RESCDAM

Loss of life caused by dam failure, the RESCDAM LOL Method and its application to Kyrkösjärvi dam in Seinäjoki.

Summary of the final report by

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LOSS OF LIFE CAUSED BY DAM FAILURE

The aim of this publication is an attempt to apply the method introduced in the report DSO-99-06 by Graham (1999) and to supplement it with considerations on flood impact (SEV) on the population living in the area at risk and defined by the damage parameter (water depth times flow velocity), this populations vulnerability (VUL), defined by the age and living conditions in one storey or higher buildings (LOC). These three components obviously have effects on the ability of the people confronted with a dam-break flood to survive and information on these components can be acquired from public registers and dam-break flood modelling simulations, both supported by geographical information system (GIS). New findings in the research of people's stability in flood water and flood emergencies, defining damming forces on different types of buildings are used in the method. The definition of flood severity is based on a dam-break flood analysis using as the main output inundation mapping and flood severity zoning. A product of water depth (d) and flow velocity (v) defines flood severity (d x v), both based on dam-break flood simulations.

This new approach has been named RESCDAM LOL evaluation method and presents an approach to combine the statistical method of DSO-99-06 with separately developed factors, based on the case by case studies for the population at risk. The method is suitable for sensitivity testing of the different impact factors. There is also an attempt to diversify the warning and emergency/rescue arrangements with a view to gaining greater efficiency. The statistical information provided in DSO-99-06 has been organised differently, although not changed in content. These re-arrangements allow an evaluation of the loss of life of a basic CASE 0 where NO WARNING at all is assumed in the total study area. This assumption is projected as the worst, theoretically possible situation in cases of unobserved dams and fast propagation of a dam-break flood wave. The resulting LOL of this case is reduced by fatality rate reduction factors (CORRFAT), where different warning efficiencies and emergency/rescue arrangements are considered.

Flooding events are proceeding in the estimated magnitude while population is acting in the flood situation. Warning and preparedness are the main factors assisting the population and improving the capabilities of managing the event successfully.

The currently known methods for evaluation of the loss of life caused by dam failures are:

Statistically based methods

- Brown & Graham (1988), “Assessing the threat to life from dam failure”.
- DeKay & McClelland (1993), “Predicting loss of life in cases of dam failures and flash floods”.
- Morris et al. (2000), “Risks and reservoirs in the UK”.

Methods using statistic information together with separately developed impact factors:

- Reiter (2001), “Loss of life caused by dam failure, the RESCDAM LOL Method and its application to Kyrkösjärvi dam in Seinäjoki”.

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Methods combining dam-break flood simulation models with models simulating the movements of the population at risk during the time of the event:


The procedure for estimating the life loss from a dam failure suggested by Graham (1999 & 2000) consists of seven (7) steps (re-print from DSO-99-06):

**Step 1.** Determine dam failure scenarios to evaluate.
**Step 2.** Determine time categories for which loss of life estimates are needed.
**Step 3.** Determine when dam failure warnings would be initiated.
**Step 4.** Determine area flooded for each dam failure scenario.
**Step 5.** Estimate the number of people at risk for each dam failure scenario and time category.
**Step 6.** Apply empirically-based equations or methods for estimating the number of fatalities.
**Step 7.** Evaluate uncertainty.

Special attention has been paid to Tables 2 and 7 of the report DSO-99-06 because they include the information used also in the RESCDAM-LOL evaluation procedure.

**RESCDAM LOL METHOD TO EVALUATE POTENTIAL LOSS OF LIFE DURING DAM-BREAK FLOODING**

The method follows the principles introduced by Graham (1999) in the report DSO-1999-06. The equations for calculating the loss of life, with respect to the population at risk, are simple and it would have been possible to combine the set of equations and thus to reduce the number of operations. This would have, nevertheless reduced the readability of the sub-results created during the processing of the analysis. It has also been assumed that step-wise output will make it easier to conduct sensitivity analyses at stages when the assessing of the sub-results so requires. Excel-table calculation has been used, since this is a simple and commonly used method. The number of tables is chosen for a suitable table size for printout.

