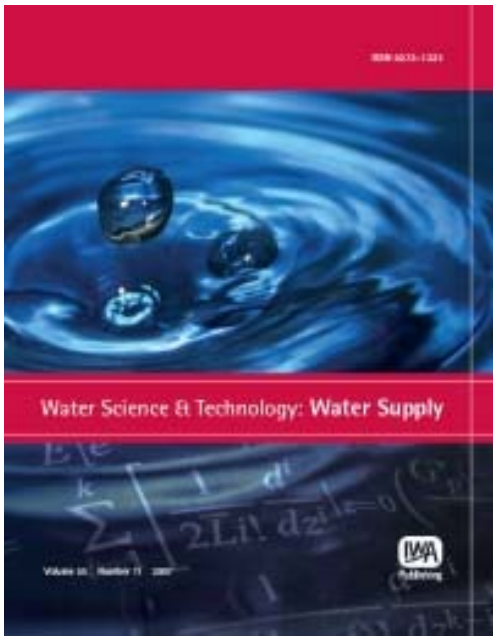

Improved risk assessment and risk reduction strategies in the Water Safety Plan (WSP) of Salta, Argentina

L. Seghezzo, M. L. Gatto D'Andrea, M. A. Iribarnegaray, V. I. Liberal, A. Fleitas and J. L. Bonifacio

ABSTRACT

The Water Safety Plan (WSP) for the city of Salta (Argentina) is presented and discussed. To develop this WSP, we used an adapted version of the methodology proposed by the World Health Organization (WHO). The new method included a preliminary weighting procedure to assess the relative importance of different parts of the system, and a more systematic estimation of the magnitude of control measures. These modifications allowed the definition of a variety of risk reduction strategies. The risk assessment step was performed during participatory workshops with members of the local water company. The Initial Risk for the entire system was 30.2%, with variations among processes, subprocesses and components. More than 60% of the hazardous situations identified require control measures to reduce the risk below an acceptable threshold. If all control measures were successfully implemented, the Final Risk could be lowered to 17.7%. Methodological changes introduced allowed a more detailed analysis of the risks and can be an important improvement of the assessment procedure.

Key words | Argentina, risk assessment, Salta, Water Safety Plan (WSP)

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INTRODUCTION

Risk assessment and management in drinking water provision systems has been proposed as an effective way of protecting public health by ensuring that water providers consistently comply with minimum quality standards (WHO 2004; Davison *et al.* 2005; Byleveld *et al.* 2008). To facilitate that process, the World Health Organization (WHO) established a specific risk assessment and risk management approach called the Water Safety Plan (WSP). A WSP is allegedly '[T]he most effective means of consistently ensuring the safety of a drinking-water supply … through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer' (Bartram *et al.* 2009: 1). Although its core components are generally the same, there are no strict recipes for developing a WSP. Instead, WSPs have to be adapted to each case and to the way each water utility is organized and operates (Rinehold *et al.* 2011). This local adaptation is important to generate useful, comprehensive and comparable analyses. Adaptation implies, among other things, a case-specific design of risk assessment tools and the establishment of unequivocal assessment criteria, two aspects that are open to improvements in the WHO's guidelines. The systematic identification of vulnerabilities and threats needed to implement a WSP and the formulation thereafter of rational strategies to minimize risks

