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Risk assessment case studies:

Summary report

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Title
Risk assessment case studies: Summary report

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Summary

Within Work Area 4 (WA4), *Risk Assessment and Risk Management*, in the TECHNEAU project, six case studies on risk assessment were carried out for six different drinking water systems during 2007-2008. The main purposes of the case studies were to assess the specific drinking water systems, evaluate methods and tools developed in WA4 and provide good examples on risk assessment practice. Some of the risk assessments were carried out using qualitative risk ranking methods and in some case studies were quantitative methods used.

The present report provides an overview of the main results from the methods applied in the six case study sites, including an estimation of resources needed. Furthermore, a discussion on when the different methods are most applicable and useful is also provided.

Drinking water systems differ in terms of both system structure, e.g. type of source water, treatment steps and distribution system, and the type of risks they are exposed to. Consequently, one risk assessment method cannot be developed and applied at all systems to assess all problems. Instead, a set of tools is necessary to assist water utilities' risk assessment and risk management work. The case studies show that both the qualitative and the quantitative methods can provide useful results. The qualitative methods generally require less input data and other resources compared to the quantitative methods. The quantitative methods, on the other hand, are shown to provide more detailed results. When deciding what method to apply it is important to consider what information the risk assessment shall provide and what resources are available. A logical approach is to first perform a qualitative risk assessment covering the entire system, from source to tap, and later use a quantitative method for a more detailed assessment. However, if the overall risk situation already is well known and document, quantitative risk assessments can be performed directly to assess the entire system or specific parts of it.

Contents

1 Introduction

The present report summarises six case study reports on risk assessment, conducted within Work Area 4 (WA4), *Risk Assessment and Risk Management*, in the TECHNEAU project. The present report presents an overview of the main results from the methods applied in the six case studies, including an estimation of the resources needed. A discussion about when the different methods are most applicable and useful is also provided. The studies include both qualitative (Chapter 2) and quantitative (Chapter 3) risk assessment methods aimed at providing good examples on risk assessment practice (Figure 1).

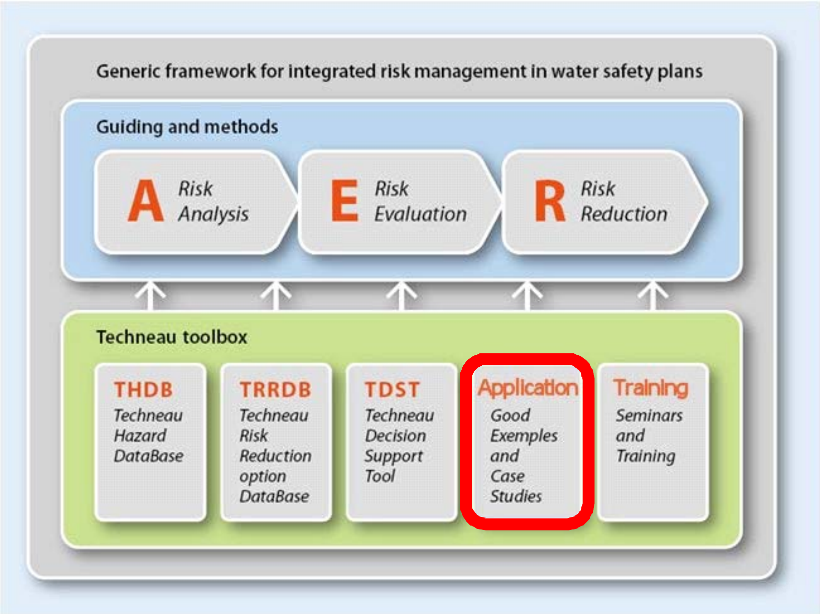

Figure 1. Conceptual schematic of the framework, guides and tools produced in WA4 with the case studies *on risk assessment put into the context.*

1.1 Background

The main objective of WA4 of the TECHNEAU project is *to integrate risk assessments of the separate parts in drinking water supplies into a comprehensive decision support framework for cost-efficient risk management in safe and sustainable drinking water supply* (TECHNEAU, 2005). To illustrate and explain the different steps in risk assessment and risk management the TECHNEAU framework has been compiled, see Figure 2. The framework should be regarded as a *structure and toolbox* for risk assessment and risk management. Risk assessment, the focus of this report, includes the two first steps in Figure 2, i.e. risk analysis and risk evaluation. In order to demonstrate and evaluate the applicability of the methods developed within WA4, and also other methods identified as useful, case studies are necessary.

