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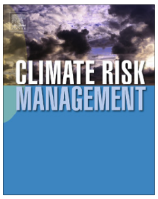

Experts' understandings of drinking water risk management in a climate change scenario

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The challenges for society presented by climate change are complex and demanding. This paper focuses on one particular resource of utmost necessity and vulnerability to climate change: namely, the provisioning of safe drinking water. From a critical perspective on the role of expertise in risk debates, this paper looks at how Swedish experts understand risk to drinking water in a climate change scenario and how they reason about challenges to risk management and adaptation strategies. The empirical material derives from ten in-depth semi-structured interviews with experts, employed both at government agencies and at universities, and with disciplinary backgrounds in a variety of fields (water engineering, planning, geology and environmental chemistry). The experts understand risk factors affecting both drinking water quality and availability as complex and systemically interrelated. A lack of political saliency of drinking water as a public service is identified as an obstacle to the development of robust adaptation strategies. Another area of concern relates to the geographical, organizational and institutional boundaries (regulatory, political and epistemological) between the plethora of public actors with partly overlapping and sometimes unclear responsibilities for the provisioning of safe drinking water. The study concludes that climate change adaptation regarding drinking water provisioning will require a new integration of the knowledge of systemic risk relations, in combination with more efficient agency collaboration based on a clear demarcation of responsibility between actors.

1. Introduction

Translation between different types of knowledge and experience is crucial to the societal management of climate change processes (Wainwright, 2010). Climate change presents many different types of risks, to ecosystems, the planet and to human society. Risks to human health (Hunter, 2003; McMichael et al., 2006) derive from extreme weather events, effects on ecosystems, sea-level rise and various forms of environmental degradation. Risk identification and risk management are central elements of adaptation to such anticipated changes (Füssel, 2007). Since it transgresses geographical, national, regulatory, scientific, social and cultural boundaries, climate change can be regarded as a paradigmatic transboundary risk issue (Linnerooth-Bayer et al., 2001; Hulme, 2008; Löfstedt, 1998; Marsalek et al., 2006; Renn, 2008; Tait and Bruce, 2001). It presents a global challenge to risk governance and demands inter-organizational interaction, communication and collaboration

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in networks that engage numerous organizational actors with diverging responsibilities, goals and organizational logic (Lidskog et al., 2010, 2011; Linnerooth-Bayer et al., 2001). To be effective, adaptation relies on co-operation and interactions at the local level between a multitude of private and public actors, including non-government organizations, stakeholders and the public (Lundqvist, 2016). All the actors in this wide range have their own understandings of what climate change is, what it means and how the associated risks should be managed in the best way (Otto-Banaszak et al., 2011). Adaptation is a highly information- and knowledge-intensive endeavour. It requires expert factual knowledge and prognostic capacity regarding potential future scenarios and events embedded in a wide array of interconnected management domains, regarding, for example, water, natural resources, urban planning, crises and disasters. Thus, experts from different science fields have and will have a key role. The integration of knowledge from different science fields with the aim of linking knowledge to decision making will be crucial to effective adaptation to climate change (Kirchhoff et al., 2015).

This paper looks at how experts from diverse science fields, with different organizational affiliation (academia, government agency and stakeholder organization) look at risk management in association with climate change adaptation. We focus on one particular resource that is locally provided and distributed and that is generally understood to be at risk from climate change: namely, the provisioning of safe drinking water. Our aim is to explore how experts assess risk issues related to climate change that affect drinking water, and how they look upon the risk management strategies needed. The research questions are: *How do experts identify risk in relation to the provision of safe drinking water in a local and regional context?*, *How do they understand the causes of unwanted events?*, *How do they identify the values at stake?*, *What actions do they propose to manage risks?*, *What problems do they identify in relation to risk management?*, and *How do they understand the role of the public in relation to drinking water safety?*.

We adopt a broad definition of expert, and include experts by nomination by means of employment, experience and scientific qualifications. The experts in this study represent both contributory and interactional expertise (Collins and Evans, 2002, 2007). They are employed at universities and agencies, and taken together, their work covers original research and commissioned research, as well as interacting, advising and negotiating with other researchers, public officials and stakeholders within their field of expertise.

2. Current state of knowledge

This section is divided into two subsections that are relevant to the two interconnected themes of this paper. First, we will address the literature on expertise and the role of experts in risk judgements. Second, we will summarize research opinions on how drinking water provisioning will be affected by climate change.

2.1. The role of scientific expertise in judgements on risk

In the sociological literature on the relationships between science and society, scientific experts are understood to have a key role as agenda setters for discourses on risk issues (Beck, 1992; Lash and Wynne, 1992). Two key issues can be identified in the extensive literature on the role of scientific expertise in society. One set of questions relates to the epistemological foundations of science in relation to other knowledge systems. Another set of questions relates to the political role ascribed to science in the legitimation of decisions and power asymmetries (Jasanoff, 2006). Decisions on risk depend on values, and in order for decisions to be legitimate, a broader inclusion of non-experts is also advocated (Shrader-Frechette, 1995). In studies of public understanding of science and the role of science in society, it has been argued that decision making on risk is inherently normative and therefore cannot, in a democratic society, be an exclusive domain of experts (Jasanoff, 2006; Joffe, 2003; Shrader-Frechette, 1995; Sturgis and Allum, 2004).