Properties of the RESCDAM LOL METHOD are:

1. The project area is divided into a practically manageable number of sub-areas.
2. A time-scenario has to be developed, consisting of differently sized components, which allows capturing fluctuations of population at risk (PAR) as well as natural events. The system also allows for describing the cycle of a reference year.
   * Seasonal effect on reservoir water levels, base-flow and population at risk and fatality rate (winter/summer/flood season).
   * Weekly fluctuations of population at risk (5 weekdays and 2 days weekend)
   * Daily fluctuations of population at risk and fatality rate (day/night).
3. The method uses a computer-aided GIS/public population register analysis to define impact on PAR and properties of PAR for:
   
   **SEV………** The people at risk in different flood severity zones.
   **SEV<sub>0</sub>** Not located in the flood inundation of the DAMFAIL simulation
   **SEV<sub>1</sub>** Low severity, people expected to survive, DAMG \((d \times v)\) = 0.0-0.5
   **SEV<sub>2</sub>** High severity, people in danger, cars floating, DAMG \((d \times v)\) = 0.5-1.0
   **SEV<sub>3</sub>** Low severity for buildings, high risk for people outside in flood water  DAMG \((d \times v)\) = 1.0-3.0
   **SEV<sub>4</sub>** Medium severity for buildings (damages) DAMG \((d \times v)\) = 3.0-7.0
   **SEV<sub>5</sub>** High severity for buildings (destruction) DAMG \((d \times v)\) = larger 7.0

   **LOC………** Living condition of PAR (1 storey houses and higher buildings)
   **VUL………** Vulnerability of different PAR groups (adults and children+old people)
4. Each of the groups (SEV, LOC and VUL) are given damage-danger factors \( SEV_{fact} \), \( LOC_{fact} \) and \( VUL_{fact} \) and a total impact factor \( IMPACT \) is created as a product of the three. Any factor of, for example 0.5, means that the impact only represents half of the mean impact and any factor of 2 means that the evaluated impact is equal to twice the mean impact. The mean impact is defined according to DSO-99-06. Factors should be defined with a sensitivity analysis approach. Practical examples of variations of the factors include:

- \( SEV_{fact} \): 0.2 – 2.0
- \( LOC_{fact} \): 0.8 – 2.5
- \( VUL_{fact} \): 1.0 – 3.0
- \( IMPACT \): 0.15 – 3.2 (common max value 1.5)

5. People living permanently in the area (PAR\(_{REGISTERED}\)) and people frequently visiting (PAR\(_{OUTSIDERS}\)) are considered separately in the analysis, due to their different characteristics.

6. Table 7 of report DSO-99-06 is modified and divided into three sections:
   - No warning resulting in base fatality rate \( FAT_{BASE} \) (0.03-0.35, mean 0.15)
   - Vague flood severity understanding resulting into risk reduction factor considering cases of different warning efficiencies \( CORRFAT_{WARN} \) (0.03-0.90)
   - Precise flood severity understanding resulting into risk reduction factor considering cases of different warning efficiencies together with emergency/rescue arrangements \( CORRFAT_{RESCUE} \) (0.02-0.40)

7. Selection of the base fatality factor from the medium range in Table 7 of DSO-99-06. (Note: PAR-dependent additional or reduced impacts are considered with factor \( IMPACT \) (see 4.).

8. Evaluation of the loss of life for a theoretical case (LOL\(_{CASE \ 0}\)) with the assumption that no warning is issued in the entire project area. This calculation is conducted for the complete time scenario, for all dam failure simulations and for all sub-areas.

9. Inundation maps for different times of flood wave propagation are used together with Table 2 of DSO-99-06 to develop different warning efficiency scenarios. The result is the definition of warning efficiency areas for each warning scenario and flood simulation case.

