Techneau, 06.
DECEMBER 2010

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Colophon

Title
TECHNEAU

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Deliverable number
D 4.3.3

This report is: **PU**
PU = Public

Summary

A number of Risk Reduction Options (RROs) can be considered for source water systems in general and specifically for surface waters, and a checklist has been provided in the TECHNEAU Risk Reduction Option Database (TRRDB). This report provides an overview of the different categories of RROs and how they are linked to each other. Examples on strategies and methods for a selected number of RROs are provided with references in the Appendix. The list also includes some information on efficiency and costs for different Barrier options.

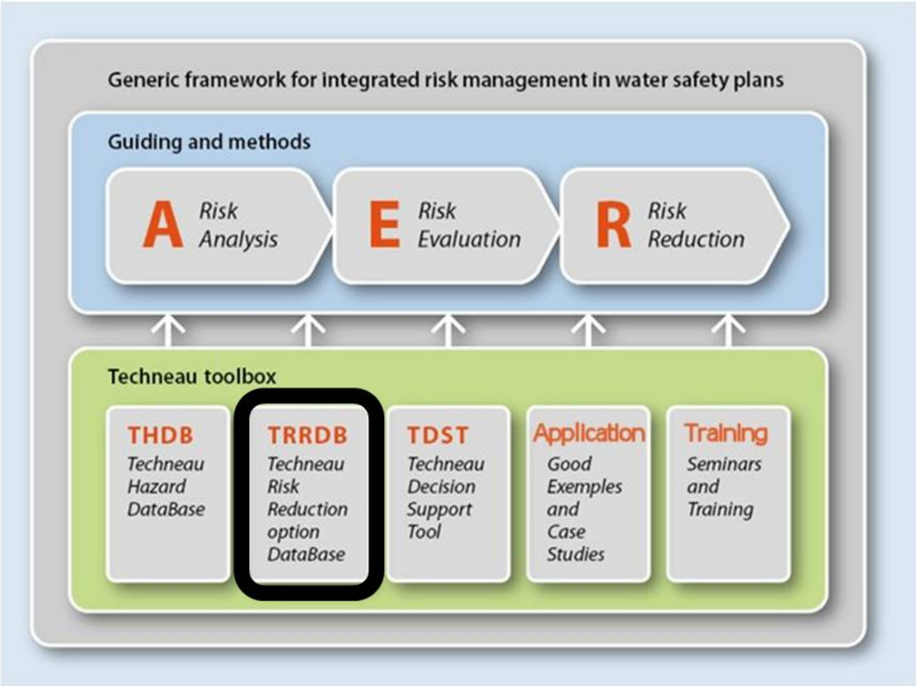
This report provides some suggestions on how RROs for Surface water catchments can be selected in terms of strategy, possible methods, risk reduction efficiency and associated costs. Rather than being a complete database, it aims to motivate water managers to collect information that is most relevant for their specific system. It can therefore be used as a starting point to select RROs and some examples on literature is provided for further reading.

Deeper studies were performed in relation to national standards for raw water quality in the EU. A separate chapter is dedicated to Microbial source tracking for prioritizing risk reduction measures, as this was partly funded by the TECHNEAU project, WP 4.3.

Contents

1 Introduction

This report describes the effectiveness of risk reduction options developed for Surface water systems (D4.3.3). It should be read as an explanation to the Surface water section in the database on Risk reduction options (TRRDB) for the water supply system, developed within the TECHNEAU project as illustrated below.



1.1 Overview of suggested risk reduction options for surface waters

The risk reduction options listed in the TECHNEAU risk reduction option database, TRRDB (TECHNEAU 2009), are for each hazardous event specified in three different categories. It should be noted that the characteristics of the risk reduction options (RRO) differ significantly between these three categories. The categories are as follows:

- Control
- Education and Information
- Barriers

The connection between these categories of risk reduction options, in the context of surface water catchments, is illustrated in the following figure. The examples given for each level are further described below.