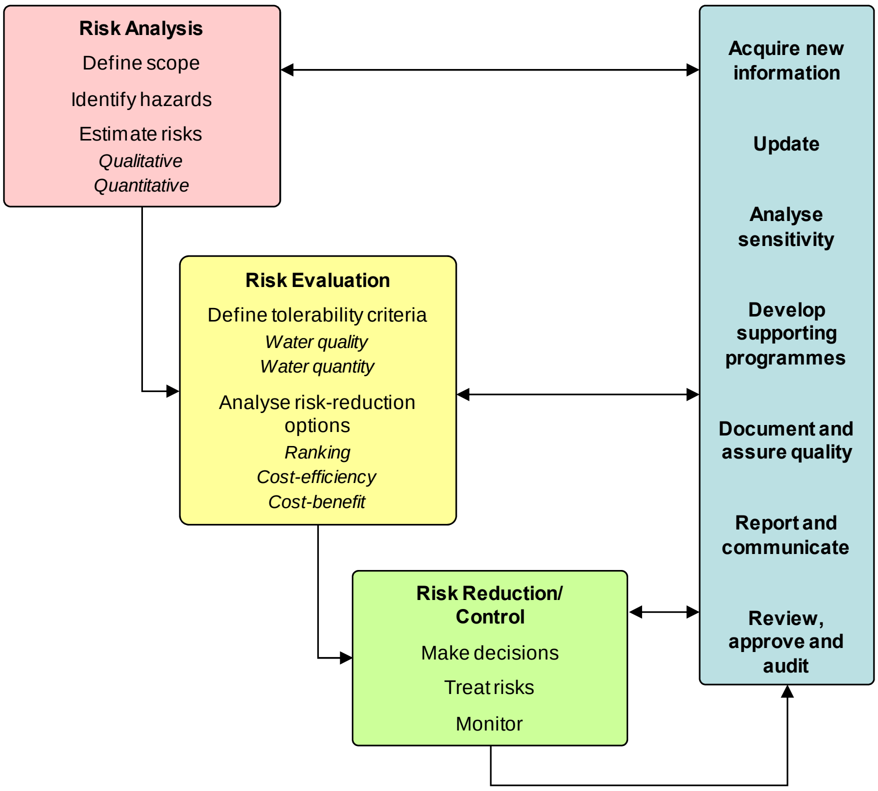

Figure 2. Main components of the TECHNEAU generic framework for integrated risk management in water safety plans (Rosén et al., 2007).

The drinking water systems in the following six locations constitute the case study sites where risk assessments work were performed:

Study site	**Deliverable**	**Full report** [1]
Göteborg, Sweden	D4.1.5a	(Lindhe et al., 2008)
Bergen, Norway	D4.1.5b	(Røstum and Eikebrokk, 2009)
Amsterdam, the Netherlands	D4.1.5c	(Beuken et al., 2008)
Freiburg-Ebnet, Germany	D4.1.5d	(Sturm et al., 2008)
Březnice, Czech republic	D4.1.5e	(Kožíšek et al., 2008)
Upper Mnyameni, South Africa	D4.1.5f	(Törnqvist et al., 2009)

[1] All full reports are public and available on the TECHNEAU website (www.techneau.org) under Publications and Work area 4.