10. Based on the warning efficiency maps, showing the sub-area division, the percentages of differing warning efficiency in each sub-area are evaluated and fed into tables.

11. The warning efficiency, based on risk reduction of LOL is accounted for by the factor \( CORRFAT_{WARN} \), modified from DSO-99-06 (see 6.). The sub-area dependent \( CORRFAT_{WARN} \) factors are defined by taking into account the warning area percentages defined in (10.). \( CORRFAT_{RESCUE} \) is developed accordingly.

12. Calculating the loss of life for the different warning efficiency cases and for the cases with emergency/rescue arrangements for all sub-areas and for the annual time-scenario. The sum of all sub-areas is the total LOL of the project area.

13. Time-weighting (length of individual time span in hours divided by annual hours) is done for each time-span in the scenario and time weighted, annual mean LOL is the sum of all time weighted LOL of the time spans. This analysis is recommended for the summary Table (project area) and possibly for important sub-areas.

14. Summary and presentation of the results, evaluation of imponderables and judgement of sensitivity analysis.

The loss of life, caused by a possible dam-break flood can be calculated using the equation (generalised):

\[
LOL = PAR \times FAT_{BASE} \times IMPACT \times CORRFAT
\]

Where:
- \( LOL \) = Loss of life caused by dam-break flood
- \( PAR \) = Population at risk
- \( FAT_{BASE} \) = Base fatality rate of PAR, table 7 of DSO-99-06, (Graham 1999), mean values
- \( IMPACT \) = Additional impact factor to account for flood severity impact (SEV), living environment
impact (LOC) and vulnerability impact (VUL) derived in the RESCDAM LOL method using public population register information on PAR.

**CORRFAT** = Correction factor to take the warning efficiency and possible emergency/rescue action into account in each sub-area (re-arranged values from table 7 of DSO-99-06, (Graham 1999).

**EVALUATION OF LOSS OF LIFE (LOL) CAUSED BY POTENTIAL DAM FAILURE OF KYRKÖSJÄRVI DAM**

The 22 million m³ Kyrkösjärvi reservoir is located upstream of the town of Seinäjoki in Southern Ostrobothnia, Western Finland. The reservoir serves several purposes, the highest priority being flood control of the discharge of Seinäjoki river, a tributary of the Kyrönjoki river. The dams are homogenous earth dams. The main dam, enclosing the reservoir on its eastern side, has a length of approximately 7 km and its highest sections are less than 10 meters high. The highest dam sites, later defined as critical breach locations are at a distance of 2 kilometers from suburbs and 6 kilometers from the town centre, with a height difference between the reservoir level and the ground level of the town centre of 40 meters.

The population of Seinäjoki is about 30 000 some 11 500 living in the project area (see Fig. 1). A significant percentage of this number of people lives in areas near the inundation boundaries or in areas that are dry, but surrounded by a flooding area. In addition to this, there are up to 12 000 people visiting the project area daily for work, school and shopping etc. There are also 12 000 –19 000 visitors participating at two cultural events, each of them lasting several days (Provinssirock and Tango Festival).

Depending on the severity of a dam-break flood event (site dependent and base-flow dependent) only a certain part of the population will be directly confronted by the flood. In the worst case of the evaluation, 60% or 6 900 people effected and in the best case less than 10% or 1 200 people. The distribution of visitors in the area and the number of people being confronted with the flood is assumed to be roughly equal to that of the permanent population.

The project area was divided into 10 sub-areas. The loss of life (LOL) evaluation was prepared by considering different impacts on PAR, different dam-break cases and different warning & emergency/rescue scenarios. The analysis took into consideration the variations of PAR, as well as possible dam-breaks at different dam sites and under different base-flow conditions. A time-scenario (hours in a day, week & weekend and seasons) of one reference year was used.