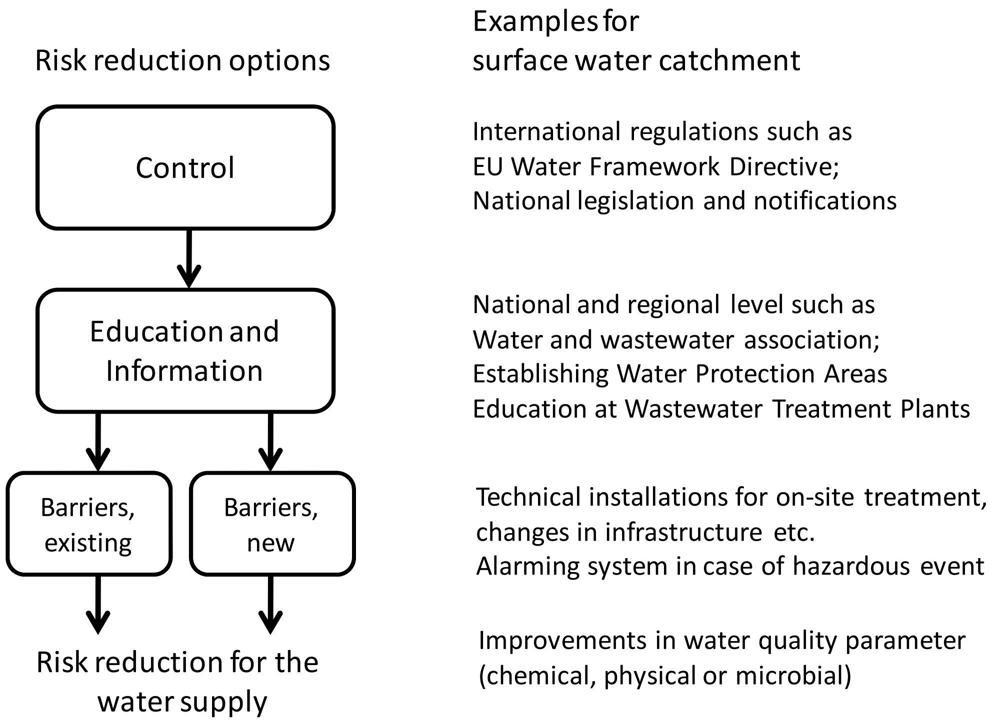


Figure 1. Risk reduction options suggested for surface waters in this report.

1.2 How to use this report

This report provides some suggestions on how RROs for Surface water catchments can be selected in terms of strategy, possible methods, risk reduction efficiency and associated costs. It does not give a total description for all RROs, but can be used as a starting point to select RROs and to read more in the literature on different options. Some references are provided for each RRO. As each system will have their specific settings, there are various decision support tools available for making appropriate decisions (further described in the report D4.4.1, Decision support for risk management in drinking water supply – overview and framework).

2 Control options: regulations

Control options are systems for regulation, notifications or legislation on an international or a national level, according to the terminology in the TECHNEAU risk reduction option database. For surface water catchment these systems aim to control or prevent hazardous events. Control measures include restrictions on industrial discharges (C1.1.1a) and additional barriers for the treatment of industrial water effluents (C1.1.2a) (TECHNEAU 2009). Other examples are regulations for increased safety in traffic, including ships, trains, vehicles and planes (C1.1.7a) aimed to control the hazardous event described as emissions and leakage of oil spills (e.g. MTBE) by shipping or traffic. As control options are not physical technical solutions but rather frameworks to control surface water quality, the risk reduction and costs are not able to specify. Risk reduction options in the control category therefore tend to be country-specific or at least EU specific. Different frameworks are in use to protect and control surface waters from hazardous events in the European Union.

2.1 EU Water framework directive

In the EU Water framework directive (WFD) it is realized that the best model for a single system of water management is management by river basins, instead of according to administrative or political boundaries (EC 2000). For surface waters, the WFD includes the protection of drinking water resources in addition to protection of aquatic ecology and other aspects. The protection of surface waters can be subdivided into ecological protection, chemical protection and other uses, where protection zones for drinking water quality protection may have even higher quality standards. River basin management plans are set up to describe how the different objectives of the river basin should be met within a required timescale. This plan includes a description of the river basin characteristics, a review of the impact of human activity on the status of water in the basin, but should also include an estimation of the effect of existing legislation and the remaining "gap" to meeting these objectives. Additional control measures might be needed, and a set of measures designed to fill the gap can be identified (EC 2009a).

2.2 National regulations

Discharges containing sewage is a category of hazardous events where RROs by control measures are often implemented, see for example effluent of Waste Water Treatment Plants (WWTP) (Event 1.1.22) and sewer system discharges due to rainfalls (1.1.12) as listed in the TECHNEAU Hazard Database (THDB). The EU Urban Wastewater directive aim to protect the water environment from the adverse effects of discharges of urban waste water and from certain industrial discharges, with focus on the reduction of phosphorous and nitrogen loads to the recipient (EC 1991). The situation on a national level, such as in Sweden, is often similar, with requirements to register wastewater point discharges (Naturvårdsverket 1990). Discharge volumes of treated effluents and untreated wastewater at WWTPs as well as discharges from sewer networks (discharges points at the network with more than 500 persons connected) also have to be annually reported (Åström *et al.* 2009). Requirements are set chemical but not on the microbial quality of wastewater discharges to the receiving water, although some hospital departments and laboratories are in Sweden prescribed to be prepared to disinfect the wastewater if needed (Socialstyrelsen 1989).

2.3 National standards for raw water quality in the EU

National regulations on the raw water quality can be used as guidance for water suppliers in the selection of water sources, but also to set pressure on activities in the catchment causing a deterioration of water quality. A screening for raw water standards was undertaken in the TECHNEAU Work Area 4, with the purpose to bring light on the use of national standards in the EU. A request was sent out in March 2007 to the Work Area WA 4 partners with the following questions:

- Are there national benchmarks on chemical and/or biological quality (surface and ground waters) for the raw water?
- What parameters are included? Are there any maximum concentrations prescribed?
- How old are these benchmarks and who are the regulators or responsible authors?

Answers were received from 7 countries, including Sweden, Norway, Germany, Portugal, England and Wales, the Czech Republic and the Netherlands. References to drinking water quality documents were given from all countries, and results as summarised in Appendix B. From this inventory it was observed that national standards were in some instances relying on the EU Drinking Water directive (EC 1998), while threshold values on raw water quality were reported from Germany, England and Wales, the Czech Republic and the Netherlands. In those countries, the threshold values were set against a specification regarding the treatment complexity at the drinking water treatment plant. Raw water quality threshold values are not given in Sweden and Norway; however benchmark values on raw water quality are since 2009 provided by the Water and Wastewater Association in Sweden.