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under different possible scenarios will certainly contribute to the development of more sustainable water management systems (Staben *et al.* 2010; Haasnoot *et al.* 2011; Iribarnegaray *et al.* 2012). The success of a WSP has to be verified by some sort of progress assessment, ideally by setting measurable monitoring performance indicators (Mudaliar 2012). Monitoring and reassessment of risks is a medium- to long-term goal that is particularly dependent on local institutional frameworks (Rahman *et al.* 2011). WSPs are being implemented in water supply utilities in both developed and developing countries (Davison *et al.* 2005; Howard *et al.* 2005; Yokoi *et al.* 2006; Mahmud *et al.* 2007; Gunnarsdóttir & Gissurarson 2008; Jayaratne 2008; Mälzer *et al.* 2010; Viljoen 2010; Schmoll *et al.* 2011; Vieira 2011; Mayr *et al.* 2012). A number of pilot WSPs have also been developed in small- and medium-sized cities in some Latin American countries (COSAALT and FUNSALUD 2007; Bastos *et al.* 2008; Pérez Vidal *et al.* 2009; Rinehold *et al.* 2011; Torres-Losada *et al.* 2012). However, full-scale implementation in the region is incipient and the performance of ongoing experiences is still under assessment.

In this article we present a WSP developed for the city of Salta, Argentina. We describe some modifications introduced to the WHO methodology that allowed a deeper and more detailed risk assessment process. The modified method provides a tool to establishing a ranking of control measures according to the perceived relevance of each part of the system. The improved risk assessment method also allows the definition of a variety of management strategies that may be implemented to minimize risks over the short, medium, and long term while optimizing the allocation of funds.

MATERIALS AND METHODS

The WSP was developed for the city of Salta, in northwestern Argentina (24°51′ S 65°29′ W; 1,187 m above sea level). The city has a population of more than half a million inhabitants. Climate can be defined as 'subtropical with a dry season' within the zone of tropical climates, and is an intermediate category between humid and dry climates. Mean ambient temperature is 16.5 °C (Arias & Bianchi 1996). Average annual rainfall is around 700 mm concentrated mostly in summer and the beginning of autumn. Drinking water coverage in the city is around 95% and water consumption is high, with current estimates at 650 L per person per day, of which approximately 35% is lost due to leakages and wastage. In Salta, the water system was transferred to the private sector in 1998, when the state-owned General Water Administration Office (AGAS) was given in concession to the company Aguas de Salta S.A. (ASSA) (Saltiel 2003). This was in line with Argentina's privatization processes of the 1990s (Azpiazu *et al.* 2005). However, after more than a decade in private hands, the government rescinded the contract in 2009 and the service reverted to a state-owned company (Compañía Salteña de Agua y Saneamiento, CoSAySa). For more information on Salta's water governance see Iribarnegaray & Seghezzo (2012). Flow diagrams for all processes, subprocesses and specific components were based on information provided by CoSAySa, interviews with key employees, and site inspections. Hazards and hazardous events were identified during visits and interviews. Risk assessment was performed in participatory workshops based on Delphi methodology (Linstone & Turoff 1975). Representatives of all areas of the company directly related to operation, maintenance or control of the water provision system were present during the workshops. Results of these workshops were analyzed by the assessment team and later discussed with the participants in a feedback process. The methodology used to develop the WSP consists of 11 modules grouped in four steps: preparation (Module 1), system assessment (Modules 2–7), management and communication (Modules 8–9), and feedback (Modules 10–11) (Bartram *et al.* 2009). This work focuses on activities included in Modules 1–4, with the exception of the reassessment of risks (second part of Module 4). This reassessment will be performed after control measures are implemented by the company. All remaining modules (5–11) will be executed by the water utility at a later stage.

Module 1. Preliminary actions

This activity focused on the establishment of a professional team with the adequate expertise needed to develop the WSP. The team was assembled by CoSAySa and was initially composed of representatives of several provincial and municipal institutions and organizations related to water and environmental protection. By means of a specific cooperation agreement signed by CoSAySa, the National University of Salta (UNSa), and the Research Institute on

Non-Conventional Energy Sources (INENCO), researchers and students took over the task of coordinating the initial modules of the WSP. During this initial stage most activities were performed by members of CoSAySa and INENCO. Remaining actors will join the process at a later stage.