The breach discharge hydrographs for four selected dam-break flood cases are the following ones:

1. Breach site “A”, Base-flow HQ$_{100}$, upper reservoir level, CODE: Ahq
2. Breach site “A”, Base-flow MQ, mean reservoir level, CODE: Amq
3. Breach site “B”, Base-flow HQ$_{100}$, upper reservoir level, CODE: Bhq
4. Breach site “C”, Base-flow MQ, mean reservoir level, CODE: Cmq

The potential breach sites “A”, “B” and “C” are shown in Figure 1.

Short-time LOL-values may rise significantly (cultural events), but their effect on the mean annual LOL is minor due to their short occurrence time-span over the year. Different weighting of warning & emergency/rescue preparedness cases were considered when evaluating the final mean annual LOL. The final results of the analysis (mean annual LOL, including emergency/rescue actions) are:

Current situation (dam-break flood analysis +.............. LOL= 14 – 23
low level emergency action plan)

After RESCDAM project defined improvements ............ LOL = 8
Future situation (automatic dam-break warning) .......... LOL = 3 (minimum achievable value)

General information on the population at risk (PAR) living in different flood severity zones (defined on page 3) is shown in Table 1.
Table 1. Registered population living in different flood severity zones. (Note: The total population living in the project area is 11,498 people).

<table>
<thead>
<tr>
<th>DAMFAIL-simulation code</th>
<th>PAR SEV&lt;sub&gt;0&lt;/sub&gt; (people)</th>
<th>PAR SEV&lt;sub&gt;1&lt;/sub&gt; (people)</th>
<th>PAR SEV&lt;sub&gt;2+3&lt;/sub&gt; (people)</th>
<th>PAR SEV&lt;sub&gt;4+5&lt;/sub&gt; (people)</th>
<th>PAR SEV&lt;sub&gt;1,5&lt;/sub&gt; (people in direct contact with the flood)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahq</td>
<td>4632</td>
<td>3719</td>
<td>2750</td>
<td>397</td>
<td>6866</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>32%</td>
<td>24%</td>
<td>4%</td>
<td>60%</td>
</tr>
<tr>
<td>Amq</td>
<td>5155</td>
<td>3508</td>
<td>2477</td>
<td>358</td>
<td>6343</td>
</tr>
<tr>
<td></td>
<td>45%</td>
<td>30%</td>
<td>22%</td>
<td>3%</td>
<td>55%</td>
</tr>
<tr>
<td>Bhq</td>
<td>6395</td>
<td>3181</td>
<td>1781</td>
<td>141</td>
<td>5103</td>
</tr>
<tr>
<td></td>
<td>56%</td>
<td>28%</td>
<td>15%</td>
<td>1%</td>
<td>44%</td>
</tr>
<tr>
<td>Cmq</td>
<td>10309</td>
<td>980</td>
<td>205</td>
<td>4</td>
<td>1189</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>8%</td>
<td>2%</td>
<td>0%</td>
<td>10%</td>
</tr>
</tbody>
</table>

The sizes of visitor population groups are:

- Working people: ca. 4,000 on weekdays 7.00-17.00
- Students: ca. 3,000 on weekdays 7.00-17.00
- Shoppers and other visitors: ca. 5,000 on all days 7.00-22.00
- Hotel-guests: ca. 675 all evenings and nights 17.00-7.00
- Provinssirollok (14.-17.6.), cult. event: ca. 12,600 day and night times
- Tango festival (12.-15.7.), cult. event: ca. 19,000 day and night times

A summary of the loss of life, potentially caused by a dam-break accident, maximum values at certain times and annual mean values, for all calculated six cases are presented in Table 2.

Table 2. Summary of the LOL evaluation results.