1.2 Aim and objectives

The overall aim of this report is to summarise the knowledge gained from the six risk assessment case studies. In addition to the overall aim the report has the following specific objectives:

- For each case study, summaries the applied method, resources needed and the main results.
- Briefly describe the difference between qualitative and quantitative risk assessment methods.
- Provide a comparison of the applicability of the methods used in the different case studies.

1.3 Limitations

The main limitations of this summary report are:

- Since this report is a summary, details about the six cases are provided in each case study report (D4.1.5a-f) and are not presented here.
- In this report, risk assessment and mainly risk analysis is discussed. Risk evaluation, i.e. the comparison of the risk level to acceptable levels of risk, is included differently in the six cases.
- People involved in the case study work are mainly researchers, i.e. WA4 partners, and end-users, i.e. water utility personnel.
- The specific limitations differ between the six case studies.

2 Qualitative risk assessment case studies

Risks may be assessed in almost an infinite number of ways depending on context. A simple way to distinguish between different risk assessment methods is to categorise them as qualitative or quantitative based on how the risk is expressed.

2.1 Description of qualitative risk assessment methods

The basic idea of a qualitative risk assessment is to present the risk without using quantitative measures. The most common qualitative risk assessment method is risk ranking using risk matrices, here also referred to as Coarse Risk Analysis (CRA). The World Health Organization (WHO, 2008), for example, suggests the use of a risk matrix to prioritise identified hazards for water supplies. Risk ranking is applied in many different fields, not only to assess drinking water supplies. When ranking risks using this method the probability and consequence of each identified hazard are assessed using discretised scales (see e.g. Rosen et al., 2007; Hokstad et al., 2010; AZ/NZS, 2004; and Bartram et al., 2009).

Risk ranking by means of risk matrices is easy to perform and the results are also easy to understand. Hence, this type of analysis is useful in many cases, especially as an initial risk analysis used to identify where further and more detailed studies are needed. However, the method also has limitations that require more sophisticated methods such as quantitative methods (see Chapter 3). Qualitative risk ranking using risk matrices is sometimes referred to as semi-quantitative, if the probability and consequence categories are assigned values (e.g. 1, 2,..., 5) and a risk priority number is calculated by e.g. multiplying the probability and consequence values.

2.2 Březnice, Czech republic

The Czech town Březnice is located in central Bohemia about 80 km SW of Prague, with a population of 3,500. A neighbouring village (200 inhabitants) is also connected to the water supply system. The water supply system in Březnice was analysed using the Coarse Risk Analysis (CRA) method and conducted by the national water authority (SZU) and the local water utility VAK Beroun (Kožíšek et al., 2008). Coarse risk analysis, often referred as the preliminary risk analysis, is a common method for establishing a crude risk picture with relatively modest effort (Aven, 2008). A summary of the applied method is resented in Table 1.

The basis for the CRA includes a description of the water supply system and identification of hazards and related undesired and hazardous events that might occur in the system. For each event, the likelihood (probability) and consequence (impact) have each been assessed using a scale of 5 categories. The risk level for each hazard (hazardous event) is expressed using four categories: extreme, high, moderate, and low.

Table 1. Summary of the applied method and the analysed system in the Březnice case study.

Method	Drinking water system
Name: Coarse Risk Analysis (CRA)	Consumers: 3,700
Required level of expertise needed: Medium	Source water: groundwater (3 different sources)
Time required for analysis: Medium (weeks to month)	Treatment train (removal of iron and manganese + disinfection): - Oxidation ($KMnO_4$) - Filtration (open sand fiter) - Chlorination (chlorine gas)
Required level of data details needed: Medium	
Type of results: - List of all hazards identified for the sources, treatment and distribution parts of the supply system. - Ranking and prioritising the hazards due to its probability and consequence as extreme, high, medium or low risks.	Distribution network: about 33 km Production: 350-520 m^3 per day

The risk level is based on the probability and the consequence for each hazard and the risk matrix suggested by the WHO in the Water Safety Plans was used (Davison, 2005).