Module 2. System description

The water provision system in Salta can be divided in four basic processes: catchment, transport, treatment, and distribution (Figure 1). Water is obtained from several surface, subsurface and subterranean sources. Surface and subsurface water is transported via open and closed aqueducts to treatment plants where, depending on the characteristics of the water, it is subjected to processes of sedimentation, filtration, and chlorination. Groundwater is obtained from more than 150 wells scattered around the city. Wells are classified in three types depending on whether the water is stored in reservoirs (type A) or injected directly into the water grid by different means (types B and C). Distribution is generally done through a system of pipes of varying diameter to the final consumption points. The distribution system includes community and household tanks, pumping stations, and cistern trucks (in certain neighborhoods).

Module 3. Hazards identification and risk assessment

This activity included two participatory workshops and several follow-up meetings. During the first workshop, 37 hazards and hazardous events were identified. Hazards were classified as: (1) natural (droughts, floods, earthquakes, extreme climatic events); (2) anthropogenic (agriculture, presence of livestock and farm animals, circulation of unauthorized vehicles, recreational use); and (3) operational (inadequate water treatment, lack of surveillance personnel, impacts caused by routine company operations). Pertinent events were selected for each one of the 17 components in which the system was subdivided. Likelihood and severity values for all hazardous events selected for each system component were loaded in a number of risk assessment matrices. The combination of 37 hazardous events and 17 components of the system generated 213 'hazardous situations'. These hazardous situations can be

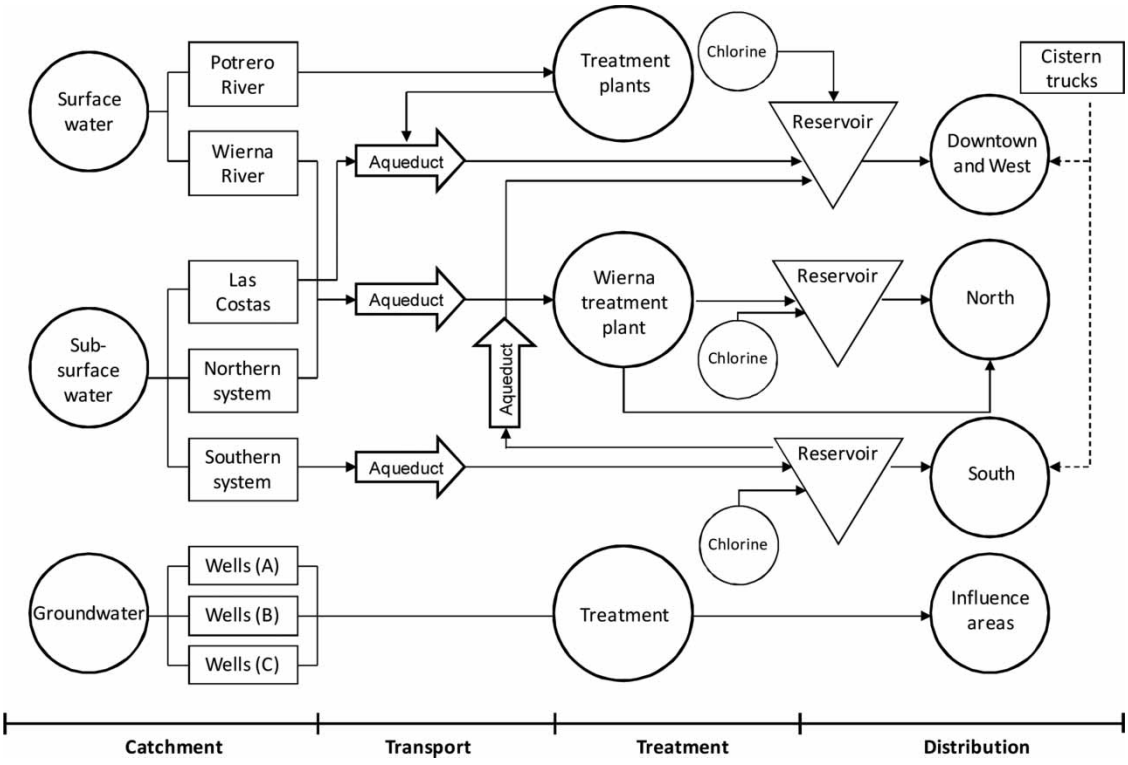

Figure 1 | Simplified flow diagram of the water system in Salta. Basic processes are indicated below the bottom line.