3 Education and Information options

Education and information activities are key components to bring out the message and contents of international and national legislation and regulations. These activities form the basis for decisions on technical installations (barriers) to mitigate specific hazardous events. In the EU Water framework directive, the river basin management plans involve activities related to education and information on a water district level (EC 2000). The next cycle of the directive, aimed at implementing the basin management plans in each river basin, is now running for the period 2010 to 2015.

Other directives from the EU relating to drinking water protection includes the Drinking Water directive (EC 1998) and the Urban Waste Water directive (EC 1991). The Drinking Water Directive aims to protect the human health by end-of-pipe testing, with standards in relation to a number of water quality parameters. This directive is currently under revision to include the concept of risk assessment and risk management as introduced in the WHO Guidelines for Drinking Water Quality (WHO 2004). The Urban Waste Water Directive in contrast, aims to protect the water environment from the adverse effects of discharges of urban waste water and from certain industrial discharges.

3.1 The EU Water framework directive in relation to drinking water protection

In the water administration, following the intentions in the WFD, everybody that comes into contact with the water issues should be involved. As the drinking water industry benefits from this work, they should be represented as an important organisation in the water administration. Others are land owners such as farmers and forest owners, professional and industrial organisations etc. (EC 2009b). Involvement from the drinking water industry in the river basin management may result in the implementation of barriers that are beneficial for the raw water quality. Although the agenda within the WFD are promising, in terms of improving the water quality status on a river basin level, the risk reduction for the raw water may not be sufficient in all situations.

As the implementation of the WFD is generally limited to chemical pollutants and improving ecological status, the microbial pollutants such pathogens are not targeted in the management plans. A typical example on this can be found in Sweden, where the water industry has promoted the inclusion of the health aspect for the catchment protection. The parasite *Cryptosporidium* spp. that may result in sever waterborne outbreaks, such as in Milwaukee, USA 1993 (Mac Kenzie *et al.* 1994), has been provided as an example of the importance of mitigating pathogens. This was however excluded from the implementation cycle 2009-2015 for the Skagerrak and Kattegat river basin (WA 2010). Animals shedding the parasite *Cryptosporidium* may therefore represent a significant health risk for the drinking water, but may not be considered as negative for the chemical and ecological status following the WFD.

However, several measures in the WFD targeting the chemical and ecological quality are beneficial in relation to the microbial quality in surface waters. Examples are enhanced treatment at wastewater treatment plants to remove phosphorous and nitrogen, and requirements set in relation to on-site sewer discharges such as combined sewer overflows, CSO (WA 2010). Many surface water quality issues and possible risk reduction measures need to be handled on a river basin level. Therefore, education and information at the local drinking water industry may be rather inefficient to provide risk reduction at the pollution sources. In the context of the WFD, the drinking water industry therefore must make their noise heard in the water administration, promoting their specific interests in protecting the raw water quality.

3.2 Water protection zones and educational activities

The establishment of water protection zones upstream raw water intakes is an example where dissemination of information and education can have a huge impact on the level of safety in general and the mitigation of specific hazardous events. The water protection zones, promoted in the WFD, are in Sweden set by the county administrative border and the municipalities, although insufficient protection and lack of zones for some of the water supplies has been recognised as a problem to handle in the coming years (WA 2010). Education and information from national authorities, such as the National Food Administration, and on a local municipality level are necessary to maintain and improve the protection level in the water protection zones.

4 Barrier options: technical efficiency and costs

This category of risk reduction options refers to technical improvements in existing water systems including additional treatment steps, constructions of cofferdams or other facilities to handle hazardous events on-site in surface water catchments. While most of the RROs in the categories Control and Education and Information are directed to lower the probability (P) of the hazardous event to occur, the RROs in the Barrier category additionally includes options to lower the consequence (C) of the event. For example, industrial discharges of chemicals (1.1.1) can be reduced by additional water treatment units at the discharge point (B1.1.1a) or by construction of cofferdams to collect accidental discharges (B1.1.1b). Infrastructural changes can be an option for lowering the discharge of sewage due to rainfalls (Event 1.1.12) such as rebuilding combined sewers to separate sewers in a municipality.

4.1 Examples on removal efficiency and potential costs for surface water barriers

Provided in Appendix A is a list describing some of the risk reduction options in the TRRDB with examples of removal efficiency and potential costs. Barriers for controlling hazardous events must be appropriate for the specific water system and local circumstances must be taken into account, such as physical limitations in the infrastructure, pollutant loads in the effluent etc. A typical example is barriers aimed to prevent discharges from sewer system (Event 1.1.12). In addition to the option of rebuilding combined sewer networks to separated sewer networks, RROs here include local handling of stormwater (B1.1.12b) and on-site treatment of discharges from sewer network (B1.1.12c). Decision support tools can be helpful to make appropriate analyses of risk reduction and costs for those different RROs.

It should be noted that there are many different ways to assess risk reduction for different barriers, depending on whether the risk should be related to human health, or for example to the provisioning of water in sufficiently large quantity. Similarly, the costs for each RRO may differ enormously between different systems. Costs are often subdivided into the investment and implementation phase, operational costs and maintenance. For example, infrastructural investments to separate stormwater from sewage in old combined sewer networks may have high investment costs but low costs for operation and maintenance. In contrast, on-site treatment at combined sewer overflows, such as ozonation or chemical precipitation, is associated with high costs for operation and maintenance.