The risk analysis in this case study covers the system from source to service connection and was focused on identification of all hazardous events which may influence the quality of distributed water, either in terms of non-compliance with national drinking water quality standards or risks to compromise consumer's health, satisfaction or confidence.

Within the assessment quite comprehensive list of hazards (44) was identified, which have been further classified and expressed as ″extreme risk“ (1), "high risk" (15), "moderate risk" (16) and "low risk" (12). To identify hazards for water quality several different tools have been used: the checklist TECHNEAU Hazard Database (THDB – available on www.techneau.org), past experience of the personnel of the water utility and the local public health authority, brainstorming of working team, and the checklist of main hazards for small water supplies developed by the Swiss Gas and Water Association (SVGW, 2003). The reason was just to test several available options; otherwise it is not necessary to combine so many methods for the CRA.

As the water utility (VAK Beroun) has not developed any own specific risk tolerability criteria, it was agreed within the team analysing the risks that both extreme and high risks would be considered as unacceptable, and therefore, risk reduction options will be developed for all extreme and high risks identified, while all low risks would be considered as acceptable.

Regarding the moderate risks, it was agreed to apply the ALARP (As Low As Reasonably Practicable) principle, i.e. the necessity of risk reduction options for these risks would be discussed on a case by case basis. Some of these risks may be accepted if it is economically and/or technically unreasonable to reduce them, but a monitoring option for such risks should be suggested.

The CRA method used in this case study seems to be a suitable tool for risk identification and estimation in small water supplies. It may be completed or replaced by a more sophisticated method at a later stage, but for the initial risk assessment process it represents a reasonable approach due to medium expertise, technical and financial requirements on the one side, but with sufficient sensitivity on the other.

2.3 Bergen, Norway

The drinking water system in Bergen, Norway, was analysed using a Coarse Risk Analysis (CRA) conducted by SINTEF and Bergen Water (Røstum and Eikebrokk, 2009). Thus, hazards were identified and assigned probabilities and consequences based on discretised scales presented in a risk matrix. Three different types of consequences were considered: (1) water quality effects, (2) water quantity effects and (3) consequences to the reputation and economy of the water utility. All elements of the supply system, i.e. from source to tap, were included in the analysis. The application of CRA and in particular the risk estimation is normally based on expert judgement. Medium level of expertise is required for producing robust estimates. A summary of the applied method is resented in Table 2.

For some of the hazards (hazardous/undesired events) a more detailed quantitative approach has been used for estimating the risk in the CRA. Different tools/methods for estimating probabilities and consequences are available for some of the identified hazards. For example, the “strength” i.e. the probability of the hygienic barriers in the water treatment step and the disinfection step has been calculated based detailed analysis of historical SCADA data.

The analysis was conducted by a multidisciplinary team including researchers and water utility personnel. Based on the analysis possible new risk reducing measures have been identified for all elements in the water supply system which will improve the safety of the system.

Table 2. Summary of the applied method and the analysed system in the Bergen case study.

<table>
<tr><th>Method</th><th>Drinking water system</th></tr>
<tr><td>Name: Coarse Risk Analysis (CRA)</td><td>Consumers: 245,000</td></tr>
<tr><td>Required level of expertise needed: Medium</td><td>Source water: Surface water</td></tr>
<tr><td>Time required for analysis: Medium (flexible)</td><td rowspan="2">Treatment train: (5 separate treatment plants)
- Coagulation
- direct filtration
- disinfection (UV and chlorination)</td></tr>
<tr><td>Required level of data details needed: Medium (flexible)</td></tr>
<tr><td rowspan="2">Type of results:
- Hazard identification
- Risk estimation (probability and consequences)
- Risk evaluation
- Risk control options</td><td>Distribution network: 900 km</td></tr>
<tr><td>Production: 108,000 m³ per day (mean value)</td></tr>
</table>

2.4 Upper Mnyameni, Eastern Cape, South Africa

Upper and Lower Mnyameni are two rural villages in the Eastern Cape province, about 80 kilometers from the south east coast. The villages are supplied with drinking water by a water treatment plant that takes its water from the Mnyameni dam. Altogether the water treatment plant supplies approximately 2 500 people with water. These communities are very rural and no major industries or other commercial activities are supplied with water from the Upper Mnyameni water treatment plant.