seen as the smallest elements of the risk assessment procedure. A combined risk assessment matrix was then built for the entire system. We introduced the following modifications to the assessment methodology in order to make it more suitable to local circumstances:

1. *Weighting of importance*. The assessment of risks was preceded by a weighting step based on a variation of the analytical hierarchy process (Belton 1986). Weights were assigned during a participatory workshop in which members of the water company were asked to allocate direct ratings to the different parts of the system on a 0–100 scale. These values reflect their perception of the relevance of each component of the system according to a (relatively) subjective scale. For some components, specific (if possible quantitative) rating criteria were chosen beforehand (i.e. water production in the case of wells). Otherwise, participants rated the different parts of the system according to their professional training and personal experience.
2. *Different risk measuring units*. Likelihood and severity of occurrence of the hazardous events identified for each component were estimated on a scale between 0 and 100. The risk calculated as the product between likelihood and severity was also expressed as a percentage. According to the participants of the workshops, percentages are easier to interpret and communicate than the different risk scales in the method proposed by WHO.
3. *Clear assessment criteria*. Assessment criteria for likelihood and severity were adapted to local circumstances. Special attention was paid to minimize ambiguities that might introduce biases or confusion to the assessment process. Whenever possible, likelihood and severity were estimated based on objective, statistic or scientific data, such as the likelihood of earthquakes or droughts, or the severity of microbial contamination of water sources. In cases where quantitative criteria could not be applied, values were assigned based on the experience and opinions of the participants. Severity was determined based on the effect of hazardous events on three aspects: water quantity, water quality, and human health. In some cases, the condition of tanks, ducts, pipes, equipment, and all relevant infrastructure was also taken into account to adjust the estimations.
4. *Establishment of risk hierarchies*. Risks were classified in equally sized categories according to the following scale: risk $< 25 =$ low; $25 \leq$ risk $< 50 =$ medium; $50 \leq$ risk $< 75 =$ high; risk $\geq 75 =$ very high (adapted from Bossel (1999)).
5. *Definition of risk thresholds*. An acceptable risk value was established as a guide to determine the severity of the control measures needed in each case. In this work, the threshold value used was set at 24%, one unit below the upper end of the 'low' range. This threshold can be changed for different components of the system, or even for each hazardous situation, if deemed necessary.
6. *Calculation of different types of risk*. The product of importance and risk was defined as the 'risk impact'. This new variable is sensitive to local circumstances because it is influenced by the weights assigned to the different parts of the system. As it will be shown later, using the risk impact can help establish more stringent, locally adjusted risk reduction strategies. By using this new variable, three types of risk can then be calculated: (1) the 'Initial Risk', this is the risk calculated in the usual way (likelihood times severity); (2) the 'Corrected Risk', which is the result of subtracting the previously established threshold value from the Initial Risk; and (3) the 'Final Risk', calculated in the same way as the Corrected Risk, but taking into account more stringent thresholds for specific components (or for single hazardous situations within them), according to the relative importance assigned to these components during the weighting step. The procedure we used to calculate the Final Risk is the following: first, the risk impact is calculated for each component of the system before and after the weighting procedure (before weighting, components at the same level are assumed to have the same relative importance). If the risk impact for a given component after the weighting procedure is higher than before, the threshold value for that specific component is proportionally lowered until the risk impact after weighting is equal to or lower than the risk impact before weighting. If not, the general threshold (in our case 24%) is maintained unchanged for that component. Then, the Final Risk is calculated for each component (and for the entire system) in the same way as the Corrected Risk. As thresholds have been adjusted (lowered) for some components, the Final Risk will always be lower than the Corrected Risk.