In risk research, the role of experts in risk identification, risk assessment and risk management has been a long-standing topic of high saliency. Studies in the late 1970s showed that there were differences in risk perception and assessment between experts and laymen (Fischhoff et al., 1978; Slovic et al., 1979, 1980). Simply put, lay people and experts were shown to assess risk differently. The difference in perceived risk between experts and lay people was understood by a "deficit model" postulating lay people's (insufficient) knowledge of risk. Since lay people make interpretations of risk from heuristics and not from assessment of actual facts and statistical probability, they overemphasize some risks or underestimate others (Sunstein, 2002).

The early studies of risk perception that compared risk perception among experts and the public have been criticized for methodological flaws. For example Rowe and Wright (2001), find little empirical support for the idea that experts judge risk differently from members of the public. When the cognitive heuristics of risk perception are taken into account, risk perception by experts and lay people are actually found to be rather similar (Sjöberg, 2002). Expert opinion, like public opinion, is shaped by a diverse range of personal and professional factors. For example, a study by Thomas et al. (2015) shows that expert judgements of probability estimates (regarding sea-level rise in a climate change scenario) depend on heuristics, choices about what information and methods they use, and personal dispositions towards optimism or pessimism in the face of an uncertain future. The distinction between expert and lay knowledge has also been strongly questioned by sociologists who argue that lay knowledge is equally valid for many risk issues (Wynne, 1996, 2001). While scientific knowledge is understood to be abstract and detached, lay knowledge is characterized as contextual, embedded and practically oriented (Wynne, 1996, 2001). Lay knowledge, although not codified in science terms, must therefore be seriously considered.

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How experts identify risk relates to their domain of expertise and their expert roles in society (Fromm, 2006). The organizational affiliation of experts, whether they are employed by industry, government or academia has been shown to influence how they perceive risk within their field of expertise. Barke and Jenkins-Smith (1993) found that scientific experts at universities had a stronger tendency to rate risks of nuclear energy and nuclear waste as bigger, compared with experts working in more direct relationship with the nuclear industry. A study by Murphy (2001) shows that organizational affiliation, whether experts were employed at agencies, in the industry or at independent research institutions shaped their understanding of risks related to tobacco smoking.

The attention to risk by experts is not limited to their own field (Sjöberg et al., 2005) and experts may well have ideas about risks in fields other than their own. Experts sometimes disagree about the same risk, and diverging viewpoints in how they assess and evaluate risk can partly be explained by their organizational roles and how they understand responsibility within their expert role. Is it their responsibility to warn the public or vulnerable groups of potential hazards, or to reassure members of the public that many of the risks that they are concerned over are actually negligible (Sjöberg et al., 2005)? In accordance with results from other studies, Sjöberg et al. (2005) found an overweight of risk issues that experts perceived as neglected, as compared to issues they considered to be over-emphasized. Opinions also vary between experts, who may assess information on risk differently even within the same field of expertise. Expert knowledge gives room for diverging views and ambiguity (Rudén, 2004).

In the literature on scientific expertise and the role of expert judgement, it is not always clear how expertise should be exactly defined (Collins and Evans, 2002). Specifically, who is an expert, and who is not? For example, Krueger et al. (2012: 6) notes that the distinction between expert and stakeholder sometimes overlaps – stakeholders may also be experts, and experts can be argued to be stakeholders since they have the means to affect decisions and are also affected by decisions.

A promising approach is adopted by Collins and Evans (2002). They do not use science versus non-science as the sole criterion for distinguishing experts from non-experts. An expert is simply taken to be someone who has special experience and knowledge regarding some specific topic. An expert can be a scientist, a manager at a government agency, a professional or even a member of the public with relevant experience and skill (Krueger et al., 2012). Sjöberg et al. (2005) suggest that experts are characterized both by excellence in performance and by nomination. An expert by nomination is identified by others as an expert, for example by being appointed to a formal or organizational role. Collins and Evans (2002: 251–4) have developed a typology of expertise that draws on different types of science. They also make a basic distinction between contributory expertise and interactional expertise. These two forms can overlap but do not necessarily have to do so. *Interactional expertise* is defined as capacity and skill to interact with participants within a field of relevance, while *contributory expertise* is the ability to actually contribute to the scientific knowledge of the field.

2.2. Climate change effects on drinking water

Climate change imposes many risks to human health, among which the provisioning of safe drinking water constitutes a global problem (Wheeler and von Braun, 2013). The Intergovernmental Panel on Climate Change (IPCC) notes that drought, increased rainfall, higher temperature and more frequent and severe natural hazards of various kinds will affect the availability and quality of drinking water (Bates et al., 2008: 45–68). All these factors affect water supplies and have consequences for conditions for the treatment, production and distribution of drinking water (Delpla et al., 2009). Water supplies can be contaminated by nutrients, toxic chemicals, and microbes such as protozoa, algae, bacteria and viruses (Delpla et al., 2009; Hunter, 2003). Increased risk of outbreaks of waterborne diseases is noted in a number of studies (McMichael et al., 2006: 862).