The objectives of this case study were to identify hazards in the drinking water supply system (from "source-to-tap"), estimate and evaluate the risks to humans and the development of the society, and evaluate the risk assessment methods that were used. The risk analysis work was conducted by Chris Swartz Water Utilisation Engineers and Amatola Water (Törnqvist et al., 2009), where two methods were tested. The first risk analysis was performed using the Coarse Risk Analysis (CRA) method, with risk ranking of likelihood and consequences and presentation of risks in risk matrices. The second risk analysis was performed by using South African Risk Evaluation Guidelines. A summary of the applied CRA is resented in Table 3.

The TECHNEAU Hazard Data Base (THDB) was used to facilitate hazard identification for both methods. Eleven hazardous events were identified from the assessment and subsequent brainstorming sessions. The hazards were rated (by experts at Amatola Water) by likelihood and consequence of occurrence. There were two consequence ratings, one focused on human health and one on number of people affected.

Risk reduction options were identified for the different risks (hazards) that were listed. Suggested risk reduction options were found to reduce the risks significantly.

Table 3. Summary of the applied method and the analysed system in the Upper Mnyameni case study.

Method	Drinking water system
Name: Coarse Risk Analysis (CRA)	Consumers: 2 500
Required level of expertise needed: Medium	Source water: Surface water (dam)
Time required for analysis: Medium (water supply systems location may be remote)	Treatment train: - Coagulation and in-line flocculation - Pressure sand filtration - Disinfection (chlorination with tablets in on-site reservoir)
Required level of data and details needed: Medium (flexible)	
Type of results: - Hazard identification - Risk estimation (likelihood (probability) and consequences) - Risk evaluation and methods comparison - Risk reduction measures	Distribution network: 48 km Production: 240 m^3 per day (average)

3 Quantitative risk assessment case studies

3.1 Description of quantitative risk assement methods

Quantitative risk assessment methods are often used when qualitative methods (see Chapter 2) are not considered detailed enough. Sometimes a qualitative assessment is performed as a first preliminary study to get an overview of the risk level and later a quantitative assessment is performed if considered necessary. However, a quantitative method can also be used directly. The idea of quantitative methods is to provide an estimation of the risk level in absolute terms (e.g. as the expected consequence) which facilitates comparison to other risks and acceptable levels of risk. Furthermore, by using a quantitative method it may be possible to quantitatively estimate the efficiency of different options for risk reduction. A wide range of quantitative methods exist and some may be applied at separate parts of a water supply system and others may be applied from source to tap.

3.2 Göteborg, Sweden

The Göteborg system was analysed using a fault tree method conducted by Chalmers and Göteborg Water (Lindhe et al., 2008). A summary of the method and the analysed system is presented in Table 4. A fault tree is a logic diagram modelling failure events and interactions between events. An integrated, from source to tap, approach was used and uncertainties of input variables (e.g. failure rates, mean down times and proportions of consumers affected) and results were considered. The two main failure events studied in the analysis were: (1) *quantity failure*, i.e. no water is delivered to the consumer; and (2) *quality failure*, i.e. water is delivered but does not comply with existing water quality standards. The risk was expressed as the expected value of Customer Minutes Lost (CML), i.e. illustrating the number of minutes per year the average consumer is exposed to quantity and quality failure. The results were presented separately for quantity and quality failures to retain transparency. In addition to risk levels, the analysis provided information on the dynamic behaviour of the system (i.e. probabilities of failure, failure rates and mean down times). The results were compared with performance targets (acceptable levels of risk) and the probability of exceeding the targets was calculated. Hard data (e.g. measurements and statistics on previous events), expert judgements (e.g. by water utility personnel) and combinations of these were used to estimate required input variables. To consider uncertainties the calculations were performed by means of Monte Carlo simulations.