<table>
<thead>
<tr>
<th>Explanation of LOL</th>
<th>CASE 1a+b</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
<th>CASE 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. LOL, SEAS 3</td>
<td>479</td>
<td>105</td>
<td>20</td>
<td>236</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Max. LOL, SEAS 4</td>
<td>137</td>
<td>17</td>
<td>2</td>
<td>49</td>
<td>3</td>
<td>0-1</td>
</tr>
<tr>
<td>Flood, SEAS 1, working time</td>
<td>136</td>
<td>24</td>
<td>4</td>
<td>63</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Sumertime max., SEAS 2</td>
<td>5</td>
<td>2</td>
<td>0-1</td>
<td>2</td>
<td>0-1</td>
<td>0</td>
</tr>
<tr>
<td>Normal day, working time</td>
<td>n.10-100</td>
<td>n.5-17</td>
<td>n.1-3</td>
<td>n.6-40</td>
<td>n.1-3</td>
<td>0-1</td>
</tr>
<tr>
<td>Normal day, during night</td>
<td>n.4-50</td>
<td>n.2-10</td>
<td>n.1-2</td>
<td>n.3-30</td>
<td>n.1-2</td>
<td>0-1</td>
</tr>
<tr>
<td>Mean value of reference year</td>
<td>57</td>
<td>10</td>
<td>2</td>
<td>23</td>
<td>2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

where:

1) CASE 1 (CASE 1a, DAY + CASE 1b NIGHT) represents a critical boundary for the current situation. The dam-break flood is assumed to be observed only after it has passed the first PAR, located downstream from the dam (daytime 15 minutes after and night-time 1 hour after). The large LOL values result from the cultural event Provinssirollok, kept outside in a very sensitive flood-area (sub-area 2 and 4).

2) CASE 2 represents the current situation where the dam is visually observed and the dam-break is observed in time. Due to inaccurate forecasts the warning is released 0.5 hours after the dam-break has occurred.

3) CASE 3 would require automatic dam-failure observations as well as improvements in the forecast techniques. The assumption that the dam failure would be observed 2 hours earlier is not possible at the moment. Present possibilities are limited to an evaluation of how the potential number of fast developing dam failure events could be decreased.

4) The currently applicable emergency/rescue action cases are CASE 4 (CASE 1a+b & rescue) or CASE 5 (CASE 2 & rescue). In both cases it can be noted that rescue actions also decrease maximum, non-weighted LOL risks.

5) The currently applicable emergency/rescue action cases are CASE 4 (CASE 1a+b & rescue) or CASE 5 (CASE 2 & rescue). In both cases it can be noted that rescue actions also decrease maximum, non-weighted LOL risks.

6) The time scenario used in the analysis is as follows:
Seasonal variation concept, length of season (days)

<table>
<thead>
<tr>
<th>No</th>
<th>Name of season</th>
<th>Time-span</th>
<th>Length of season (days)</th>
<th>Code of DBFA simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEAS1</td>
<td>Spring-flood</td>
<td>1.4.-31.5.</td>
<td>61</td>
<td>Ahq</td>
</tr>
<tr>
<td>SEAS2</td>
<td>Summer except SEAS2&amp;3</td>
<td>1.6.-31.7.</td>
<td>54</td>
<td>Cmq</td>
</tr>
<tr>
<td>SEAS3</td>
<td>Special cultural event 1</td>
<td>14.-17.6.</td>
<td>3</td>
<td>Amq</td>
</tr>
<tr>
<td>SEAS4</td>
<td>Special cultural event 2</td>
<td>12.-15.7.</td>
<td>4</td>
<td>Amq</td>
</tr>
<tr>
<td>SEAS5</td>
<td>Summer</td>
<td>1.-31.8.</td>
<td>31</td>
<td>Amq</td>
</tr>
<tr>
<td>SEAS6</td>
<td>Autumn-flood</td>
<td>1.9.-31.10.</td>
<td>61</td>
<td>Abq-10%</td>
</tr>
<tr>
<td>SEAS7</td>
<td>Winter-flood</td>
<td>1.11.-31.12</td>
<td>61</td>
<td>Bhq</td>
</tr>
<tr>
<td>SEAS8</td>
<td>Winter, low-flow</td>
<td>1.1.-31.3.</td>
<td>90</td>
<td>Amq</td>
</tr>
</tbody>
</table>