4.2 Tools for assessing the efficiency of risk reduction measures

There are different tools to assess the impact on risk reduction measures on the source water quality downstream. In the case of microbial contamination, large-scale models of different types can be considered. Geographical Information System (GIS) based models appears to be a promising approach in this context. For example, Ferguson *et al* (2007) presented a process-based model to describe the generated load and export of *E. coli*, *Giardia* spp. and *Cryptosporidium* spp from different sub catchments. This model can be further used to estimate the impact of different catchment management scenarios, such as exclusion of stock from watercourses and enhanced effluent treatment (Bryan *et al.* 2009) Another example is hydrodynamic modelling, nowadays possible to run on a three-dimensional scale, where the risk reduction (concentration levels of selected contaminants) of various barriers and remediation measures can be assessed more in detailed for specific water bodies.

In urbanized areas, pathogens mostly originate from point sources of human faeces, such as wastewater treatment effluents and CSOs. Zoonotic pathogens from animals, on the other hand, may be distributed as a diffuse leakage from pastures in the catchment area. Compared to human faeces, the risk related to domestic and agricultural animal faeces is usually assumed to be low. However, waterborne outbreaks have been linked to zoonotic pathogens such as *Campylobacter* spp. and the parasites *Giardia* spp. and *Cryptosporidium* spp. (Craun *et al.* 2004; Hrudey & Hrudey 2004). To mitigate pathogens in the water, and to evaluate the effect of different measures, there is therefore a need to identify and distinguish between human and animal sources.

5 Microbial source tracking for prioritizing risk reduction measures

Several methods for microbial source tracking have been developed during the last years. By the ability to track faecal contamination back to their host, these methods can potentially be very valuable for prioritizing risk reduction measures in surface waters. Among the highly diverse microbial source tracking (MST) methods described in the literature, PCR (polymerase chain reaction)-based methods for detecting or quantifying faecal anaerobic bacteria such as Bacteroidales appears to be very promising, in several aspects. These bacteria are expected to have limited or no reproduction after release into water environments (Field & Samadpour 2007). In addition, they occur in concentrations in faecally contaminated water that are several log-units higher than received in traditional *E. coli* cultivation (Reischer et al. 2008). Furthermore, the methods are reported to be sensitive enough to detect a few hundred pictogram of faecal matter in water samples (Reischer et al. 2007).

In WP 4.3 in the TECHNEAU projekt, Bacteroidales quantitative PCR (pPCR) assays for quantifying genetic markers from human (Reischer et al. 2007) and ruminant faecal contamination (Reischer et al. 2006) were evaluated on a surface water source in Sweden (Åström 2010). Earlier MST applications have been mostly performed for the purpose of protecting recreational waters and few studies are reported in the area of surface water for drinking water protection purposes. Surface waters in Sweden are often considered to have a low degree of faecal pollution under non-event conditions with *E. coli* often below detection limit in the raw water. Furthermore, in a comparative evaluation to determine the sensitivity and specificity of different available qPCR based Bacteroidales assays, these two assays appeared to be the most promising for the conditions in Sweden in terms of sensitivity and specificity (unpublished data). Sorbitol-fermenting bifidobacteria, a culture-dependent and less expensive MST method, was included to compare MST results from the Bacteroidales qPCR assays.

As reviewed by Santo Domingo (2007), several research gaps can be identified with current host-specific assays used for MST. We explored some of the research issues that can be mentioned in relation to the selected Bacteroidales qPCR assays (Figure 2). Research issues dealt with in this project included general methodological questions, such as inhibitors in the analysis and data interpretation of qPCR results. Other investigated areas were detection limits in sewage and manure and potential background levels in soil. Furthermore, the applicability of these methods in surface waters were investigated, as well as the variability in concentrations under nominal versus rain event conditions and the correlations with other microbes.

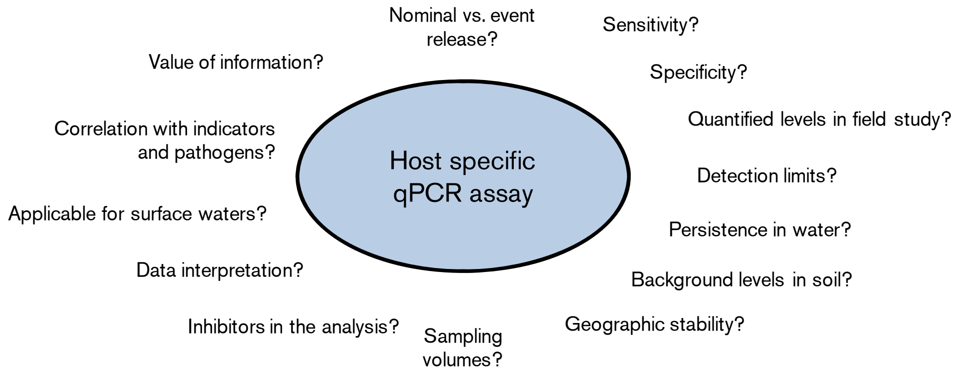


Figure 2. Research issues addressed for the Bacteroidales qPCR assays. Adapted from Santo Domingo et al (2007).

Although Bacteroidales qPCR assays are often assumed to be geographically stable, this is not necessarily the case. Inevitably, MST results will be judged in the light of previous knowledge about faecal sources in the catchment and faecal indicator bacteria measurements. Positive detections of a human marker at a water sampling site expected to be free from human faecal contamination will raise relevant criticism from water managers used to rely on faecal indicator measurements and who are well informed about faecal contamination sources in the area.