The risk analysis was conducted by a team including researchers and water utility personnel. Hazard identification was performed through brainstorming sessions and using the TECHNEAU Hazard database. The fault tree model was built up based on the identified hazards. In addition to required knowledge on the system the construction of a fault tree requires

Table 4. Summary of the applied method and the analysed system in the Göteborg case study.

<table>
<tr><th>Method</th><th>Drinking water system</th></tr>
<tr><td>Name: Fault tree analysis</td><td>Consumers: 500,000</td></tr>
<tr><td>Required level of expertise needed: High</td><td>Source water: Surface water</td></tr>
<tr><td>Time required for analysis: High</td><td rowspan="3">Treatment train: (2 treatment plants)
- Chemical treatment
- Filtration (GAC)
- Chlorination</td></tr>
<tr><td>Required level of data details needed: High</td></tr>
<tr><td rowspan="3">Type of results:
- Risk levels expressed as Customer Minutes Lost (CML)
- Probability of failure
- Failure rate
- Down time (i.e. duration of failure)
- Probability of exceeding acceptable risk levels</td></tr>
<tr><td>Distribution network: 1,725 km</td></tr>
<tr><td>Production: 168,000 m^3 per day (mean value)</td></tr>
</table>

knowledge on, for example, fault tree analysis and Bayesian statistics. Subsequently, water utilities normally need external help to construct the model. However, to use the finished model requires only limited training. The level of data needed to feed the model is high as well as the time required to build the model.

Different risk reduction options that may be considered can easily be modelled and evaluated by the fault tree method. By comparing the different sub-systems (raw water, treatment and distribution) contribution to the risk and evaluate the efficiency of different risk reduction options, sub-optimisation of risk reduction options can be minimised. Hence, the method facilitates discussions on risks to the system and system function.

3.3 Amsterdam, The Netherlands

The case study report for Amsterdam describes a risk assessment performed by KWR and Waternet (Beuken et al., 2008). Waternet is responsible for the supply of drinking water to approximately 890,000 people in Amsterdam and some surrounding municipalities. Drinking water is supplied by two treatment plants (Leiduin and Weesperkarspel) and a distribution system of approximately 2,700 km.

The risk identification was performed with the TECHNEAU Hazard Data Base (THDB) and covers the drinking water supply from source to tap of the Leiduin chain. Three types of risk estimation methods were evaluated in this case study with focus on supply failures of the water distribution system. CAVLAR and Bayesian networks were evaluated using the distribution network of Waternet. A third risk estimation method, the Combined Risk Analysis developed within the joint research programme of the Dutch water companies (BTO), was evaluated using the network of the small town of Montfoort. A summary of the applied methods is presented in Table 5.

No acute hazards are identified in the Amsterdam water supply system, although some aspects require attention. These aspects are recognised by Waternet.

CAVLAR is a simulation model for water distribution networks that can be used for risk calculations, as it combines pipe bursts with probable failures of valves and the effect on customers (expressed in Customers Minutes Lost - CML). It calculates the total effect for the network and identifies critical valve sections. The calculation illustrates the effect of the reliability of valves on the total of customer interruptions.

Bayesian networks have the ability to combine qualitative information and quantitative information of different accuracy. They consist of a diagram of quantified cause-effect relations. These relations are based on existing knowledge or experience. It was found that the applicability of Bayesian networks is still limited due to shortage of knowledge and data. However it is expected that in the future more information will be available for completing Bayesian networks.

Table 5. Summary of the applied methods and the analysed system in the Amsterdam case study.