The causal relationship between the climate-change-related effects of extreme precipitation, temperature rise and waterborne diseases (conveyed through drinking water) is complex, involving a systemic interplay of different types of microorganisms, geographical area, season, type of water supply, water source and water treatment technology. There are huge knowledge gaps regarding systemic causes and effects (Herrador et al., 2015) and considerable uncertainty about how heavy rainfall, microbial pollution of water supplies and increased turbidity actually interrelate. Several outbreaks of waterborne diseases in recent years can be traced back to extreme hydrometeorological events (Cann et al., 2013; Karthe, 2015; Nichols et al., 200.

Another climate-change-related risk identified by the IPCC is the prospective increase of extreme weather events, both regarding frequency and severity. Khan et al. (2015) underscore that floods, cyclones, droughts, heat waves, extreme cold and wildfires all have potential in various ways to negatively impact water supplies and water treatment processes. Existing guideline documents and regulations regarding the management of drinking water quality in relation to extreme weather events are judged to be insufficient (Khan et al., 2015). Extreme weather events can have negative impacts not only on water quality but also on the availability of drinking water (Luh et al., 2015), calling for strategies for adaptation and mitigation to reduce vulnerability. Better planning and more investments in maintenance are therefore needed (Wols and Van Thienen, 2016).

Indirect effects of climate change are also discussed in the research literature. Increased risks of contamination of water supplies by chemicals and heavy metals, mediated by a broad range of environmental factors, call for protection and mitigation strategies (Emelko et al., 2011). Climate change is expected to increase the need for herbicides in agriculture, and herbicide leakage into groundwater has effects on the quality of the drinking water supply (Steffens et al., 2015). Although the concentration of individual chemicals in water supplies might be low, complex mixtures of chemicals might have unknown adverse health effects (Villanueva et al., 2014).

These causes and effects in relation to the provisioning of safe drinking water need to be addressed by effective management regimes in a number of areas, such as supervision and monitoring of water quality, technical infrastructure and water processing technology. For example, more effective measures to monitor microbial pollution are identified as a key prerequisite in order to assess microbial risks as threats to public health (Jung et al., 2014). Increased browning of surface water supplies due to organic matter must be dealt with in the drinking water treatment process (Brookes et al., 2014; Weyhenmeyer et al., 2016). Climate-change-induced droughts resulting in lowering of the groundwater table can damage underground pipeline infrastructure, and more effective predictions of the probabilities of failure of water pipelines are needed (Wols and Van Thienen, 2014). The impacts of climate change on drinking water must be addressed by decision makers in local government and in the local water production industry (Li et al., 2014).

Raw water supplies will require integrated monitoring programmes, focusing on both water quality and availability (Karthe et al., 2016a). Overall, there are many consequences from climate change to be dealt with by operative decisions at the level of the waterworks. According to mainstream technology, raw water is industrially treated in a number of steps in order to remove contaminants. These steps include coagulation, sedimentation, filtration and disinfection by chlorine or UV light. Although the technology is well established, many things can go wrong, resulting in contaminated drinking water being delivered to the consumer (Hrudey and Hrudey, 2004; Hrudey et al., 2006). Water treatment plants use a number of chemicals for processing raw water into drinking water. Disinfectant agents can have adverse health effects. Increasing water temperature (and browning) due to climate change is expected to motivate an increased use of disinfectant chemicals, which can in turn result in higher concentrations of disinfectant by-products (Kovacs et al., 2013).

The wide range of pollutants identified in the literature (Delpla et al., 2009) present challenges for water treatment and have implications in terms of disinfection by-products with potential carcinogenic effects. Chlorine is known to react chemically with organic substances, creating trihalomethane, which is carcinogenic; however, chlorination kills waterborne microbial agents that can cause disease. Chlorinating versus not chlorinating as a risk management strategy represents a classic case of trade-off in the protection of public health (Putnam and Wiener, 1995). The water treatment industry therefore needs to develop adequate instruments to measure and analyse substances and by-products of substances (Delpla et al., 2009). Overall, a changing climate combined with regionally disparate population development poses many new challenges for water management in terms of technical solutions, along with logistic and organizational arrangements to deliver safe drinking water (Karthe et al., 2016b). Therefore, urban hydrology is expected to play a future key role in integrated urban planning for sustainable development (Niemczynowicz, 1999).

Furthermore, drinking water management must develop adaptation and mitigation strategies that are aligned with several regulatory frameworks, such as the European Water Framework Directive, the European Drinking Water Directive and the European Waste Water Directive. Successful provisioning of drinking water within such regulatory frameworks will depend on institutional and organizational co-ordination and collaboration on the regional and national levels (van der Hoek et al., 2014) and on the European level (Leventon and Antypas, 2012).

As we have seen from this research overview, climate change effects on drinking water are complex and involve a number of biological and chemical processes. The provision of safe and sufficient drinking water is also a question of social organization and management regarding technical solutions for water treatment; the practical operations of water treatment; drinking water production and distribution; and risk assessment, planning and foresight, based on implicit or explicit valuation of needs, benefits and vulnerabilities – all within a political and regulatory framework of interacting institutions and organizations. Transdisciplinary approaches (Wainwright, 2010) that effectively combine natural science with social science, and which can accomplish translation between knowledge domains in order to build comprehensive and integrated knowledge, are essential.