The information improvement when going from catchment surveys and traditional faecal indicator analyses to the utilization of MST assays is not easily described. The problem is illustrated in Figure 3; the information from microbial source tracking studies in relation to traditional indicators and sanitary surveys is often unclear (indicated by the question mark beside the arrow). Ideally, however, is to combine the information from sanitary surveys and traditional faecal indicator analyses with the microbial source tracking data (option C).

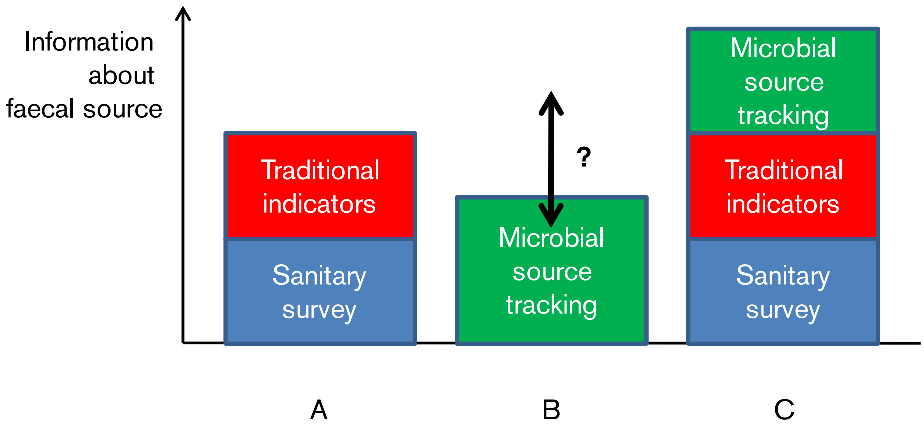


Figure 3. Information about faecal sources emanating from (A) sanitary survey coupled with samplings for traditional indicators, and (B) microbial source tracking. A situation where the different information sources are combined for improved information is illustrated in (C).

We developed an approach for combining faecal source tracking data with previous knowledge on local sampling sites (Åström 2010). A group of 10 experts including staffs from the waterworks, the environmental office, researchers and consultants were asked to give an estimate on the probability of having human versus ruminant contamination in randomly collected water samples at specific sites around Lake Rådasjön, Sweden. They were also asked to rate their uncertainty concerning upstream faecal sources for each site, using a four-grade scale (from very poor to excellent). A description of each sampling site, faecal hosts reported in the area and statistics for *E. coli*, intestinal enterococci and somatic coliphages was provided to all experts. Beta distributions were used to describe each expert judgement and to provide site-specific consensus probabilities for human and ruminant faecal contamination. Furthermore, beta distributions were also used to describe the uncertainty behind the regional sensitivity and specificity of the human and ruminant Bacteroidales qPCR assays.

Monte Carlo simulations were applied in the estimations of Bayes' theorem given in the equation below. Thereby, the posterior probability P(H|T) was estimated for each MST sample location, which is the probability of a true human source of faecal contamination (H) in a sample given a *positive* test result (T) with the human specific assay.

$$P(H|T) = \frac{P(T|H)P(H)}{P(T|H)P(H) + P(T|H')P(H')}$$

where P(T|H) is the probability of a positive signal with the human-specific assay in a faecal sample that is human derived (sensitivity), and P(T|H') is the probability of a positive signal with the same assay in a faecal sample that is not human derived (1-specificity). The background probability P(H) of human derived faecal contamination was provided from the expert judgements. Moreover, Bayes' theorem was used to determine the probability of a true human source of faecal contamination (H) in a sample given a *negative* test result (T) with the human specific assay. Corresponding estimations were performed in relation to the ruminant marker in order to discuss the reliability in the MST results from water samples taken around Lake Rådasjön.

Results showed that highest probabilities of human contamination given a positive result in the human specific assay, P(H|T) were at sites potentially affected by on-site sewers upstream. Furthermore, a high value but with a large range of uncertainty was calculated for a stormwater outlet, where all samples were positive for the human marker. For ruminant contamination, highest posterior values P(R|T) were calculated for sites where the ruminant marker was also detected at high frequency and in high levels. All results are available in a publication of this work (Åström 2010).

In conclusion, analysis for source specific Bacteroidales genetic markers by qPCR is a promising tool for MST in surface drinking water sources, and human and ruminant markers were detected at several locations around lake Rådasjön. Using Bayes' theorem, subjective probabilities on source-specific faecal contamination at different sites collected from expert judgements can be successfully combined with performance data for the Bacteroidales assays (sensitivity and specificity) to assist the MST data interpretation.

The Bayesian approach motivates a clear thinking about

- expected source-specific faecal contamination at different sampling locations in a surface water source;
- how the sensitivity and specificity values for certain assays affect the results, and that the regional performance should be guiding in the selection of assays;
- the collection of more faecal samples to determine assay performance lowers the uncertainties, which may also lower uncertainties in field data interpretation based on the posterior;
- the need to improve the understanding on faecal sources at different catchment locations in order to update the prior knowledge.

Microbial source tracking based on analysis for Bacteroidales human and ruminant genetic markers apper to be a promising tool for surface water management. Results from the field study in Sweden (Lake Rådsjön) suggested that human faecal contamination was of higher importance compared to ruminant faecal contamination, which gives a prioritization in the risk reduction. A weakness with the method, however, is the background levels of human and ruminant markers found in soil, which emphasize the need for including soil samples reference samples when analysing for Bacteroidales qPCR generic markers in new areas.