<table>
<tr><th>Method</th><th>Drinking water system</th></tr>
<tr><td>Names:
- CAVLAR (A)
- Bayesian networks (B)
- Combined Risk Analysis (C)</td><td>Consumers:
- 890,000 (A+B)
- 3,400 (C)</td></tr>
<tr><td>Required level of expertise needed:
A. Medium
B. High
C. High</td><td>Source water:
- Surface water (A+B)
- Groud water (C)</td></tr>
<tr><td>Time required for analysis:
A. Medium
B. High
C. High</td><td rowspan="3">Treatment train: (2 treatment plants for A and B)
- Pre-treatment (coagulation and filtration)
- Ground water infiltration
- Filtration
- Ozonation
- AC filtration
- Slow sand filtration</td></tr>
<tr><td>Required level of data details needed:
A. Medium
B. High
C. High</td></tr>
<tr><td rowspan="3">Type of results:
A. Identification of critical sections and valves and calculation of performance (CML)
B. Identification of critical mains and/or dominant factors contributing to criticality
C. Identification of risk level (probability and consequences of failure) per section.</td></tr>
<tr><td>Distribution network: 2700km (A+B) and 47 km (C)</td></tr>
<tr><td>Production: 180,000 m^3 per day (A+B) and 1,500 m^3 per day (C) (mean values)</td></tr>
</table>

The case study on Combined Risk Analysis focused on the feasibility of making a quantitative risk assessment of a water distribution network by combining 5 types of effects into a hazard, in this case a pipe burst. It was found that this is feasible, although the execution is time-consuming. It is expected that upon full implementation a more efficient assessment will be possible.

The main objective of a risk analysis of a water distribution network is the identification of critical elements. In this case-study it is shown that CAVLAR and the Combined Risk Analysis are valuable instruments to identity critical mains. Bayesian networks can be used to quantify risks, but this technique is not yet applicable for end-users. Risk analysis of water distribution networks is performed for large numbers of elements (mains) and with considerable input and modelling uncertainties. Therefore, the result of a risk analysis has to be considered as decision support. The presented methods for risk estimation have, however, the advantage of analysing large amounts of data in a uniform and unbiased way.

3.4 Freiburg-Ebnet, Germany

The case study on risk assessment of the drinking water system in Freiburg-Ebnet was conducted by DVGW Water Technology Center Karlsruhe (TZW) in collaboration with badenova AG & Co. KG, the local water utility (Sturm et al., 2008). The case study site Freiburg-Ebnet is located in south-western Germany. The Ebnet wells abstract groundwater in the valley of the river Dreisam. The risk analysis focused on water quality aspects in the groundwater catchment.

A summary of the applied method and the analysed system is presented in Table 6. A Geographical Information System (GIS) Assisted Risk Analysis ('GARA-method') was used for catchment risk assessment. Risk estimation hereby includes the assessment of a potential hazard's harmfulness and the intrinsic groundwater vulnerability. The vulnerability is defined by intrinsic natural factors (e.g. the hydrogeological properties of the catchment). The final outcome of the risk analysis is a Risk Intensity map. It results from the GIS-overlay procedure of hazard layer and vulnerability layer. The Risk Intensity map visualises the risks associated with the hazardous events, depending on the hazards' properties and their location within the catchment, based on its natural protective function. The assessment for each resulting single spatial risk element (e.g. any parcel of land under intensive agricultural use or a tank containing hazardous liquids in an area with good permeable subsoil) can be traced back by using the GIS attribute table.

The apparent advantage of the applied method is the possibility to manage large sets of spatial data within the GIS simultaneously for the whole catchment area. Risks can be identified and described by their precise location and related attributes, offering possibilities to analyse risks individually as well as merged. The plain visualisation of Risk Intensity is a very vivid and convenient tool for communication of risks between involved stakeholders.

Table 6. Summary of the applied method and the analysed system in the Freiburg-Ebnet case study.