3. Background: Drinking water provisioning and management in Sweden

Drinking water has been identified as a critical resource at risk from future effects of climate change in a series of investigations by the Swedish government (SOU, 2006:196; SOU, 2014:53; SOU, 2015:51; SOU, 2016:32). In Sweden, half of all water used for drinking water comes from surface water. The other half is divided equally between natural groundwater from dug or bored wells, and so-called artificial ground water produced by infiltration by allowing surface water to pass through a land gravel layer. Communal infrastructure for water management (drinking water and waste water) is not provided in more sparsely populated rural areas. More than a million permanent residents and about as many part-time residents have private facilities for drinking water and waste water. The majority of citizens live in urban and peri-urban surroundings, and have access to communal water supplied by their municipality.

Sweden has 290 municipalities and 20 County Administrative Councils. The municipalities have a high level of local self-government and, within the boundaries of national legislation, they can set priorities and make choices of organizational solutions for the provisioning of services to citizens. The responsibilities of the municipalities include the supervision and enforcement of regulation and service provisioning within a number of areas: local spatial planning, enforcement of building regulations, local road infrastructure, drinking water provisioning, waste water management, household solid waste management, primary schools, elderly care and social services.

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The Swedish National Food Agency is the regulatory authority on the national level responsible for drinking water quality. Its work is aligned with European rules and regulation for food safety by the European Food Safety Authority (EFSA). Drinking water is regulated by the European Drinking Water Directive Council Directive (3 November 1998), which states a number of rules for water used for human consumption, regarding contamination by microorganisms, parasites, chemicals and other harmful substances that can be a risk to public health.

The Swedish Public Water Services Act (SFS, 2006:412) ensures that the drinking water and waste water is managed in an integrated manner for the protection of human health and the environment. Municipalities are legally required to organize water services. In contrast to other areas of municipal responsibility such as road infrastructure, schools, social services and elderly care, drinking water and waste water management are funded by fees rather than taxes. The fee is based on the costs for the service divided across the collective of users. The municipalities are legally restricted by the principle of prime cost, which means that they are not allowed to charge fees that exceed the actual costs for drinking water production, distribution and management. The rate of the fee is decided by politicians in the municipal city council. Within this self-governmental system, different municipalities have chosen different ways to organize and manage their supply of drinking water. The organization of the production and distribution of drinking water can be solved in several ways: drinking water may be produced and distributed by a municipally owned and operated facility; it may be produced and distributed by a municipally owned company with a political board; it may be bought from a neighbouring municipality where it is produced, or an association of municipalities act as the producer.

This paper focuses on drinking water that comes from surface water, and particularly from Göta Älv in Southwest Sweden – the largest river system in Sweden in terms of drainage area and average water flow. Göta Älv has a number of important social and economic functions with a long history (Mulder and Kaijser, 2014). For hundreds of years up to the present, it has been an important shipping route from Lake Vänern to the port in Göteborg. The river also generates hydro power (104 MWe) at Olidan in Trollhättan, which was the first hydro power plant in Sweden (1910). Göta Älv is also among the oldest and most dense industrial areas in the country, and industrialization has left behind a number of locations with severely contaminated ground. In addition to sea transport, the Göta Älv valley is an important transport route for road traffic and railway. The area is particularly prone to flooding, and the Göta Älv valley is one of the regions in Sweden where landslides are most frequent, due to geological and topological conditions. This paper focuses on one particular aspect of Göta Älv: namely, its function as a drinking water supply for over 700,000 people, who are resident in seven municipalities.

The risk issues that characterize the Göta Älv water system are quite complex, due to the presence of systemically interrelated risk issues (Boholm, 2009), which engage interconnected and partly overlapping responsibilities of a complex risk governance network of regulatory bodies, stakeholders, and public and private actors (Boholm et al., 2012; Karlsson, 2010; see also Lewis et al., 2013). The risk governance network includes the County Administrative Council; the Swedish Transport Authority; the power-producing company Vattenfall; Svenska Kraftnät (a government agency responsible for the national electricity grid); the Swedish Geotechnical Institute (SGI); municipalities; Göteborg Vatten (the city of Göteborg waterworks organization); the Vänern-Göta Älv River Council; the National Food Agency; the Swedish Agency for Marine and Water Management; the National Board for Building, Housing and Planning; the Swedish Civil Contingencies Agency; the Public Health Agency of Sweden; and the Swedish Water & Wastewater Association (a stakeholder organization set up by municipalities).

4. Method

Interviews with a total of ten experts, who were selected by nomination and have specialist knowledge on risk issues relating to drinking water and Göta Älv, were conducted during the spring of 2015. The selection of expertise covered a broad range of relevant knowledge fields, such as environmental and spatial planning, geology, hydrogeology, microbiology, contingency planning, chemistry, and water engineering. The experts were employed by universities and government agencies with sectoral responsibilities relevant to drinking water provisioning and safety; in one case, the employer was a nongovernmental national stakeholder organization. The selection included an equal number of male and female respondents. All respondents have academic degrees, seven have a PhD and four are professors or associate professors. The characteristics of the experts are presented in Table 1.

The work tasks of the respondents ranged from research and development to collaboration, co-ordination, planning, networking and advising. Some experts had a stronger research orientation, while others had a stronger emphasis in their work on collaborative networking activities and responsibilities. To some extent, the emphasis on research and networking overlapped with employment; those working at universities all did research and to some extent collaboration, but some of the experts employed by expert agencies also performed research and scientific activities as a vital component of their work. Other agency experts were not personally engaged in research. Their main role was as planners, co-ordinators, and advisors in public decision making (Table 1).