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Appendix A: Strategy, efficiency and associated costs for RROs by barriers

Table 1. Surface water catchment: risk reduction options by barriers. Strategy, efficiency and associated costs

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
1.1.1	Industrial discharges of chemicals	B1.1.1b	Construction of cofferdams to collect accidental discharges	C	Install cofferdams or tanks adjacent to the industry to prevent chemical discharges to the raw water	Locating the cofferdam or tank downstream between industry and raw water source and provide collecting ditches or channels. Ensure impervious ground surfaces; e.g. pavements or subsurface membrane layer	Very effective to measure to avoid chemical discharges to the raw water source	Costs due to excavation and installing concrete constructions	Very low costs
1.1.2	Industrial discharge of biological matter	B1.1.2a	Treatment plant/additional units at the industry outlet	P	Define which substances are most critical for the drinking water source, for example organic material or bacteria	Membrane Bioreactors can be considered for industrial wastewater treatment (Cicek 2003)	Effective removal of nitrates, herbicides, pesticides, and endocrine disrupting compounds reported (Cicek 2003)	Relatively high cost (Ren *et al.* 2010)	Operationally complex

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
						For treating pulp and paper mill effluents, chemical precipitation, electrochemical treatment, advanced oxidation processes, or photo-Fenton degradation can be considered	In one study, chemical precipitation using CaO was the most effective to remove organic compounds, as indicated by COD removal of up to 90% (Eskelinen *et al.* 2010)	Low cost for activated sludge and anaerobic digestion. High cost for advanced oxidation processes (Eskelinen *et al.* 2010)	
1.1.4	Traffic accidents with ships, trains, vehicles and planes	B1.1.4a	Improved barriers for protecting source waters (e.g. around railways)	C	Cofferdams is an appropriate barrier to install around motorways and railways	Cofferdams described under B1.1.1b			
1.1.7	Emissions and leachage, oil spills (MTBE) by shipping or traffic	B1.1.7a	Restricted areas for traffic with ships, trains, vehicles and planes	P	Avoid entrance to sensitive and strategic areas around raw water sources	Consider fencing and comparable physical barriers	May be very effective, depending on the local situation	Very low costs	
1.1.8	Harbour activities, emissions, accidents	B1.1.8	Physical barriers around harbour areas	C	The same principles as described for B1.1.7a				
1.1.9	Latrines in boats	B1.1.9a	Proper installations for handling latrines in boats	P	The MARPOL 73/78 Convention provides an international legal framework for the prevention of marine	Sequencing Batch Reactor (SBR) technology is one treatment option, to be installed on ships (Dokianakis *et al.* 2007)	The efficiency is limited from basic marine sanitation device, but a high dilution in seawater has been reported for discharges from	Sequencing Batch Reactor probably more expensive than basic marine sanitation device	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
					pollution by sewage from ships (Dokianakis *et al.* 2007)		cruise ships (Loehr *et al.* 2006)		
1.1.12	Sewer system discharges due to rainfalls: CSOs (Combined Sewer Overflow) and SSOs	B1.1.12a	Rebuild combined sewers to separate sewers	P	Separate sewers minimize the release of pathogens during wet weather flow, but do not treat the stormwater (Butler & Davies 2004)	Sewer network modelling can be undertaken for the specific site to assist the decision. Such hydraulic models include network dimensions, population densities, water supply rates, precipitation, etc.	Separated systems may potentially be worse in terms of total pollutant mass discharged into receiving waters (Mannina & Viviani 2009) but represent lower pathogen loads (Åström *et al.* 2009; Marsalek & Rochfort 2004)	Costs for rebuilding combined systems to partly separated systems vary depending on the specific urban settings, geological properties etc.	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B1.1.12b	Local handling of stormwater	P	Semi-natural devices such as infiltration trenches, swales and ponds should be considered instead of large traditional storm sewers (Butler & Davies 2004)	Sustainable urban drainage systems (SUDS) include inlet control such as retaining stormwater on flat roofs, infiltration devices, vegetated surfaces, pervious pavements, filter trains and ponds (Butler & Davies 2004)	Consult for example the CIRIA website for a guidance on how SUDS should be used in combination and how they should be selected for a particular application (CIRIA 2010)	A drainage system that will never flood has to be extremely large and very expensive. A balance should be find between the cost of the drainage system and the risk and consequence of flooding in relation to drinking water supply (CIRIA 2004)	
		B1.1.12c	Treatment of discharges (CSOs) from sewer networks	P	Combined sewer overflows located nearby raw water intakes may imply high pathogen loads and additional treatments should be considered	Chemical precipitation (Hanner *et al.* 2004), ozonation (Joss *et al.* 2008) or microstaining (Diaper & Glover 1971) can be considered	Precipitation in existing primary settlers operated at a surface loading of 3.75 m/h removed phosphorus to 0.35 mg /l. BOD can be reduced by 50-60% (Hanner *et al.* 2004)	Low investment cost and demanded area, but deep primary settlers are required (Hanner *et al.* 2004)	
						Installing a modified vortex separator followed by UV disinfection for CSO treatment (Boner *et al.* 1995)	A removal of 55-65 % achieved for TSS, BOD, COD and Phosphorous, and 2.5 log of faecal coliforms (Boner *et al.* 1995)		

