical or radiation emergency, the population may be able to protect themselves in their homes, but in case of a dam failure the situation is different. Some buildings fill with water and collapse due to structural strain of masses of water, whereas some buildings remain intact. The bulletin is very important for the credibility of the warnings and decisions about action taken in a dam failure situation. The bulletin decreases the need for an individual to find further assurance of the threatening danger and gives a prepared operational model for escaping the danger area. In this situation, even a short warning time may allow the correct procedure to be followed in keeping with instructions from the responsible authority.

This project showed that a bulletin must be prepared with information on the dam, along with safety monitoring of the dam and an emergency action plan in case of a dam failure. This was also mentioned in the recommendation for the development of the Finnish Dam Safety Code of Practice.

5.2.5 Evacuation of the population and supplying an evacuated population

The success of an evacuation (see Chapter 5.2 in Appendix 24) greatly depends on the success of the warning operation. If people are not convinced about the reality of the danger, evacuation becomes more difficult.

When planning the evacuation, the emergency action plan of the dam including the inundation maps and damage parameter maps must be examined to make the decision on the areas to be evacuated. On the other hand, the situation is effected by the behaviour of the population. An assessment might show, that water levels will rise only slightly in some houses of the area. People would cope well, if they stayed indoors, but some of the people will surely seek their way to dry land and thus be in danger when moving in flowing water.

The purpose of warning and evacuation is to evacuate areas that will be flooded according to the inundation maps. This applies in particular to buildings without upper storeys. Rooms below ground must always be evacuated. If there is not enough time to evacuate the population from under the flood, people might have to be rescued, as they try to get to dry land from the flood.

Rescue authorities carry out evacuation in danger areas. Taxis, local buses and ambulances are used as evacuation vehicles in the evacuation organised by the rescue authorities. If people living in the danger area leave on their own, they go on foot, use their own vehicles or other means of transportation. When warning and evacuating people, they are instructed to take personal medication with them.

Vehicles used for evacuation are alerted to specified meeting places by the emergency response centre. There drivers are given their tasks as well as instructions and materials required to execute the tasks. Subsequently vehicles are sent to the evacuation areas to execute their evacuation tasks. Evacuation units execute the evacuation under the supervision of the personnel of rescue services. Vehicles are not to proceed with the evacuation on their own, since drivers may have problems managing anxious people on their own.

Evacuated people are taken to evacuation centres. These centres are organised by the social and health services using voluntary rescue service personnel. The location of the evacuation centre must be planned so that a dam failure does not have an effect on its water and heat supply, distribution of electricity and sewage system. Four schools were chosen to be evacuation centres in Seinäjoki (see Plan map of rescue services in Appendix 24).

The following supply services (see Chapter 8.1 in Appendix 24) are organised in the evacuation centres:

- first aid
- crisis bulletin for evacuated people, their families and people who have lost their homes
- psychosocial help for evacuated population and people who have lost family members or friends
- catering and clothing for evacuated population
- temporary accommodation.

The evacuation period may be long, since repair work on buildings and site work may be hampered by wet conditions or damage incurred by the flood and may take anything from days to months. When emergencies that require evacuation were examined, it was noted that about half of the evacuated people stayed with their relatives and families and did not need the organised temporary accommodation (Eränen 1994). Social services must, however, be prepared to organise temporary accommodation.

5.2.6 Rescue operations

One of the golden rules of rescue operations is ”control the greatest threat first”. The starting point of a rescue operation must be the warning and evacuation of the population so that an actual rescue is unnecessary. In the emergency action plan there must be an assumption that people may have to be rescued from the water or from buildings surrounded by water (rescue operations: see Chapter 5.1, Chapter 5.3, Chapter 5.4 in Appendix 24).

Determining areas of responsibility (see Plan map of rescue services in Appendix 24)

The danger area is divided into areas of responsibility when rescuing people in danger the same way as warning and evacuating people. Rescue services personnel occupy these areas of responsibility in the order of urgency. A water rescue readiness is required, as the capability to operate in a traffic accident situation in every area of responsibility.

The determination of areas of responsibility facilitates efficient use of resources, helps the response management and enables the starting of an evacuation simultaneously in several areas.

Rescue methods

Equipment suitable for warning the population is emphasised when considering equipment for rescue operations. The planning of rescue operations must include the capability for water rescue.