The interviews were conducted by the main author and the co-author, who both took notes that were compared later for consistency. The interviews were also recorded, so the notes could be verified. Most of the interviews were conducted in the office of the informant or in a meeting room at the respondent's workplace. The interviews lasted between 1.5 and 2 h. Three interviews were done by telephone, for practical reasons. The interviews were semi-structured and included the following topics: identification of risk issues relating to drinking water; connections between climate change and risks to drinking

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Table 1
Experts interviewed.

Expert	Gender	Research and development	Collaboration, planning, decision support, etc.	Agency employed	University employed	Other
1	Male		X	X		
2	Female		X	X		
3	Male	X	X		X	
4	Female	X	X	X	X	
5	Male	X			X	
6	Female		X	X		
7	Male	X		X		
8	Female	X		X		
9	Male	X			X	
10	Female		X			X

water; neglected and overemphasized risks regarding drinking water; present knowledge status; institutional and organizational responsibilities; co-operation and institutional collaboration; responsibility; and the role of citizens. Each interview was transcribed and coded with respect to risk issues, causal relationships, unwanted outcomes, values at stake, overemphasized risk issues, neglected risk issues, relationships between climate change and drinking water safety and provisioning, main actors mentioned and their responsibilities, strengths and limitations of institutional capacity for risk management, and knowledge and engagement of the public in matters of drinking water and its management.

5. Results

All experts had a great deal to say about the connections between climate change and risks to drinking water. Climate change was mentioned often in the interviews, both spontaneously and in prompted answers to direct questions by the interviewers. We found considerable agreement between the risk issues identified in the research literature on climate change impacts on drinking water provisioning and the elicitations by the experts. Although the experts varied in disciplinary orientation and employment, taken together their viewpoints offer a broad picture of the complex, systemically interrelated risk-related interdependencies (Klinke and Renn, 2006) regarding both drinking water quality and its provisioning. Climate change is understood to be causally connected to drinking water in several ways:

Increasing temperature causes microbial growth: Water contamination is a possible consequence of microbial growth; and, if the waterworks treatment is insufficient, contaminated drinking water can affect public health. Another possibility is for microbial growth to occur in the water distribution system, likewise increasing the risk of contaminated drinking water reaching the public.

Heavy rain causes flooding: In this scenario, the waste water system can be overfilled, likewise resulting in microbial contamination of drinking water (at the water source in combination with or through the distribution system). Another possible consequence of flooding is a landslide, causing the release of chemicals into the water supply. If the waterworks treatment is insufficient, drinking water can be contaminated.

Sea-level rise causes an infusion of salt water into the water supply: If waterworks have insufficient treatment, drinking water quality might be at stake.

5.1. Identification of risk

The experts identified a number of risks that are associated with drinking water quality and that might jeopardize public health. Two main values at stake were identified, namely, public health and food safety. As we have noted above, drinking water is categorized as a food item from a regulatory point of view (EFSA) and there is a direct causal link between food safety and public health. Food containing contaminants or harmful by-products might adversely affect the health of the consumer. Disease and cancer were mentioned specifically. All experts were aware of the linkage between drinking water, food safety and public health.

Two main risks were identified: delivery failure and quality failure. The quality of drinking water is understood to be at risk from contamination of various kinds and due to various causal circumstances. Drinking water, according to the experts, can be contaminated by viruses and by microorganisms such as bacteria and protozoa; specific mention was made of cryptosporidium and legionella. Another category of contaminants is that of (human-made) chemicals. In this category, specific mention was made of polyfluorinated and perfluorinated alkyl substances (PFASs) – which were addressed by several of the interviewees – as well as trihalomethanes, the elements mercury and arsenic, medicinal drugs (with specific mention of hormones) and herbicides. Other, more natural contaminants were also mentioned, including contamination through salt water intrusion and leakages of manure from grazing farm animals.

Sources of potential contamination are manifold, and cover a broad array of phenomena. The experts mentioned the mining industry, industrialization, urbanization, road building, house building, gas stations, landfills, contaminated ground from former industrial activities and waste dumping along the river shoreline, old and neglected pipelines, inadequate treatment technology at waterworks, sea-level rise, municipal waste water treatment plants, terrorism, airports and agriculture. Con-

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tamination of drinking water was understood by several experts as a by-product of modern society, industrial production and accumulation of waste, and widespread use of chemicals. It will also be a by-product of continuing modernization and developmental change in the future, through increasing urbanization, road building, and use of motor vehicles and air traffic.

Direct causal mechanisms leading to the contamination of drinking water, as discussed by the experts, were understood to be systemically connected by means of geological, hydrogeological and weather-bound events involving land erosion, landslides caused by heavy rain and floods, rising temperature, animals grazing near water supply areas, overfill of waste water systems, industrial accidents, run-off from roads, and spills from industries close to the river.