Weekly variations:
- Two time-spans are used:
  - Weekdays (Monday - Friday) total 5 days / week
  - Weekends (Saturday - Sunday) total 2 days / week

Daily variations:
- Three time-spans have been used at all days of the year:
  - 07:00 - 17:00 (7 AM - 5 PM) working time, school 10 hours
  - 17:00 - 22:00 (5 PM - 10 PM) leisure time at home 5 hours
  - 22:00 - 07:00 (10 PM - 7 AM) night, asleep 9 hours

Evaluation of application to current situation, the near future situation (RESCDAM level) and future situation with automatic dam-break observation:

The following evaluations shall consider only the CASES including emergency/rescue arrangements. Each of the cases will have a certain probability for success, but the weight considered will shift towards high warning efficiency, when automation and forecast methods make early detection of dam-failures possible. Different weighting assumptions are used for Table 3.

Table 3. Evaluation of the future development effect on the loss of life.

Current situation (Dam-Break Flood Analysis, DBFA + low level emergency action plan):
- CASE 4: 60%, CASE 5: 30%, CASE 6: 10%

After RESCDAM developments are implemented:
- CASE 4: 33%, CASE 5: 34%, CASE 6: 33%

Future situation (automatic dam-break warning):
- CASE 4: 10%, CASE 5: 30%, CASE 6: 60%

<table>
<thead>
<tr>
<th>Explanation of LOL (Reference full analysis)</th>
<th>CASE 4</th>
<th>CASE 5</th>
<th>CASE 6</th>
<th>Current situation</th>
<th>After RESCDAM</th>
<th>Future Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. LOL, SEAS 3</td>
<td>236</td>
<td>21</td>
<td>2</td>
<td>149</td>
<td>86</td>
<td>31</td>
</tr>
<tr>
<td>Max. LOL, SEAS 4</td>
<td>49</td>
<td>3</td>
<td>0-1</td>
<td>30</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Flood, SEAS 1, working time</td>
<td>63</td>
<td>5</td>
<td>1</td>
<td>39</td>
<td>23</td>
<td>8</td>
</tr>
<tr>
<td>Summertime max., SEAS 2</td>
<td>2</td>
<td>0-1</td>
<td>0</td>
<td>1-2</td>
<td>1</td>
<td>0-1</td>
</tr>
<tr>
<td>Normal day, working time</td>
<td>n.6-40</td>
<td>n.1-3</td>
<td>0-1</td>
<td>5-25</td>
<td>2-15</td>
<td>1-5</td>
</tr>
<tr>
<td>Normal day, during night</td>
<td>n.3-30</td>
<td>n.1-2</td>
<td>0-1</td>
<td>2-19</td>
<td>1-11</td>
<td>1-4</td>
</tr>
<tr>
<td>Mean value of reference year</td>
<td>23</td>
<td>2</td>
<td>0.1</td>
<td>14</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

The location of the assumed dam-break locations and the sub-area boundaries are shown in Figure 1 and an example of a warning boundary (warning efficiency area) map is presented in Figure 2.
Figure 1. Sub-areas of the “near inundation area” of the pilot project and locations of potential dam-break sites at Kyrkösjärvi dam.
Figure 2. The sub-area concept of the pilot project and the warning CASE 1a, DAY Ahq. (A total of 24 maps, 6 for each dam-break-flood simulation have been prepared and used to define the case dependent warning efficiency areas).
REFERENCES:


Reiter, P. 2001, Loss of life caused by dam failure, the RESCDAM LOL Method and its application to Kyrkösjärvi dam in Seinäjoki. RESCDAM project, Final report of PR Water Consulting Ltd.