Rescue parameters must be considered when preparing the emergency action plan. The main influences on water rescue are flow velocity and depth of water. Debris in the flood water also affects rescue operations, posing a threat to boat engines and rescue personnel. Underwater diving is a very high-risk activity in fast flowing water with debris. Underwater rescue operations should not be undertaken in dam break situations if the safety of the rescuers cannot be guaranteed. Surface rescue operations carried out from the shore (by swimming) are not suitable in a strong water flow.

The best rescue method is using a helicopter (Figure 9). It can be used in rescue operations under a number of different water flow conditions. A personnel lift in the helicopter is essential for the rescuer to be able to descend to a person in danger. Rescuers participating in lift rescuing must have the appropriate training. Mention of the required equipment is essential when alerting the helicopter. Helicopters without a lift can be used to find people afloat or surrounded by water as well as to help in the management operations and transporting injured people.

Figure 9. Helicopter of the Border Guard performing a surface rescue operation during dam failure training at Uljua in Finland, 1999.

Prevailing flood conditions are very important as concerns the use of boats in rescue operations. A boat with a jet engine can function in strong flowing of water and at low water, but the turbine and the cooling system is exposed to debris. The study to thirty fire brigades (Honkakunnas & Lepistö 2000) suggests that instead of a jet engine, a strong outboard engine is recommended for flood conditions corresponding to those of a dam failure situation.

5.3 Emergency action plan for Kyrkösjärvi dam

The emergency action plan for the Kyrkösjärvi dam (Appendix 24) is based on a dam break hazard analysis (Chapter 3). In the worst case scenario, a dam failure may cause a flood that covers in excess of 10 km^2 of populated areas and about 1400 buildings. A dam failure will directly or indirectly affect the lives of many thousands of people. A flood will cause significant damage to the distribution of energy, water, the road and railway network, sewage and businesses in the town of Seinäjoki. A dam failure would cause a serious emergency in Seinäjoki and the resources of the town are not adequate for dealing with the situation. The danger to human lives depends mainly on how fast a dam failure is detected.

The emergency action plan for the Kyrkösjärvi dam is prepared mainly according to the existing Finnish Dam Safety Code of Practice. Plans for warning the population are emphasised in order to make certain that an evacuation proceeds as required. More attention is paid to instructions of the emergency response centre, medical rescue services and informing the public and the organising of supplies to the evacuated population.

A sufficient guarantee of successful rescue operations must be taken into account when preparing an emergency action plan. The basis for planning should be the worst possible emergency situation. In the emergency action plan of Kyrkösjärvi, the dam failure will occur during a natural flood in the water body. The dam will fail without warning and in the worst possible place. Other possible failure scenarios were also considered.

The preparation of an emergency action plan is almost entirely based on the flood information from the hazard assessment of the dam. Flood information must be prepared in such a form that rescue services are able to interpret and process it to their own use. During the project work, inundation maps were produced from the three-dimensional digital terrain model (see Chapter 3 and Appendices 5-11 in Appendix 24).

Emergency action plans prepared earlier in Finland are mainly prepared on paper maps. MapInfo software (or some other geographical information system = GIS) allows the processing of more information. Several different kinds of database combined with co-ordinates can be used to aid planning. Examples of this kind of database include population, road network and building register data as well as various maps. These improve the quality of planning to a great degree and facilitate the preparing and updating of plans. The results of the RESCDAM project are very significant in this area.

5.4 Recommendations to update the Finnish Dam Safety Code of Practice

Legislation and guidelines concerning dam safety and emergency action plans for dams are quite sufficient today and they form a good basis for maintaining dam safety. Recommendations for the development of the Finnish Dam Safety Code of Practice presented in Appendix 25 do not change the present planning practice very much. The recommended changes do, however, have a great influence on the practical implementation of dam safety work.

Each dam in Finland subject to the Dam Safety Act has a safety monitoring programme. It is recommended, that when revising the current Dam Safety Code, an addition concerning an automatic monitoring system should be considered. Some P dams in Finland would be the principal candidates needing an automatic monitoring system, P dams such as the embankment dam of the Kyrkösjärvi reservoir. A primary function of an automatic monitoring system is to reveal abnormalities in real-time and thus provide an early warning of potentially serious incident or a dam failure.

One of the most significant changes influencing dam safety concerns the spreading of information. Today, information about dam failure risk and about the emergency action plan should be directed to the population in the danger area. The word “should” gives the dam owner and authorities a lot of opportunities avoid action and has normally lead to a situation with no information at all. With the RESCDAM project it was noted that advance information has a great significance when warning the population. The project recommendation suggests that the population in the danger area must be informed about the emergency action plan and about the risk of a dam failure.