One indirect causal condition that was identified as a risk to the quality of drinking water relates to the inherent vulnerabilities of the technical infrastructure of drinking water production and distribution. Several experts pointed out the issue of failures in the separation of waste and sewer water from drinking water; for example, in cases when sewage plants upstream leak contamination into a water supply area downstream, or when insufficient separation exists between pipelines for waste water and pipelines for drinking water. The fact that the waste water and drinking water infrastructure is rather old was a recurring topic (see SOU, 2014:53); since investments in repair and upkeep have not been made at the same speed as the deterioration of the system, sewage water might leak into the drinking water system. Insufficient maintenance of infrastructure for drinking water pipelines, water treatment works and waste water management facilities was regarded as a serious problem by a majority of the experts.

The complexity of the causal relations bridging the material and the social domains was a recurrent topic in the interviews. One university expert formulated as follows: *"Cause and effect, connections, making connections between what-if chains of associations – that is what I work on. It is one thing to work in a technical system – nuts, bolts and pumps. If you go outside where contaminated water is released: what are the effects, who is affected? Hospitals do no work, operations have to be cancelled, people lose their jobs, people have to fetch water by bicycle. Difficult stuff."* (University Expert 3)

Organizational failure, lack of institutional capacity and regulatory shortcomings formed another risk theme that was identified by the experts. The waterworks are old, and mismanagement in the treatment process might result in the chlorine that is used as a disinfectant agent reacting with other substances and causing toxic by-products. Several experts viewed the municipalities as a weak link in the risk management chain. In particular, small municipalities were understood to lack the necessary competence and resources. In the near future, much of the staff currently working with water management will retire; this was identified as a problem for municipalities, which will lose a considerable amount of competence that will be difficult to replace. Drinking water risk management is threatened by human error due to a number of factors related to organizational shortcomings: a lack of compliance with safety plans, a lack of knowledge and expertise, a lack of co-operation, and inadequate decision making. However, the national regulatory system was also understood to be a problem due to complex regulation and to national policy goals that might be contradictory in a local risk management context, such as contradictions between goals to protect the environment versus goals to protect public health. Centralization of drinking water production and distribution was understood as creating vulnerability, both regarding water quality and delivery. The lack of alternative water supplies was mentioned by several experts as a serious problem.

5.2. Overemphasized and neglected risks

The interviews included explicit questions about overemphasized and neglected risk issues; that is, risks that the experts believed were receiving too much or too little attention (Sjöberg et al., 2005). The experts identified a greater number of neglected risk issues than overemphasized ones – roughly twice as many. No expert thought that there were no neglected risk issues. Of the total number of neglected and overestimated risk issues that were mentioned, 42 are neglected and 19 are overemphasized. In this sense, the experts can be understood to adopt the role of risk promoters who have a duty to raise warnings about risks (Sjöberg et al., 2005).

Although several experts were of the opinion that there were no overemphasized risk issues, some identified the substances Bisphenol A, drugs, herbicides/pesticides, radon and uranium as overestimated. In addition, browning (which occurs when water is blended with organic matter and humus and becomes discoloured) was understood to be overestimated as a risk issue. The sources for these overestimated risks were linked to agriculture, land contamination and local effects of climate change. Several experts thought that agriculture was overestimated in its association with risks to drinking water. In addition, the incoming raw water quality at the water treatment works was seen as an overestimated risk; given that there are effective processes and technology for water treatment, poor quality of incoming water is manageable and does not result in poor quality of the drinking water produced.

The identified neglected risk issues are in the clear majority. Contaminants that were understood as neglected risks were discussed in two areas: chemicals that might contaminate the water supply and chemicals that cannot be managed in the waterworks. Mention was also made of drugs, microbiological matter, specific chemicals such as PFASs, and uranium. In addition to landslides, subsidence has the potential to damage underground pipelines; the experts mentioned poor ground conditions and neglected maintenance of pipelines. The sources for the neglected risks were mainly technical, organizational and managerial: street work, loss of pressure in water systems, road and ship transport, lack of reserve water and accidents. The experts also brought up neglected areas in risk management, such as a lack of innovation in municipalities, the West Swedish package,[1] a lack of political engagement, poor co-ordination and collaboration among societal actors, a lack of risk awareness, municipalities that overestimate their preparedness for crisis management, and a lack of understanding and knowledge among planners and decision makers in the municipalities.

5.3. Risk management measures and governmental steering

The experts had many opinions on the risk management of drinking water. One idea that came up in several interviews was that the raw supply should be more differentiated and include alterative supplies. To be dependent on one major supply source, such as Göta Älv, was understood to be risky. Should anything serious happen to Göta Älv, resulting in contamination or infrastructure failure (e.g., a broken main distribution pipeline), it would be disastrous. The use of alternative water supplies – such as the exploitation of smaller groundwater reservoirs and additional water protection areas – and stricter monitoring of raw water quality were suggested as risk management actions.

The role and necessity of efficient planning were emphasized by several experts: planning must be more effective and more aligned to existing regulation (e.g., the Planning and Building Act and Safety Plans). The quality of documents used in the planning process, especially those used by municipalities and those related to the institution of water protection areas, was understood to be in need of improvement. Drinking water ought to be more generally raised on the planning agenda; it should have a higher saliency in risk and contingency planning and in strategic physical planning. Examples of planning actions that were mentioned in order to mitigate the effects of climate change included building on heights; building infrastructure and houses that do not risk being flooded; changing physical planning; and opening up new spaces for water, wetlands and reservoirs of water. In addition, the consequences of landslides need to be investigated, and an inventory should be made of landslide risk.

