Risk analysis of drinking water storage reservoirs in Norway focusing on microbiological contamination

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Sammendrag

Risikoanalyse av drikkevannsbasseng i Norge med fokus på mikrobiell forurensning. Vann er vårt viktigste næringsmiddel og befolkningen er helt avhengig av rent vann og en tilfredsstillende vannforsyning for å kunne opprettholde et funksjonsdyktig samfunn. Dersom det skulle skje en svikt eller forurensning i vannforsyningen vil det raskt skape problemer for et samfunn. Denne artikkelen tar for seg mikrobielle farer og mulige uønskede hendelser som kan føre til kontaminering av drikkevannet i drikkevannsbasseng og i verste fall føre til en helsefare for befolkningen. Mulige farer og uønskede hendelser ble undersøkt ved å gjennomføre en systematisk gjennomgang av tilsynsrapporter fra Mattilsynet, feltundersøkelser med befaring og intervjuer samt en etterfølgende risikoanalyse. Gjennom disse undersøkelsene ble det avdekket flere farer og uønskede hendelser. Tilførsel av zoonotiske smittestoffer (*Campylobacter sp.*, *Escherichia coli* (*E. coli*), *Salmonella sp.* og parasitten *Cryptosporidium sp.*) via fugler og pattedyr som kommer i indirekte kontakt med drikkevann i drikkevannsbasseng ble vurdert som en stor risiko, noe som betyr at risikoen må reduseres og forebyggende tiltak iverksettes.

Summary

Water is the most important substance on earth and human existence is reliant on a stable supply of clean drinking water to maintain a functioning society and survive. Thus, water supply failure or contamination would have significant consequences. This article aims to investigate microbial hazards and possible hazardous events that could lead to the contamination of drinking water storage reservoirs and health risks to the Norwegian population. Possible hazards and hazardous events were investigated by conducting a review of supervisory reports from the Norwegian Food Safety Authority (NFSA) and a field study that involved a survey and interviews before the final risk analysis. Through these investigations, several hazards and hazardous events were revealed. The introduction of zoonotic hazards (*Campylobacter sp.*, *Escherichia coli* (*E. coli*), *Salmonella sp.* and the parasite *Cryptosporidium sp.*) due to birds and mammals having indirect contact with the drinking water in drinking water storage reservoirs was considered a major risk. This risk must be reduced, and preventative measures need to be implemented.

Introduction

Water is commonly considered the most important substance on earth because human existence is reliant on a stable supply of clean drinking water to maintain a functioning society and survive. Thus, water supply failure or contamination would have significant consequences. The design of the water storage reservoirs makes it difficult to detect, identify and resolve damage and leakages. Routine surveillance conducted by the Norwegian Food Safety Authority (NFSA) has revealed several incidents where drinking water was shown to contain contaminants such as *E. coli*. Guzman-Herrador et al. (2016) describes the status of waterborne disease outbreaks in Norway between 2003–2012 in order to better understand the development of such outbreaks. During this period, 28 waterborne outbreaks were reported, with 8,060 cases of illness. Water supplied from waterworks accounted for 57 % of these 28 outbreaks (Guzman-Herrador *et al.*, 2016). In addition to these outbreaks, one incident was reported to the NFSA in 2014, in which further investigations determined that contaminants were introduced into the water supply at the drinking water storage reservoir. This was found to be due to poor construction, and the fact that the current reservoir design is vulnerable to contaminants entering from the outside (Wahl, 2014). This was also observed in 2017 (Lorås, 2017), when an outbreak of campylobacteriosis in Steinkjer municipality, Norway occurred that was assumed to have been caused by contamination introduced into the drinking water via the storage reservoir infrastructure. In this last case, the construction of the drinking water storage reservoir also made it vulnerable to microbiological contamination. In a review focusing on the production and distribution of microbially safe drinking water that examined drinking waterborne outbreaks that occurred in Europe, North America and New Zealand in the period between 2000 and 2014, some of the causes of contamination was found to be contamination of drinking water storage reservoirs (Moreira and Bondelind, 2017).

In 2019 a waterborne campylobacteriosis outbreak, with 2000 cases, occurred in Askøy municipality, Norway. The investigation determined that contaminants were introduced into a drinking water storage reservoir. The most plausible explanations for the contamination were heavy rainfall and leakage of feces from birds and/or animals via cracks and/or leaks. (Askøy kommune, 2019; Annonymous, 2019).