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B1.1.12d	Retention storage of stormwater		Storage in urban drainage system aim to limiting flooding and reducing the amount of polluted storm flow discharged to a watercourse	Stilling ponds, hydrodynamic vortex separator, high side weir or storage or screens are strategies for retention storage in combined sewers (Butler & Davies 2004)	Pollutant removal through settling and storage in the treatment tanks was in one study found as the most effective for CSO treatment, with a removal efficiencies of 20-50% for BOD and 25-70% for TSS (Szabo *et al.* 2005)		
1.1.15	Earthquake, landslides	B1.1.15a	Reinforcement of land areas with increased risk for landslides	P	Slopes with clay soil around surface waters needs special considerations for reinforcements	Limestone pillars may be installed on critical slopes around surface waters	May be very effective, depending on the local situation		
1.1.19	Manure spread from animals and livestock in protection zone,	B1.1.19a	Vegetative filter strips and grassed waterways	P/C	Vegetated buffer strips are promoted as a practical method to reduce waterborne transport of *Cryptosporidium parvum* and other zoonotic pathogens nearby surface water supplies (Atwill *et al.* 2002)	By placing a vegetated buffer of adequate width between the livestock and adjacent surface water supplies, microorganisms will be removed as they are transported through the vegetated buffer (Tyrrel & Quinton 2003)	A vegetated buffer strip at a slope of ≤20 %and a length of ≥ 3 m should function to remove ≥ 99.9 % of *C. parvum* oocysts from agricultural runoff during rainfall (Atwill *et al.* 2002)	Vegetated buffer strips may be economically more feasible and more efficient compared to reducing the number of adult dairy cattle, as has been shown for *Giardia duodenalis* (Miller *et al.* 2007)	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B1.1.19c	Treatment of manure before disposal (e.g. thermal, ozone, electrolytic or anaerobic)	P	The health risks associated with animal operations depend on various factors, where animal species and concentration of pathogenic microorganisms in manure determines the level of necessary treatment (Bicudo & Goyal 2003)	Treatment options include thermal treatment, chemical addition, ozonation, electrolytic treatment and anaerobic lagoon (Bicudo & Goyal 2003)	A large variety of treatment options are available, with the choice and efficiency being dictated by the complexity of a specific situation, and the amount of money the farmer, the government and the general public is willing to pay (Bicudo & Goyal 2003)		
1.1.22	Effluent of WWTP (Waste Water Treatment Plant), normal operations or failure	B1.1.22a	Disinfection of treated wastewater, such as chlorination and ozonation	P/C	Enhanced treatment should be weighed against the likely formation of toxic by-products. The choice of disinfectant depends on the wastewater quality.	Ecological friendly techniques exists, such as sunlight or artificial UV radiation to promote photo-chemical disinfection processes (Acher *et al.* 1997)	UV disinfection of wastewater is one option (Lindenauer & Darby 1994). Chlorination is reported to give highly varying removal (Scott *et al.* 2003)	Highly depending on the type of disinfection, where UV and ozonation are more expensive alternatives than chlorination.	
		B1.1.22b	Additional removal (e.g. microfiltration)	P/C	Several options are available for tertiary treatment at wastewater treatment plants (microfiltration described under B1.1.12c)	Examples includes tertiary filtration, membrane bioreactor (MBR) and upflow anaerobic sludge blankets (UASB) and microfiltration	A 5-log removal of E. coli was reported for MBR and a weak removal of pathogens in general for UASB (Ottoson *et al.* 2006)		

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B1.1.22c	Minimize the number of flow peaks by reducing the stormwater intrusion in sewer networks	P	Combined systems are normally carrying large volumes of stormwater (see B1.1.12a). Different facilities can be considered as an alternative to a separated system	Wet weather treatment facilities can be installed upstream the WWTP (Szabo *et al.* 2005)	Settling and storage in treatment tanks has been shown to give a removal efficiency of 20-50% for BOD5 and 25-70% for TSS (Szabo *et al.* 2005)		
1.1.23	Stormwater effluents	B1.1.23a	Local handling of stormwater	P	Moving away from hard engineering solutions to sustainable urban drainage systems (Butler & Davies 2004)	See B1.1.12b			
		B1.1.23b	Reduce pollutants at their source in the society	P	Control programs should be considered to reduce contaminants at their source (education and information being essential issues)	Pollutants that can be reduced in the society include copper roofs, paints with zinc content, brake, tyre and road wear. The effect of reduction can be modelled (Ahlman *et al.* 2005)	A study in Sweden reports the potential reductions for several pollutants, e.g. 77% for Cu, 26 % for Zn and 50% for PAHs (Ahlman *et al.* 2005)	Probably very expensive as efforts are needed in many different parts of the society	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B1.1.23c	Install additional treatment, such as wetlands before entering the recipient	P	Stormwater ponds or wetlands have been showed to provide a reduction of contaminants before entering raw water sources	The pond area should be dimensioned with respect to pollutant load, but also the pond geometry is relevant and dead zones should be avoided (Pettersson 1999)	Removal efficiency of wetlands depend on the physical processes that govern the sedimentation of particulate bound pollutants (Pettersson 1999)	Moderately expensive, costs includes excavation and cover with membrane	Low operational costs
3.1 SW intake									
3.1.1	Physical obstacles for the intake of raw water, ice formation	B3.1.1b	Enable closure of raw water intake and alternative raw water sources	P	Monitoring hazardous events upstream by regular water quality measurements and reports	Monitor raw water quality parameters, rainfall data and reports from municipalities, e.g. related to sewer overflows (Åström *et al.* 2007b)	Regulations shown to be effective regarding indicator bacteria, while reports on discharges are needed for handling pathogens (Åström *et al.* 2007a; Åström *et al.* 2007b)	Relatively high costs for installing monitoring system at the raw water intake and upstream. Depends on equipment and parameters and water transport	Depends on the need for manual samplings, equipment for data transfers from upstream monitoring station, parameters to analyse
3.1.2 and 3.1.3	Failure in the raw water construction, by accidents or by terrorist attack; Bad condition or external causes	B3.1.2a, B3.1.3a	Possibilities to change raw water source during the failure	C	Change to another raw water source during periods of unacceptable raw water quality	Physically switch the raw water intake to another source (reserve raw water supply)	The risk can be reduced by avoiding contaminated raw water, such as infection risk due to parasites and virus (Åström *et al.* 2007a)	Costs associated with investing alternative raw water source and to install piping for raw water transport	Costs associated with monitoring chemical and microbial quality in alternative raw water source
3.2 SW transport									