The need for state-of-the-art technological management measures was emphasized, including the need to rebuild and upgrade waterworks with new cleaning technology such as ultrafilters and UV light. Another risk management theme that was mentioned was that of regimes to control animal husbandry; examples included having stricter control over where farmers put their cattle, having restrictions such as no grazing animals near a water supply area, having stricter control of animal health, and keeping track of the location of animals. It should be noted that the experts did not agree on how they rated farming and animal husbandry as a risk for biological contamination of the drinking water supply. While some experts, as mentioned earlier, viewed this as an overemphasized risk, others were confident that farming and animal husbandry did indeed require stricter regulation as a potential and serious threat to safe drinking water.

Combinations of a wide array of risk management strategies were also advocated:

Interviewer: “Strategies for risk management? If you think about that, what strategies do you see? Or methods?”

Respondent (Agency Expert 6): “The classical method is to focus on technical systems; one looks at release points and points of influx, barriers in the waterworks, delivery performance, those types of questions, are of course crucial. Then there are softer approaches, associated with societal planning, contingency planning, limitations on private enterprises for example such as the establishment of water protection areas and their regulation.”

There was a clear agreement among the experts that drinking water is a non-issue for citizens and is mainly absent on the political agenda. Drinking water was understood to be taken for granted unless there are problems with delivery or quality. Political engagement was thought to be lacking. Citizens were believed to have high trust in the provisioning of the service and in the authorities responsible. Attitudes of citizens and consumers, and especially what the experts understood as a lack of proper appreciation of the value of safe drinking water, were identified as a target for risk management actions. A key element that was emphasized many times was that citizens were believed to need education about the actual costs of keeping up the drinking water infrastructure. Pedagogical schemes were suggested to promote attitude change, such as studies on citizens’ willingnss to pay, the highlighting of water in terms of ecosystem services, and virtual water declarations that show how much water is actually needed to produce goods and services. Several of the experts emphasized a need for increasing public awareness about what it takes for society to build a sustainable and resilient system for the provisioning of safe drinking water. They identified an overall lack of political engagement as an obstacle to achieving this goal.

The existing regulatory system, which places responsibility at the local level for the production and provisioning of drinking water, and in which a number of government agencies have disparate responsibilities and roles in steering partial aspects of drinking water provisioning and management, was understood to be inefficient. In addition to the Swedish Food Agency, the experts mentioned a number of government agencies with different responsibilities: the Swedish Meteorological and Hydrological Institute, the Swedish Agency for Marine and Water Management, the Swedish Civil Contingencies Agency, the Swedish Geological Institute and the Swedish Chemicals Agency. Seven out of ten experts identified the municipality as responsible for risk management; five out of ten mentioned the Swedish Food Agency; five out of ten mentioned the County Administrative Council; and other authorities received occasional mentions regarding responsibility. One expert

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[1] This is a 34 billion SEK investment in infrastructure for commuter trains, including road and railway tunnels and bridges, to provide the city of Göteborg with more efficient public transport.

working at an agency pointed to difficult decision processes that are due to the sheer amount of documentation; officials are "drowning in documentation", and documents are often disparate, providing a fragmented picture of the relevant facts.

Regulatory conflicts between different funding and steering principles were underscored as a cumbersome problem. These include fees based on a prime cost principle versus taxes, and environmental goals at the national level versus local public health goals. Since water services are based on fees in relation to cost for the water collective and not on taxes, it is not possible for politicians to decide to allocate more resources to water services if these are not directly motivated by costs. It was also noted that it might be difficult to calculate the exact cost of water services.

The experts generally considered there to be too many authorities and too many agencies, and noted that the decision making and management have an unmanageable and complex structure. Water management is described as "complex", "complicated" and "fragmented", with many "overgrown groups" that have emerged out of "100 years of traditions". The County Administrative Council is generally understood to have unclear responsibilities.

"One thing is interesting with the provisioning of drinking water: according to the law, it is a municipal responsibility, but in practicality, in many parts of Sweden this issue is managed at the regional level. It is as if the practical organization for management has somehow grown out of the regulatory framework. It works, since there are a few strong actors who drive development." (Agency Expert 6)

Although municipalities are responsible for providing drinking water, they are generally viewed as lacking capacity and the necessary knowledge, especially when it comes to risk assessment. The experts generally agreed that there are too many authorities involved and that there are great problems with interaction.

The experts pointed to the need for more interdisciplinary collaboration and better integration between authorities in order to achieve an integrated water resource management. Education, interdisciplinary research and structures for collaboration are needed. Some experts considered that a new, overarching agency is needed in order to promote collaboration between different parts of the governance system regarding source water and groundwater. However, other experts opined that there are already many authorities involved, and that adding new ones would not solve much. Instead, they advocated stronger state steering, especially with the County Administrative Councils doing more and being more active in drinking water management. One viewpoint articulated was that the risk perspective is too specialized, with each actor focusing on specific risk issues and having little recognition of risk issues in other areas. It was noted that interdisciplinary and inter-organizational collaboration is crucial but not easy to accomplish. The experts emphasized the strong need for collaboration, a holistic perspective, comprehensive understanding, education and cross-disciplinary endeavours, in order to reach "balanced knowledge" that is not partial or hampered by conflicts of interest.