Method	Drinking water system
Name: GIS assisted risk analysis	Consumers: 105,000
Required level of expertise needed: Medium - high	Source water: Groundwater
Time required for analysis: High	Treatment train: (1 treatment plant) - de-acidification, - UV disinfection
Required level of data details needed: High	
Type of results: - Spatial distribution of Hazard value - Spatial distribution of Vulnerability of the groundwater - Risk level expressed as Spatial distribution of Risk Intensity Index	Distribution network: 250 km Production: 31,500 m^3 per day (mean value)

The decisive factor for the use of a GIS is the availability of appropriate information or digital data. Simplifications and coarse assumptions are possible, which may result in a lower significance of the outcome. Many utilities possess CAD datasets on water supply structures, well locations and other GIS data may be available from regional authorities. If no digital data exist, they have to be created by geo-referencing paper maps, and digitising information obtained from maps and field surveys. This step is quite time consuming.

The use of GIS Assisted Risk Analysis in this case study illustrates that risk management is an iterative process of continuous updating as new information becomes available and as preconditions change. This outcome is in line with the TECHNEAU Generic framework. Starting the risk assessment cycle, it often will be necessary to deal with the missing of data or a limited resolution of spatial data on the one hand and uncertainties and assumptions on the other hand. The GIS technology opens the option to cope with these two main limitations, with the first limitation being inherent with all spatial data-processing procedures. The GIS offers the option to define gaps of knowledge and the priority of further research strategies. The risk analysts can also use the GIS method to simulate the possible effects of appropriate risk reduction options.

4 Discussion and conclusions

4.1 Discussion

The performed case studies show that the qualitative and the quantitative methods provide different kind of results but they are all useful. The case studies where qualitative Coarse Risk Analysis (CRA, i.e. risk ranking using risk matrices) where preformed, showed that this kind of assessment typically require a medium level of expertise, time and level of data details. The assessments provided a prioritisation of identified risks that guide the water utility where risk-reduction measures are most important. CRA is useful to provide an overview of the risks in all parts of the system, i.e. form source to tap, and can be used to identify what further more detailed assessments are required.

The quantitative methods that were applied in the case studies required a medium or high level of expertise, time and data details. At the same time, the results were more detailed compared to the qualitative methods and could more easily be compared to acceptable risk level, system requirements and similar measures. Some of the quantitative methods presented here are focused on specific parts of the system, e.g. the source water of the distribution system. However, one of the applied quantitative methods was developed for analysing the entire system, from source to tap.

Which method is then most suitable to apply for a water utility that should carry out a risk assessment? It is important to consider what information the risk assessment should provide and what resources are available for performing the assessment. One suitable approach is to first perform a qualitative risk assessment including the entire system, from source to tap, and later use quantitative methods for more detailed assessments of the entire system or at critical parts of the supply system. However, if the overall risk situation already is well known and documented, quantitative risk assessments can be performed directly to assess the entire system or specific parts of it.

Irrespective of whether a risk assessment is quantitative or qualitative, some tasks always need to be carried out. As part of the risk analysis step, the scope always has to be defined and the purpose of the analysis clearly stated. The purpose of the study should be linked to relevant decision situations. Furthermore, hazard identification should be carried out and the estimated level of risk (qualitative or quantitative) should be evaluated in order to determine if it is acceptable or not.

Drinking water systems differ in terms of both system structure, e.g. type of source water, treatment steps and distribution system, and the type of risks they are exposed to. Consequently, one risk assessment method cannot be developed and applied to all types of systems and problems. Therefore, a set of tools is necessary to assist water utilities in their risk assessment and risk management work. Consequently, both qualitative and quantitative risk assessment methods are needed.

4.2 Conclusions

Based on the results and experiences from the six risk assessment case studies the following main conclusions are drawn:

- Qualitative Coarse Risk Analysis (CRA) is useful to provide an overview of the system and may guide for further assessments.
- Both qualitative and quantitative methods can be used to assess entire systems, from source to tap.
- Quantitative methods require more resources compared to qualitative methods but also generate more detailed results.
- The selection of method should be based on what results are needed and what resources are available.
- One single tool cannot be used to analyse all risk-related problems. Water utilities need a set of qualitative and quantitative tools.

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