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
3.2.2	Failure in mains or transport tunnels (e.g. landslides, heavy traffic)	B3.2.2a	Regular renovation and reinforcement of mains	P	Mains and tunnels needs to be regularly inspected and reinforced to avoid collapse	Regular inspections can be carried out by means of camera robots. Risk assessment (e.g. fault tree analysis) can be used to predict collapse of aged mains.	Disruption of raw water rock tunnels may take several years to repair, while mains may be repaired within weeks	Potential costs due to the difficulties to close down raw water tunnel (reserve supply needed, see 3.1.2a)	Inspection equipment and personal resources

Appendix B: Raw water standards, examples on current regulations and guidelines in countries within the European Union

Table 1. Screening on raw water standards within the EU. Results from a questionnaire sent to delegates within the TECHNEAU-project (WA4) in 2007.

Country	Documentation (reference to web page)	General description	Threshold values on raw water
Sweden	Livsmedelsverkets föreskrifter om dricksvatten (SLV 2001), Vägledning till Livsmedelsverkets föreskrifter om dricksvatten (SLV 2004).[1]	Threshold values given on water quality within the piping network, bottled water, at groceries etc.	Threshold values not given (Target values in Guidelines published 2008[1])
Norway	Drikkevannsforskriften (HOD 2001); Veilderer til drikkevanns-forskriften (Mattillsynet 2005)	Threshold values given on water quality within the piping network, bottled water, at groceries etc.	Threshold values not given. Requirements on sampling frequency within the raw water to set the appropriate treatment level. General prohibitions on polluting the raw water
Germany	Trinkwasserverordnung	General description with threshold values for finished drinking water	Reference given to technical standards
	DVGW-Guideline W 251 (Eignung von Wasser aus Fließgewässern als Rohstoff für die Trinkwasserversorgung)	Technical standard. Threshold values given for normal situations (natural treatment, such as bank filtration) and for minimum requirements (advanced treatment processes)	Includes a number or parameters; physical, inorganic, organic and microbial. E. g., for normal situation, max total coliforms 50/100 mL, faecal coliforms 20/100 mL and enterococci 10/100 mL.
	IAWR - Rheinmemorandum – 2003[2]; IAWR – Grundwassermemorandum (IAWR 2004)	General description on the status needed for surface- and groundwater sources	Threshold values not given (Target values in the memorandum from 2008[2])
	LAWA - Zielvorgabe Trinkwasserversorgung	Working group that has given quality criteria for surface water sources, based on quality targets within EU-directives (75/440/EU, 80/778/EWG)	
Portugal	(No specific documentation was provided)	Classification of water quality criteria based on the water use. References given to Instituto da agua and to the water industry (IRAR)	Threshold values not given

[1] A Guideline document for raw water (Råvattenkontroll - krav på råvattenkvalitet) was published in 2008. Available: <http://www.svensktvatten.se>

[2] An extended version (Danube, Meuse and Rhine Memorandum) was published in 2008. Available: <http://www.iawr.org/docs/publikation_sonstige/memo2008.pdf>

Country	Documentation (reference to web page)	General description	Threshold values on raw water
England and Wales	The Water Supply (Water Quality) Regulations 2000 (DWI 2010)	Detailed description including 11 sections covering the whole water supply chain. Risk analysis explicitly mentioned.	Sampling frequency for a number of parameters within the raw water source, a function of number of consumers and subdivided into "reduced" and "standard"
The Czech Republic	Act 274/2001 Coll. and the Decree 428/200 Coll. The Water Act 254/2001 Coll. and the Decree 137/1999	Threshold values depending on the category; simple physical treatment and disinfection (A1), basic physical treatment, chemical treatment and disinfection (A2), enhanced physical and chemical treatment (A3). Guidance values and mandatory values are given.	Include a number or parameters; physical, inorganic, organic and microbial (47 parameters in total). E.g., guidance values for Enterococci are 20 (A1), 1000 (A2) and 10000 /100 mL (A3) respectively (no mandatory values given).
The Netherlands	Regulation based on the EU guideline 75/440/EEC	Threshold values depending on the degree of treatment; simple treatment and disinfection (I), regular physico-chemical treatment and disinfection (II) chemical and physical treatment and disinfection (III). Guidance values (A) and mandatory values (B) are stipulated.	Include a number or parameters; physical, inorganic, organic and microbial E.g., guidance values for Enterococci are 10 (IA), 1000 (IIA) and 10000 /100 mL (IIIA) (mandatory values (B) are not given).