6. Discussion and conclusion

Our results highlight the trans-scientific complexity of climate change adaptation as it relates to drinking water provisioning. Regarding the technical infrastructure, organization and decision making processes (Brookes et al., 2014), the experts were concerned about how risk management of drinking water provisioning will actually work in the (near) future. The experts pointed to an aging infrastructure, where upkeep has been neglected for reasons of high cost and a political lack of priority; increasing technical demands on cleaning processes at the waterworks (regarding microbial and chemical contamination as well as the increased risk of adverse by-products); consequences from extreme weather events; an ill-fitted and fragmentary regulatory framework that combines a cost principle with the main responsibility residing at the local level; and an unclear division of responsibility between a number of regional and national government institutions.

Risk governance and management literature (Power, 2007, 2016) addresses the complexities inherent in risk regulation and management across sectoral and organizational boundaries and within specific cultures of work. Risk governance in a number of policy areas has been shown to involve complex decision processes that draw on diverging and sometimes conflicting knowledge claims, perspectives and interests (Renn, 2008; Hood et al., 2001; Hutter and Power, 2005). Hood et al. (2001) conclude that risk regulation is shaped by policy context, organizational and institutional features, legal and regulatory structures, and interaction patterns among governance actors. Governance interactions are often multi-purpose and take place in arenas that are characterized by multi-level and multi-sectoral governance (Leventon and Antypas, 2012). The Swedish system for spatial planning in the context of climate change adaptation has been shown to be fragmented and susceptible to local political ideas about the attractiveness of place, resulting in *ad-hoc* solutions and a lack of overarching strategic planning (Storbjörk and Hjerpe, 2014).

Although drinking water provisioning is basically the responsibility of local municipal authorities governed by local politicians, risk management depends on complex collaboration between local, regional, national and European authorities (Leventon and Antypas, 2012; Orru and Rothstein, 2015) within a complex and historically evolved regulatory framework. Cross-sectoral collaboration (Bryson et al., 2015) and effective inter-agency interaction are key to drinking water risk management (Jalba et al., 2010). Climate change adaptation in a multi-level governance context and, specifically, the risk management of drinking water require planning to be coordinated above the municipal level (Lundqvist, 2016). Furthermore, the decisions made must be considered legitimate by citizens and stakeholders. In addition, management actions should be effective in the sense that they align with state-of-the-art knowledge and agreed-upon goals (Lundqvist, 2016).

Our results point to a considerable gap between the scientific knowledge of climate change effects and adaptation capacity at the local level. To fill this gap, participatory approaches through boundary organizations with the capacity and man-

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date to integrate scientific knowledge and adaptation policy are recommended (Kirchhoff et al., 2015). Participation in deliberation and decision making not only includes government networks, experts and elite stakeholders, but also the public. Experts however tend to believe that the public misunderstands the causes and nature of environmental problems and their solutions, and have identified this issue as an obstacle to integrated environmental decision making (Petts and Brooks, 2006).

In a study of climate change adaptation at the local level, Hjerpe et al. (2015) identify three trigger factors of political engagement in climate adaptation: institutional incentives, relative political weight and political leadership. If these factors are weak or absent, political engagement can be expected to be low. If citizens lack knowledge regarding a particular policy issue, if they are unengaged, and if they have high trust in the efficiency of the provisioning of a service, there will be very little pressure on local politicians to place the issue on the political agenda. Engagement can be foreseen to be low. The interviewed experts were all of the opinion that drinking water risk management is a highly attenuated issue on the local level, to citizens and politicians alike.

Since their expert roles varied between contributory and interactional expertise (Collins and Evans, 2002, 2007) it is not surprising that the experts had slightly different focuses. While contributory experts are more directly involved in science production, interactional experts focus more on policy work such as inter-organizational activities, collaboration with other agencies (in some cases on a European level) and dialogue with stakeholders. In agreement with the literature on the varied roles of expertise, dependence on discipline, policy area and employment, we conclude that the concept of an “expert” needs to be approached with caution, especially in studies of expert roles in “wicked” planning problems, in which the problem formulation and solution are intertwined (Rittel and Webber, 1973). Wicked planning problems are also trans-scientific (Weinberg, 1972); although they involve questions about scientific facts, knowledge about facts alone cannot provide a solution to a wicked problem. Since there is no clear and agreed-upon way to define a wicked problem, exactly what (scientific) knowledge is relevant to a problem’s definition and solution cannot be determined. Interactional expertise, as defined by Collins and Evans (2002), captures the trans-scientific element of translation of knowledge. Therefore, what an expert role amounts to specifically can vary depending on organizational affiliation, the context of work and the trans-scientific negotiations involved in that work.

Although the experts differ according to role, their viewpoints are in unison in two important respects. A lack of political saliency of drinking water as a public service is generally understood to be an obstacle to the development of robust adaptation strategies. Citizen awareness and knowledge is regarded as a prerequisite for climate change adaptation with regard to drinking water. Another point of agreement is that geographical, organizational and institutional boundaries are understood to make risk management fragmented. The partly overlapping and sometimes ambiguous responsibilities for the provisioning of safe drinking water are seen as an obstacle to adaptation. To conclude, climate change adaptation in the area of drinking water provisioning is understood by the experts to be in need of new forms of integration of knowledge of systemic risk relations, in combination with more efficient agency collaboration, based on clear demarcation of responsibility between actors.

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