These failures in the water distribution system indicates a need for more information in order to gain a better understanding of the public health risks associated with water quality degradation that occurs within the water supply network. Drinking water storage reservoirs make up an important part of this network (Brunkard *et al.*, 2011). A drinking water storage reservoir is defined as a closed drinking water storage facility with one or more water chambers, operating housings, operating equipment and devices that provide pressure stability and reserve supply (Standard Norge, 1999). Drinking water storage reservoirs can be built in different materials, such as glass fiber reinforced plastic, concrete and steel, or blasted in solid rock. The water reservoirs may have the shape of a tower, be built on the ground or buried below ground (Sirum, Trøan og Mostue, 2011).

This study aims to investigate microbial hazards and possible hazardous events that can lead to the contamination of drinking water storage reservoirs and possible health risks to the Norwegian population.

Study methodology

Systematic review of supervisory reports

A systematic review of 76 supervisory reports concerning the condition of drinking water storage reservoirs was carried out. The 76 reports describe inspections performed by the NFSA's regional offices in the period 07.03.2017 – 13.12.2017. The results of the supervisory reports were compiled in a table to provide a simplified overview of the results. The inspections were based on the Norwegian drinking water act which includes the following to be inspected: internal control, hazard mapping, risk and vulnerability analysis, expertise, regular inspection, cleaning, maintenance, exterior cleaning, sampling, roof drains, downspout, roof hatches, pollutant airflow, pressure relief and safety valve and access control (Drikkevannsforskriften, 2017). The compilation provides an overview of observations of lack of compliance with the regulations which has led to a notice of decision or where guidance has been provided. Due to the sometimes large variation in the degree of detail and structure in the existing audit reports, the data quality for use in this study is limited. The existing database of NFSA was used mainly when preparing the checklist for inspections. The selection and access to relevant audit reports was facilitated by the supervisor from the NFSA. The checklist used in inspections was prepared based on the NFSA's reports on drinking water storage reservoirs, existing NFSA checklists for inspections of drinking water storage reservoirs, as well as the Norwegian Water Report 181/2011 *Guidance on the construction and operation of the drinking water storage reservoir*. Table 1 shows the completed checklist.

Field study

The first part of the field study, inspections of 15 drinking water storage reservoirs, were carried out in six different municipalities in Trøndelag county: Steinkjer, Stjørdal, Trondheim, Melhus, Skaun and Meldal. The technical inspections were carried out in collaboration with the supervisor from the NFSA.

Interviews of employees at the waterworks were conducted after each inspection. Table 2 shows an excerpt of the questions used and table 8 provides an overview of the results. The full list of questions used during the interviews can be found in (Rostad, 2019).

Prior to the interviews, the interviewees were asked if they were comfortable with audio recording of the interview. Audio recordings permit the interviewer to concentrate so that the interview object can participate in a "conversation" without the distraction of note taking.

It was emphasized that the interview would be completely anonymized, used exclusively for research and that the audio recording would be deleted as soon as the project is completed.

Table 1: Compiled checklist used for technical inspections of drinking water storage reservoir. The main points of the checklist are structural engineering and physical condition.

Structural engineering	**Observations**	**Comments**
Type of construction - Water storage reservoir: Glass fibre reinforced plastic, concrete, steel, blasted in solid rock - Roof construction - Geometric design of water reservoir (one or more chambers)		
Inlet roof drains		
Roofing materials (gravel, peat)		
Roof hatch / stairwell with hatch in the wall		
Airflow, ventilation		
Contamination through overflow		
Backflow via an overflow pipe		
Physical state		
General impression		
Facing of walls		
Roof		
Area surrounding water storage reservoir (trees)		

Table 2: Excerpt of questions asked during interview with subsequent explanation.