Module 4. Determination of control measures

The adapted methodology allows an automatic calculation of the magnitude of the required control measures. For each hazardous situation, this magnitude is determined by the difference between the Initial Risk and the applicable threshold (either the initial threshold value or the one adopted after the weighting procedure). The magnitude determines the type and intensity of control measures, according to the following categories: magnitude $< 25 =$ small; $25 \leq$ magnitude $< 50 =$ intermediate; $50 \leq$ magnitude $< 75 =$ severe; magnitude $\geq 75 =$ extreme. Once the numerical magnitude of control measures is known, company personnel must identify tangible procedures and actions that would adequately reflect this magnitude on the ground. This process is relatively subjective and therefore experience with the operation and maintenance of the system is essential. External audits can also help identify the appropriate type of control measures and avoid over- or under-estimations.

RESULTS AND DISCUSSION

Table 1 presents a summary of the results obtained for the entire WSP. Columns B, E, and I show the relative importance assigned to the respective processes, subprocesses and components during the weighting procedure. For the sake of comparison, columns C, F, and J show the unweighted values. Catchment and Treatment received the highest weights during the assessment (30.8 and 32.1, respectively; see Table 1, column B). Workshop participants emphasized the existence of a very direct link between these two processes and the quality and quantity of the water consumed in the city. Within Catchment, Surface water was considered the most important source (weight: 13.4), primarily based on its higher relative contribution in terms of flow rate, followed by Groundwater and Subsurface water with similar weights (9.0 and 8.5, respectively).

Initial Risk for the entire system was 30.2% (range: medium) (see Table 1, bottom of column K). If all control measures, as determined for an initial threshold value of 24%, were successfully implemented, the resulting Corrected Risk would be 19.5% (Table 1, bottom of column L). Aggregated risks for subprocesses and processes can be calculated by averaging the values obtained for their lower categories (components and subprocesses, respectively). As shown in Table 1, the Final Risk was lower than the Corrected Risk for many components (compare columns L and M). Lowering the threshold for some components implies that those components will require more and/or more stringent control measures (compare pie charts in Figure 2). This is beneficial for the overall goal of achieving a safer water provision system and can be seen as a justification of the weighting step. In fact, the overall Final Risk should be only 17.7% (Table 1, bottom of column M) after implementation of improved control measures. Whether the amount or magnitude of the control measures needed is high or low is debatable. Nevertheless, it seems clear that the system studied is far from safe, since almost 60% of the hazardous situations identified require some sort of control measure.

Risk reduction strategies

For technical or financial reasons, it could be difficult to implement all required control measures at once. In those cases, it could be wise to establish gradual and responsible risk reduction strategies.

These strategies greatly depend on local specificities (Hrudey *et al.* 2011). Water utilities can adopt different risk reduction targets for a variety of financial scenarios. It is always important that strategies, targets and assumptions made during the assessment are thoroughly communicated to water authorities and the public. Some guidelines could be suggested to establish strategies based on the results of the WSP. As seen in Figure 3, a hierarchy of risks can be made after the results of the first round of risk assessment. We can apply a 'hierarchical approach' by dealing stepwise with risks of decreasing importance and the overall risk reduction will follow a gradual path (see Figure 4, line with square markers). Following this approach, the risk for our entire system will be below the initial threshold of 24% after stage 2. The duration of the stages or periods has to be established for each case; it could be days, weeks, months or years. The Final Risk of 17.7% will only be achieved in stage 5, when all hazardous situations

Table 1 | Summarized risk assessment matrix used to calculate the WSP for the city of Salta, Argentina