The redrafting of the Act and Decree on Rescue Services as well as the regulations based on this legislation influence the Dam Safety Code most of all. These parts of the recommendation mainly concern updating the Code.

5.5 Conclusions

The important part of preparing an emergency action plan for a dam must be in organising the warning, alerting and evacuation activities. The consequences of a dam failure as well as the conditions following the emergency are very difficult for rescue operations, and evacuation before the arrival of flood waters must be the main line of approach. In addition to the development of warning and evacuation procedures, an automatic dam monitoring system to provide an early warning of a potentially serious incident or a dam failure, should be developed further. In the RESCDAM project seminar it was very unambiguously stated that the risk of human casualties is strongly influenced by the time lag in a dam failure alert. If the failure is not noticed early enough, the benefit gained from public warning sirens is lost and people do not have enough time to escape from the flood area.

The dam failure risk should also be taken into account in construction code legislation. Assembly rooms, hospitals, maintenance institutions and corrective institutions should not be built in the dam danger area, because the evacuation of such buildings is very difficult in an emergency situation. Buildings in the danger area should be built in such a manner that dam failure will not endanger people living in the buildings.

When preparing for a dam failure, it is important to consider human behaviour in a crisis situation. Studies of this topic show that people do not always believe in the reality of warnings. Home is generally considered a sanctuary and leaving home is no easy step. In the planning and implementation of rescue operations, the compliance with warning and evacuation instructions must always be ensured using vehicles with a loudspeaker system moving in the danger area and rescue units going from house to house.

Compliance with warnings and instructions given by authorities can be made easier by issuing a safety bulletin to people in the danger area in advance (see Appendix 12 of the Kyrkösjärvi emergency action plan). In Finland this kind of advance information has generally been a matter of recommendation , as opposed to a regulation. Advance information does play an important part in the success of rescue operations and as such it should be a routine requirement.

The hazard assessment of a dam together with inundation maps for the flood area subsequent to a dam failure are only the first steps for an emergency action plan prepared by rescue services. The needs of rescue services must be noted when presenting the flood information and inundation maps. The availability of maps in digital and printout form should be further developed. Digital maps were developed by the RESCDAM pilot project of Kyrkösjärvi dam. These maps can also be applied to other dams and results and reactions have been very promising.

REFERENCES

Douglas K., Spannagle M. and Fell R. 1999. Analysis of concrete and masonry dam incidents. Hydropower & Dams, Issue Four 1999.

Eränen, L. 1994. Katastrofipsykologia (Catastrophe Psychology). VAPK-kustannus, Valtion painatuskeskus. Sisäasiainministeriö (Finnish Ministry of the Interior). Helsinki. In Finnish.

Honkakunnas, T. & Lepistö, H. 2000. Opinnäytetyö Pelastusopiston päällystökurssilla 8: Väestön varoittaminen, evakuoiminen ja pelastaminen pato-onnettomuustilanteessa. (Thesis of the Fire Officer Course 8 in the Emergency Services College: Warning and Evacuation of the Population and Rescue Operations in a Dam Failure Situation). Kuopio. In Finnish.

Lemperiere, F. 1999. Risk Analysis: what sort should be applied and to which dams? Hydropower & Dams, Issue Four 1999.

Saukonoja, I. 1999. Pelastustoiminnan johtaminen kriisi- ja suuronnettomuustilanteissa (Managing rescue operations in crisis and large accident situations). Julkaisematon (Unpublished). Pelastusopisto (Emergency Services College). Kuopio. In Finnish.

6 CONCLUSIONS AND FURTHER DEVELOPMENT

Risk assessment (see Chapter 2)

According to the risk analysis for Kyrkösjärvi dam, the safety of Kyrkösjärvi dam may be considered to be on an acceptable level on specific conditions presented (see Chapter 2.4.2 of this report or Chapter 7.5 in Appendix 3). One of the primary considerations is to scrupulously follow the monitoring programme, including annual and regular (every five years) inspections.

The concept of probabilistic risk analysis may be used for different purposes and at different levels (see Chapter 2.4.3 re-printed from Chapter 8 in Appendix 3). The application example of the risk analysis of Kyrkösjärvi dam may be included as a basis for decision-making when making a selection among different remedial actions and upgrading old dams within the prevailing restraints of time and finance.

According to a study written by Slunga (Appendix 3) there are still many areas, where further guidance is required (see a list in Chapter 2.4.3 re-printed from Chapter 8 in Appendix 3).