Question	Explanation
Overall questions	
Does the drinking water storage reservoir supply water to vulnerable consumers? If so, which ones?	Vulnerable consumers would be hospitals, kindergartens, schools, nursing homes, food businesses and the like. It is important that the water authority is aware of the vulnerable consumers they cater for and the drinking water storage reservoir that supplies them.
Risk and vulnerability analysis - is there one being carried out that includes the drinking water storage reservoir?	The drinking water act require that the waterworks include the drinking water storage reservoir in their risk and vulnerability analysis
Which hazards of drinking water contamination does the drinking water storage reservoir face?	This question is relatively open, and the employee can answer freely about the hazards. Since the employee has not been given the opportunity to prepare the answers, the answer is not likely to be exhaustive.
Which hazards are the most relevant for this specific drinking water storage reservoir?	Different drinking water storage reservoirs face different hazards that need to be considered. This question aims to investigate what the waterworks are most concerned about.
Have there been any problems with the roof before? Cracks, leaks?	Have any roof problems been identified previously but not been reported in any of the NFSA's reports? Cracks and leaks can be stopped before contamination occurs.
What kind of air ventilation is there in the drinking water storage reservoir?	What kind of ventilation is there in the drinking water storage reservoir? Are there two filters? One on the outside and one on the drinking water side?
How often is the drinking water storage reservoir cleaned?	In order to find out how often cleaning is done.
Monitoring of the drinking water storage reservoir	
How often is inspection carried out, and are there any plans for inspection procedures?	Are there routines for inspection? Is the inspection frequency sufficient? This depends on the location of the drinking water storage reservoir. Is the reservoir far away from settlements, or is it easily accessible?
Do you have any routines for inspecting the filter air ventilation?	It is desirable to have an intact, coarse filter towards the outside of the drinking water storage reservoir that stops vandalism, animals and larger insects. A fine filter must be intact to stop contaminated air particles, dust, insects and the like from getting into the drinking water storage reservoir. During winter, care must be taken that the filter does not freeze and thus prevent the air passage. (Sirum, Trøan og Mostue, 2011)

Results from interview and survey will only be used for comparison.

Risk Analysis

A risk analysis was carried out based on the methodology described in the standard "*Security of drinking water supply. Guidelines for risk and crisis management. Part 2 Risk management*" (NS-EN 15975-2:2013). The procedure starts with a description of the object of analysis, drinking water storage reservoirs in Norway, followed by an identification of hazards and hazardous events (Rostad, 2019). In this study we limited the hazards to biological hazards, and we did not consider intentional hazardous events (threats).

The risk associated with each hazardous event was described by identifying the likelihood of occurrence (a discussion of probability or possible frequency and causes of the hazardous event) and the severity of the consequences (possible types of injury to the consumers or the potential impact on public health) as shown below in tables 3 and 4.

Risk acceptance criteria are given by the colours in the risk matrix and the risk priority numbers (RPN). According to table 5, RPN ≥ 6 (red area) indicates that the risk needs to be reduced and an RPN of 5 (yellow area) indicates that a risk control measure could be used to prevent or eliminate hazardous events. RPN ≤ 4 (green area) denotes an acceptable risk. However, risk should be reduced wherever practicable.

The risk analysis is based on data from the present study, existing supervisory reports from the Norwegian Food Safety Authority (Mattilsynet, 2017, 2020) and the academic literature and reports cited in this article.

Results and discussions

Systematic review of supervisory reports

Table 6 shows an overview of the results of a systematic review of 76 existing supervisory reports from drinking water storage reservoirs. Several of these reports were not specific as to the number of drinking water storage reservoirs within the waterworks network, nor which of these reservoirs were included in the reported observations. According to the reports, six waterworks have internal roof drains.

Table 6 shows that "Contamination through air ventilation" is the hazardous event that has been observed most frequently, followed by inadequate cleaning, and inadequate sampling.

Field study

Table 7 and 8 show the results from the inspections and interviews. The main observations which can lead to hazardous events are weaknesses in exterior and interior hatches, interior roof drains, roof shutters, overflow pipes and ventilation.

Table 3: Classification of probability classes of a hazardous event.

Probability (likelihood of occurrence)	Description
1 Small	The event is unknown in the industry. Professional judgement indicates that the event cannot be completely excluded.
2 Medium	The industry knows that the event has occurred in the last 5 years.
3 Large	It is known in the industry that the event occurs annually.
4 Very large	The event occurs from time to time in the industry.

Table 4: Classification of possible consequences of a hazardous event according to their severity.

Consequences	Description
1 Little	Short term and limited quantity of serious illness.
2 Medium	Less severe and transient illness.
3 Large	Potentially serious illness for vulnerable groups.
4 Very large	Potentially serious illness with great risk to life and health. Possible deaths for vulnerable groups.

Table 5: Risk matrix with risk priority number (RPN), based on the classification in table 3 and 4.