A Process	B Importance Weighted	C Unweighted	D Subprocess	E Importance Weighted	F Unweighted	G Component N°	H Name	I Importance Weighted	J Unweighted	K Risk Initial	L Corrected	M Final
Catchment	30.8	25.0	Subsurface	8.5	8.3	1	Las Costas (LC)	2.2	2.8	18.4	15.4	15.4
						2	Northern system	3.4	2.8	27.3	18.3	14.9
						3	Southern system	3.0	2.8	23.0	15.1	13.8
			Surface	13.4	8.3	4	Potrero River	9.4	4.2	30.8	19.5	8.7
						5	Wierna River	4.0	4.2	31.6	19.7	19.7
			Groundwater	9.0	8.3	6	Wells (A)	2.1	2.8	18.8	14.6	14.6
						7	Wells (B)	2.5	2.8	15.5	12.9	12.9
						8	Wells (C)	4.3	2.8	16.8	13.8	8.8
Transport	17.9	25.0	Transport	17.9	25.0	9	Injection (LC)	4.1	6.3	53.8	23.6	23.6
						10	Conduction (LC)	1.8	6.3	25.6	19.3	19.3
						11	Northern aqueduct	6.8	6.3	37.0	23.8	21.9
						12	Southern aqueduct	5.2	6.3	37.0	24.0	24.0
Treatment	32.1	25.0	Treatment	32.1	25.0	13	Treatment plant (LC)	12.6	6.3	37.2	22.2	11.0
						14	Northern system	7.2	6.3	36.5	22.4	19.3
						15	Southern system	5.6	6.3	29.8	16.7	16.7
						16	Wells	6.7	6.3	32.3	22.3	20.8
Distribution	19.2	25.0	Distribution	19.2	25.0	17	Distribution	19.2	25.0	24.7	17.8	17.8
Total	100.0	100.0		100.0	100.0			100.0	100.0	30.2	19.5	17.7

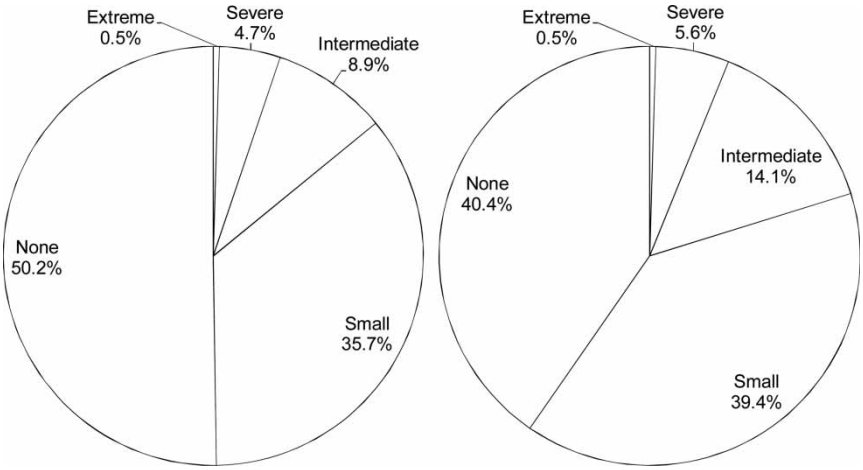

Figure 2 | Proportion of control measures in each category for the 213 hazardous situations identified. Values in left pie chart were calculated according to a fixed threshold of 24%, leading to a Corrected Risk of 19.5%. In the right pie chart, threshold varies according to the relative importance of the system's components, leading to Final Risk of 17.7%.