The damage parameter (flow velocity times water depth) deriving from a dam break flood proved to be a useful tool for estimating consequences of a dam failure (property damage and loss of life) as well as for emergency action planning. The findings of the earlier studies concerning damage parameters were combined and a recommendation for Finnish 1- and 2-storey houses was made (see Chapter 2.3.3 of this report). Please note that the above-mentioned values are a general guide, and that in practice circumstances and the type of individual house will bear upon the kind of damage parameter that is dangerous. It should also be noted that flood wave calculations contain specific uncertainties.

Dam break hazard analysis (see Chapter 3)

Dam break hazard analysis (DBHA) provide information on the consequences of a possible dam break for use in emergency action planning and risk analysis (downstream risks to population, property and environment). Numerical models are used in the DBHA to determine the flow through a dam breach and to simulate flood propagation in the downstream valley. In the RESCDAM project a one-dimensional flow model and two separate two-dimensional models were used in the flow modelling to model the same flood cases. The results shows that with careful modelling and accurate data, the results of different modelling approaches may yield results that correspond with relative closeness. During the project, special methods were tested to model the flow in urban areas. The results of EDF, which used the porosity approach, and Enel.Hydro, which used the geometry approach, are promising and they give a good basis for further development.

There are several topics in dam break hazard analysis that need more research. According to the DBHA in the RESCDAM project the following are the foremost topics:

- Determination of a dam breach formation (flow hydrograph).
- Determination of roughness coefficients used in flow simulations.
- The effect of debris flow and urban areas in DBHA.

Emergency action planning (see Chapter 5)

Dam failure is an extremely demanding accident situation to everyone involved. Thus the population in the danger area must be evacuated before the arrival of a flood wave. Definitely the most important factor, affecting the warning, evacuation and rescuing of the local population, is the time period between dam failure and notification of the failure and commencement of the rescue operation. If the failure is not noticed early enough, the benefit gained from a warning system is lost and people do not have enough time to escape from the flood area. Thus, and particularly in cases where the consequences of a possible dam accident would be considerable or catastrophic, an automatic monitoring system should be considered. Some of the large dams in Finland would need an automatic monitoring system, dams such as the embankment dam of the Kyrkösjärvi reservoir. A primary function of an automatic monitoring system is to reveal abnormalities in real-time and thus provide an early warning of a potentially serious incident or a dam failure. Early warning also makes possible emergency repair work to a dam which in many cases may prevent an actual dam accident.

The alarm level model on the basis of the Portuguese code of practice (see Rocha's seminar paper) was taken into use for the Kyrkösjärvi emergency action plan (EAP), (see Chapter 3 of the EAP in Appendix 24 of this report). The alarm level model ensures right alerting activities in the beginning of a dam failure.

When the consequences of dam failure are potentially great, an estimated dam break flood area should beforehand be divided into areas of responsibility for the rescue units, in order to ensure an efficient response during a dam accident. In the case of Kyrkösjärvi dam, there are eight areas of responsibility (see Appendix 9 of the EAP of Kyrkösjärvi dam).

Advance information, i.e. a compact guide for the population on how to act in the event of a dam failure is necessary (see Safety bulletin for residents of Seinäjoki: Appendix 12 of the EAP of Kyrkösjärvi dam). In Finland this kind of advance information has been a matter of recommendation. As the sociological research (questionnaire) concerning the population at risk in Seinäjoki demonstrated, advance information does play an important part in emergency operations and as such it should be a routine requirement. The current EAP ought to be presented to the local inhabitants during a public information meeting.

In case the EAP of Kyrkösjärvi dam were to be applied to another dam, one should note that every EAP must be tailored to site-specific conditions.

7 SUMMARY AND DISSEMINATION

In summation, the RESCDAM project has met all the aims originally set. The measurable result elements are:

- The risk analysis methodology has been studied and refined on the basis of literature and Finnish experience and as an application example, the risk analysis of Kyrkösjärvi dam was conducted (see Chapter 2 of this report).
- The numerical flow models (1- and 2-dimensional) were applied to Kyrkösjärvi dam and the results of the different models compared (see Chapter 3).
- Emergency/rescue action plan for Kyrkösjärvi dam was drafted (see Chapter 5.3).
- Recommendations to update the Finnish Dam Safety Code of Practice (guidelines) concerning emergency and rescue activities were made (see Chapter 5.4).

The multimedia CD-ROM including all the RESCDAM project material will be distributed to the emergency/rescue authorities of the EU and associated countries, and participants of the RESCDAM seminar and workshop, and will be available to the public at a low cost. In addition the content of CD-ROM will be available in web address as follows: http://www.vyh.fi/eng/research/euproj/rescdam/rescdam.htm.