Probability	Consequence			
	1 Little	2 Medium	3 Large	4 very large
4 Very large	5	6	7	8
3 Large	4	5	6	7
2 Medium	3	4	5	6
1 Little	2	3	4	5

Table 6: Overview of the results from the systematic review of existing supervisory reports. The numbers do not represent a certain drinking water storage reservoir, but waterworks. The table shows an overview of the number of water suppliers with notice of decision or guidance. (n = 76)

Deviation	Number of waterworks which received notice of decision or guidance from the NFSA
Contamination through air ventilation	18
Inadequate cleaning	15
Inadequate sampling	10
Leaks through roof hatch	8
Inadequate Internal control (quality management)	7
Inadequate hazard mapping	7
Leaks in roof drainage pipes	6
Inadequate regular inspections	5
Inadequate maintenance	5
Inadequate exterior clean-up	5
Blowback in overflow pipes	5
Inadequate risk and vulnerability analysis	2
Leaks in roofing	2

Table 7 shows an overview of the results from the inspections of the 15 different drinking water reservoirs. 13 of the drinking water storage reservoirs are built of concrete, while of the remaining two one is made of fiberglass and the other blasted in solid rock. Three of these are completely buried below ground level, two are partially buried, nine are built above ground level, while one is blasted. Five of the drinking water storage reservoirs have flat roofs, all of which also have internal roof drains. In other words, all the reservoirs with internal roof drains also have flat roofs. Reservoirs with dome or sloping roofs all have exterior roof drains. When it comes to roofing materials, there is a great variety among the various drinking water reservoirs. Ten of the reservoirs have access to a water chamber via an external descent hatch, whereas the remaining five have internal access to the water chamber. The ventilation of the water chamber takes place via a gooseneck with filter mesh in six of the 15 drinking water storage reservoirs. Three of the reservoirs have ventilation through a roof drain cup, two of which have a mesh front. In four of the drinking water storage reservoirs the water chamber is ventilated using a system with a filter. One of the reservoirs has ventilation through the raft box with a filter under the roof. In ten of the drinking water storage reservoirs the air goes directly from outside into the water chamber, while in the remaining five the ventilation is broken. When it comes to overflow, four of the drinking water storage reservoirs have water locks on the overflow pipe. The area around all of the drinking water storage reservoirs is forested, with the exception of one reservoir which is surrounded by an open area.

Table 8 gives an overall overview of the results from the 15 interviews at waterworks in six different municipalities. Among the 15 drinking water storage reservoirs included in this study, 13 supply drinking water to vulnerable consumers. All the waterworks that were visited have performed risk and vulnerability analyses, including the fortified drinking water storage reservoirs. In the interviews, employees from the waterworks described an average of 1.47 hazards for each drinking water storage reservoir.

Table 7: Overview of the results from the inspections of 15 different drinking water storage reservoirs in six different waterworks using the compiled checklist

Drinking water storage reservoir number	Type	Buried	Roof construction	Number of chambers	Internal roof drain	Roofing material	Access to chamber	Ventilation	Breached Ventilation***	Risk of contamination through wateroverflow pipe	Surrounding area
1.1	Concrete	No	Inclined	1	No	Cardboard, gravel, mem-brane	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest
1.2	Concrete	No	Inclined	1	No	Cardboard, membrane, gravel	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest
2.1	Glass fiber	No	Chinese roof**	1	No	Rubber layer	Roof hatch	System with filter	Yes	Yes	Forest
2.2	Concrete	No	Flat	2	Yes	Foil, gravel	Internal roof hatch	System with filter	Yes	Yes	Forest
2.3	Concrete	Yes	_*_	3	_*_	_*_	Internal roof hatch	System with filter	Yes	Yes	Open
2.4	Blasted in solid rock	_*_	_*_	2	_*_	_*_	Via stairs on top	System with filter	Yes	Yes	Forest
3.1	Concrete	Partial	Inclined	1	Noe	Shingle	Direct access through door	Soffit with filter	No	No	Forest
3.2	Concrete	Partial	Inclined	1	No	Concrete	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest
3.3	Concrete	Yes	_*_	2	_*_	_*_	Internal roof hatch	Ventilation box with mesh	Yes	No	Forest
4.1	Concrete	No	Flat	1	Yes	Cardboard	Roof hatch	Roof rain cup without filter mesh **	No	No	Forest
4.2	Concrete	No	Flat	2	Yes	Cardboard	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest
5.1	Concrete	No	Flat	1	Yes	Cardboard, PVC-cover, gravel	Roof hatch	Roof rain cup with filter mesh**	No	No	Forest
5.2	Concrete	No	Dome	1	No	Glass fibre, concrete	Roof hatch	Roof rain cup with filter mesh **	No	No	Forest
6.1	Concrete	No	Flat	2	Yes	Concrete, cardboard	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest
6.2	Concrete	Yes	_*_	1	_*_	_*_	Roof hatch	Gooseneck pipe with filter mesh	No	No	Forest