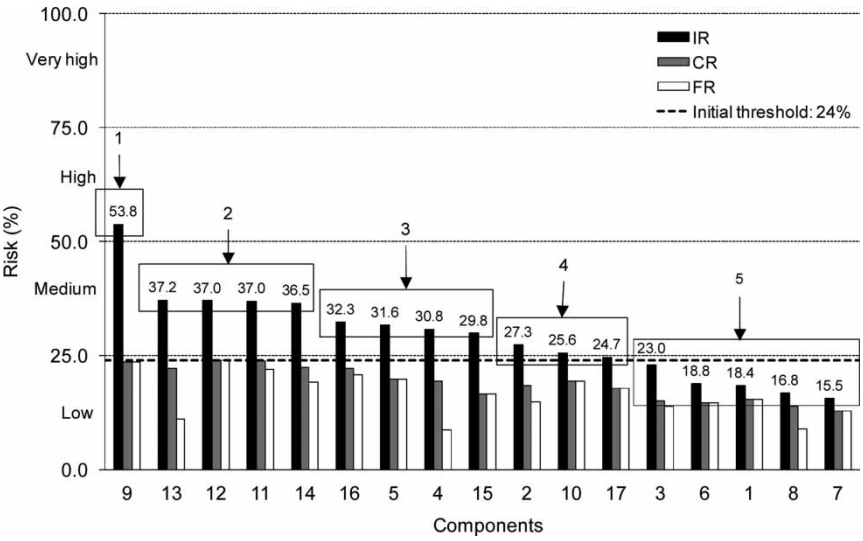

Figure 3 | Estimated risks for the 17 components of the water supply system in Salta. See component names in Table 1, column H. IR: Initial Risk; CR: Corrected Risk; FR: Final Risk. A hierarchy of components with similar risks indicated with numbers 1–5.

above their respective thresholds have been addressed with adequate control measures.

Risk reduction can focus on average values at the level of component, subprocesses or even entire processes. This approach can be important for communication and monitoring purposes. In most cases, however, risk reduction has to focus primarily on the results obtained at the level of hazardous situations. In some places, not only the magnitude of the risks can be of interest, but also the separate values assigned to likelihood and severity (i.e. very unlikely hazards that might have catastrophic consequences). Other possible risk reduction strategies could be based on the following approaches:

(a) *The threshold approach*. Risk reduction proceeds by gradually strengthening the threshold until an acceptable Final Risk is attained.
(b) *The proportional approach*. Risk reduction is based on politically agreed yearly percentages of the Initial Risk (see the line with rounded markers in Figure 4, calculated for a fixed risk reduction of 20% per period).

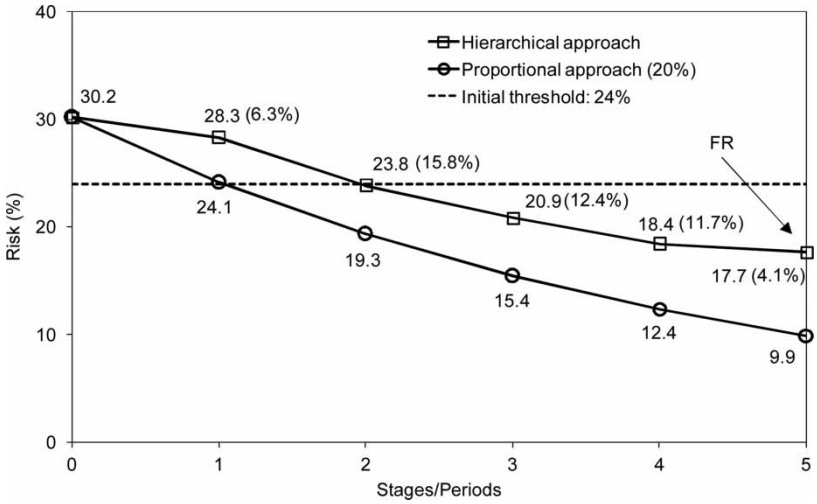

Figure 4 | Risk reduction paths that could be obtained with two different strategies: (1) the hierarchical approach (□) addresses sequentially the groups of risks in Figure 3; and (2) the proportional approach (○) reduces risk 20% per period. Risk reduction percentages indicated between brackets. FR = Final Risk calculated for our case (see bottom of column M in Table 1).

(c) *The spatial approach*. Gradual correction and control programs focusing first on areas of the city with greater combined risks.