* Not relevant for the given drinking water storage reservoir, ** Round roof with pointed top, *** the ventilated air is not drawn directly into the water chamber

Table 8: Overview of the results from interviews with employees from the six different waterworks visited

Drinking water storage reservoir number	Vulnerable consumers	Completed risk and vulnerability analysis	Number of hazards identified	Most relevant hazard	Problems with roof, cracks, leakage	Routines for monitoring roof	Problems with ventilation	Routines for monitoring ventilation	Inspection of ventilation (number of times per year)	Cleaning	Inspection routines (number of times per year)
1.1	Yes	Yes	3	Lead fracture	Yes	Yes	No	Yes	2	Every 5. year	2
1.2	Yes	Yes	2	Lead fracture	Unknown	Yes	No	Yes	2	Every 5. year	2
2.1	Yes	Yes	2	Roof leakage	Yes	Yes	No	Yes	12	Every year	12
2.2	Yes	Yes	1	Internal drain	No	Yes	No	Yes	9	Every 3. year	9
2.3	Yes	Yes	2	Roof leakage	Yes	Yes	No	Yes	7	Every 3. year	7
2.4	Yes	Yes	1	Inlet mountain wall	No	Yes	No	Yes	12	Every 2. year	12
3.1	Yes	Yes	1	Sabotage	No	Yes	No	Yes	4	Every 5. year	4
3.2	No	Yes	1	Sabotage	No	Yes	No	Yes	4	Every 5. year	4
3.3	Yes	Yes	2	Roof leakage	No	Yes	No	Yes	4	Every 5. year	4
4.1	Yes	Yes	1	Roof leakage	Yes	Yes	Unknown	No	Unknown	Every 3. year	Unknown
4.2	Yes	Yes	1	Internal drain	No	Yes	No	Yes	Unknown	Every 3. year	Unknown
5.1	No	Yes	2	None	No	No	No	Yes	1	Every 5. year	52
5.2	Yes	Yes	1	Insufficient circulation	No	No	No	Yes	-*	Every 5. year	52
6.1	Yes	Yes	1	Roof leakage	No	No	No	Yes	2	Every 5. year	2
6.2	Yes	Yes	1	Leakage roof hatch	No	No	No	Yes	2	Every 5. year	2

* Indicates that ventilation inspection happens less frequently than every year

As shown in table 8 the employees describe roof leakage as the most relevant hazard for five of the reservoirs. Nine out of 15 reservoirs are described as being exposed to leaks to the water chamber. Furthermore, four of the drinking water storage reservoirs that were inspected had previously had problems with cracks or leaks in the roof. When it comes to roof monitoring routines, four of the reservoirs reported not having such routines. None of the inspected drinking water storage reservoirs were previously reported to have problems with ventilation. All but one of the drinking water reservoirs, 14 out of 15, have routines for monitoring ventilation.

Risk Analysis

The initial work with the risk analysis is described in Pia Rostad's master's thesis (Rostad, 2019). The study is limited to biological hazards, and the hazards are grouped in zoonotic and anthropogenic hazards. The zoonotic hazards that were assessed are *Campylobacter* sp., *E. coli*, *Salmonella* sp. and *Cryptosporidium* sp., and the anthropogenic hazards included in the assessment are *Shigella* sp., *Norovirus* and *Giardia* sp.

Possible hazardous events considered in the study are:

1. The introduction of biological hazards (zoonotic and anthropogenic) via water penetrating into drinking water storage reservoirs.
2. The introduction of zoonotic hazards via birds, insects and mammals that come in direct contact with water in the drinking water storage reservoir.
3. The introduction of zoonotic hazards via birds and mammals that come into indirect contact with water in the drinking water storage reservoir.

Possible causes for hazardous event number 1 could be;

- Contaminated water that penetrates through cracks / holes in the roofing
- Contaminated water that penetrates through cracks / holes in the membrane surrounding the exterior descent hatch roofs
- Contaminated water penetrating via an external descent door due to a lack of membrane inside the descent hatch
- Contaminated water that penetrates through cracks / holes in the membrane surrounding the roof drainage
- Contaminated water that penetrates through cracks / holes or where there is a discontinuity of internal drainage pipes
- Contaminated water that penetrates through a rock / mountain wall
- Contaminated water that enters through a concrete wall in the water chamber
- Contaminated water that enters the water chamber via overflow pipes

The probability level of this hazardous event is assessed to 2 and the consequence level is assessed to 4, which gives hazardous event number 1 an RPN of 6 i.e. within the red area. This means that the waterworks need to investigate the introduction of zoonotic and anthropogenic infections into the drinking water storage reservoir through the following potential points of entry: cracks/holes in the roof, cracks/holes around the outside descent hatch, cracks/holes in the outer drainage membrane, areas missing membrane inside the descent hatch, holes on the internal roof drainage pipes, rock walls, concrete walls and possible backflow via overflow pipes. This must be done in order to identify possible risk mitigation measures.

Possible causes of hazardous event number 2 could be;

- Failure to secure overflow pipes resulting in birds, insects and mammals coming in direct contact with the drinking water
- Failure to secure ventilation pipes resulting in birds, insects and mammals coming in direct contact with the drinking water.

The probability level of this hazardous event is assessed to 2 and the consequence level is assessed to 4, which gives the hazardous event an RPN of 6 i.e. within the red area. This means that risk mitigation measures need to be implemented. The waterworks must check the drinking water storage reservoir to investigate the possible introduction of zoonotic infections through overflow pipes and/or ventilation pipes.

Possible causes for hazardous event number 3 could be;

- Failure to secure ventilation pipes, resulting in birds, insects and mammals accessing the ventilation pipe directly above water level.
- Failure to secure ventilation pipes resulting in birds, insects and mammals accessing the inside of the water chamber (hence coming into direct contact with the reservoir water).
- Failure to secure overflow pipes, potentially resulting in birds building nests inside the water chamber.

The probability level of this hazardous event is assessed to 3 and the consequence level is assessed to 4, giving the hazardous event an RPN of 7 i.e. within the red area. This means that risk-reducing measures must be implemented. Risk mitigation measures may include, for examples, fuse on ventilation pipes (possibly broken ventilation) and fuse on overflow pipes.

Possible consequences of the three hazardous events described above, depend on the types of hazards present and the health of persons being infected. Possible health conditions that could affect consumers include asymptomatic carrier condition, mild gastrointestinal inflammation, severe gastrointestinal inflammation and/or death (Granum og Kapperud, 2015; Kapperud, 2015; L'Abée-Lund og Wasteson, 2015; Gjerde, 2015).

The three hazardous events that falls within the red area of the risk matrix summarized:

1. The introduction of biological hazards (zoonotic and anthropogenic) via water penetrating into drinking water storage reservoirs.
2. The introduction of zoonotic hazards via birds, insects and mammals that come in direct contact with water in the drinking water storage reservoir.
3. The introduction of zoonotic hazards via birds and mammals that come into indirect contact with water in the drinking water storage reservoir.

It is difficult to assess the consequences of any one of these hazardous events in detail, since the size and structure of Norwegian waterworks varies. Some are large, with many drinking water storage reservoirs that supply many consumers, while others are small with few or even without drinking water storage reservoirs. Therefore, the consequences of a hazardous event will vary according to several factors, among them: the total number of consumers and the number of vulnerable consumers.

These types of hazardous events could also have consequences for the waterworks' economy and reputation.

Conclusions

Through a preliminary risk analysis and investigations of 15 drinking water storage reservoirs in Trøndelag, several possible hazards and hazardous events were discovered.

Three hazardous events fall within the red area of the risk matrix (table 4), which means that some drinking water storage reservoirs in Norway are likely or very likely to be exposed to these types of hazardous events. Therefore, it is important that risk-reducing measures are implemented. Among the hazardous events investigated, "The introduction of zoonotic hazards via birds and mammals that come into indirect contact with water in the drinking water storage reservoir", was considered to present the highest risk with an RPN-number of 7. The health consequences for consumers as a result of these hazardous event can be mild gastrointestinal inflammation, severe gastrointestinal inflammation, asymptomatic carrier state/condition and at worst, death.

It is important that these types of hazardous events are included in the waterworks' risk and vulnerability analyses, and not least, that the waterworks' drinking water storage reservoirs is included in the analysis object when such an analysis is carried out.

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