(d) *The economic approach*. Cheaper or cost-efficient control measures are implemented first and risks are then recalculated, with or without a reduction target per period.

(e) *The hybrid approach*. Any combination of the above strategies.

Final discussion

The modifications introduced to the method allowed a deeper and more systematic assessment of risks according to the characteristics of each part of the water system. The weighting step made the whole assessment more sensitive to local specificities, enhancing the potential effectiveness of control measures. This step can be particularly helpful in prioritizing actions and devising efficient and cost-effective risk reduction strategies. Lessons learned during participatory events conducted for this WSP can help improve future assessments. First of all, the identification of pertinent hazardous events for each case is paramount. Participation of people with field experience is therefore indispensable at this stage. Before assigning any quantitative values in the risk assessment matrix, it is also essential that everybody in the audience has had ample access to all relevant information on the system. The establishment of qualitative or quantitative decision criteria beforehand was particularly useful for facilitating the weighting process and minimizing prejudices and biases. It is advisable to discuss the meaning and the value of the initial threshold at the beginning of the workshops. This relatively arbitrary value can be changed at will by the assessment team and can become part of the planning and improvement strategy. The assessment of risks and the determination of target thresholds relate, to a great extent, to the will, interests, and expertise of the assessment team. Therefore, it is advisable to conduct similar workshops with different interest groups such as non-governmental organizations, scientists, or end users to compare results and detect different perspectives on the safety of the water system. A WSP contains quantitative objective measurements, and semiquantitative figures. The latter are numerical estimations reflecting subjective, expert and nonexpert judgments obtained by means of personal consultations and panels of relevant stakeholders. These estimations are important to determine the magnitude of control measures and the type of performance indicators needed to assess progress. Therefore, they should be guided not only by their ability to reflect a relevant aspect of the system but also by their amenability to numerical translation (Saleth & Dinar 2004). When estimations are inherently subjective/judgmental, expert and non-expert assessment teams face the difficult task of assigning numerical values to essentially qualitative variables. The validity of

these values will be related to the validity and social acceptability of the stakeholders in the assessment team (Robbins 2004). The decision-making process during risk assessments is partly unconscious and choices are usually made in a few seconds during a participatory workshop. In-depth and open discussions among participants help minimize extreme positions and biases, but there will always be a certain degree of subjectivity in the final result. This is not undesirable in the least. Rather, subjectivity and expert/non-expert judgments are essential to the method.

The Initial Risk estimated for our system (30.2%, bottom of column K in Table 1) can be considered relatively low, especially when compared with the large numbers of control measures identified. As indicated above, this value reflects the opinions of members of the water company. Other assessment groups will probably assign higher (or lower) risk values to the system. It is important to highlight, however, that absolute values are not as important as their relative ranking or their expected variation in time once control measures are implemented. Therefore, as long as the assessment complies with basic standards of transparency and technical rigor, it is possible to counterbalance the effect of possible biases from homogeneous groups. In that sense, assigning low values to the Initial Risk can be comforting for company representatives (assuming they are doing the assessment), but this will affect risk reduction percentages in time, potentially reducing the political acceptability of the assessment. In our case study, control measures are now being implemented by the water company and therefore the reassessment of risks has not been performed yet. Nevertheless, perspectives for the full implementation of the WSP described in this paper are good, as the assessment team included both company personnel and external experts. As discussed in Summerill *et al.* (2010), the effective implementation of the WSP requires commitment and cooperation from water utilities as there are numerous financial and legal implications involved.

CONCLUSIONS

The development of this WSP led to a thorough and updated knowledge of the current water system by both the external assessment team and members of the water utility not directly involved in field operations. During the assessment there was sufficient evidence to suggest that risks can be better prioritized by previously weighting the relative importance of the different parts of the water system. The adapted methodology helped emphasize the most significant risks and identify the necessary magnitude of control measures. Based on this process, rational and cost-effective risk reduction strategies can be established.

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