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Water Safety Plans from the Engineer's Perspective

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Abstract: *Water safety plans are public health related risk management plans, covering the entire water supply system, based on the theorem of prevention. Risk evaluation is fundamental for setting up a risk management system. A modified risk assessment equation is shown which takes into account the severity of consequences of the hazard an accentuated way. This method was used successfully n a number of practical water safety system applications. Water safety plans are practical tools for water utility operators which can be applied in different fields of operation, from water quality improvement of decision support tool of developments. The role of the distribution system and its operation is clarified from water quality deterioration and risk mitigation point of view.*

Keywords: *drinking water supply, water safety plan, risk management, risk evaluation*

1. ANTECEDENT

In the history of water supply the management of public health related risks became fundamental from the turn of the 19^{th} and 20^{th} century. Water safety turned out to be the focus area of water supply: safety in both the short and the long term during the entire process chain of water utility operation.

The most significant step to prevent water born epidemics was the introduction of disinfection by chlorine, resulting in magnitudes of risk reduction in water supply. Nevertheless the Cryptosporidium infection in Milwaukee in 1993, effecting 400,000 people with mortality over 100 clearly showed, that even negligible looking risks can become reality, and that in risk mitigation the theorem of prevention has to prevail. In 1998 another Cryptosporidium outbreak occurred (in Sydney), this time with a more fortunate outcome. This event became the milestone in the history of water safety plans: the theory of the risk management systems in water supply started to be set up.

The World Health Organisation (WHO) presented its first recommendations for water safety plans (WSP) in its Drinking Water Guidelines in 2004 [1]. Based on these recommendations the WHO's Water Safety Plan Manual [2] was released in 2009, providing detailed guidance for water supply system operators.

In Hungary the release of the 65/2009 (III. 31.) Governmental Decree imposes a legal obligation on utility operators regarding to the establishment of water safety systems. Supply systems exceeding 1,000 m^3/d capacity, or serving more than 5,000 people must have a water safety plan.

2. RISK MANAGEMENT IN WATER SUPPLY

In the course of water supply different public health related hazards can occur, which can be of physical, chemical, or biological origin, representing events with different risks. Risk evaluation is fundamental for setting up a risk management system.

In the engineering practice the most common way of quantifying risk mathematically is according to Eq. (1).

$$R = W x K \quad (1)$$

where:

R – is the risk;
W – is the likelihood;
K – is severity of consequences.

The parameters are in the range (0;1). The most severe consequence is death with K=1. In case of the certain occurrence of an event W=1.

The base unit of risk is the micro-risk, of which $R=10^{-6}$, which is used for the statistical determination of health related limit values [3]. 1 micro risk means that it effects one person out of a million. It is roughly equivalent of the risk we are imposed when we travel 2,000 km by plane, 65 km by car, 3 km by motorcycle, or getting a thunder strike within 10 years. Water quality recommendations are generally calculated with a 1/10 micro-risk.

Using this analogy, to characterize water supply related risks, the possible hazards can be evaluated in a two dimensional event field, according to Figure 1.

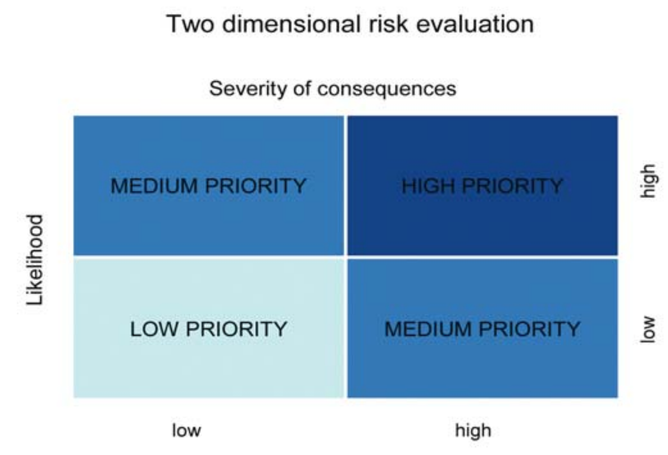

Figure 1. Risk prioritization in a two dimensional event field

The scaling of the axes can be set taking into account the actual circumstances of the evaluation task. The general WHO recommendation is a 5x5 risk evaluation matrix [1], which can be successfully applied in actual systems.

The key for the successful risk evaluation in water safety plans, according to our experience, does not depend on the size of the matrix: even a 5x5 matrix is complex enough for the task. The key is the consequent application of the matrix, which depends on the clear definition of likelihoods and severities of consequences.

During the realization of water safety systems for several Hungarian water supply systems [4], a modified 5x5 matrix has been used: the severity of consequences was evaluated not in a linear, but in a power scale, taking into account the severity of effects on human life. For the risk evaluation Eq. (1) was used, with the following modification:

$$K=2^{f} \qquad (2)$$

where:

f – is the factor of severity.

In the applied water safety plans the *f* factor ranges from 0 to 4. The actual value of *f* is determined on the basis of its effect on human life: from f=0 of no quantifiable effect, through f=1 of local/minor aesthetical effect, to f=4 in case of catastrophic, epidemic related events.

The practical risk evaluation matrix that is based on Eq. (1) and (2) is shown in Table 1.

MVB Risk evaluation matrix				**Severity of consequence**				
				Insignificant	Minor	Moderate	Major	Catastrophic
			W\K	1	2	4	8	16
Likelihood	Rare	5 years	1	1	2	4	8	16
	Unlikely	2 years	2	2	4	8	16	32
	Moderately likely	1 year	3	3	6	12	24	48
	Likely	monthly	4	4	8	16	32	64
	Almost certain	weekly	5	5	10	20	40	80

1-5 low	6-15 medium	16-39 high	40-80 very high

Table 1. Modified 5x5 risk evaluation matrix.

3. THE THEORY OF WATER SAFETY PLANS

Water safety plans are public health related risk management plans, covering the entire water supply system, based on the theorem of prevention. The WHO WSP recommendations were created taking into account the food industry's HAACCP (Hazard Analysis and Critical Control Points) experience and methodology, but it is important to clarify, that WSP systems are not meant to be standardized HAACCP systems. The WHO recommendations [1] also take into account the specificity of water supply systems, the characteristics of utility operations, thus leaving a reasonable space for the utilities to build water safety systems according to their specific needs and goals, still focusing on public health risk mitigation.

The core elements of the WHO recommendations are as follows:

1. The entire water supply system has to be taken into account, including the water resource, the treatment technology and the distribution system.
2. Hazard assessment and risk evaluation.
3. Control measures.
4. Monitoring.
5. Corrective measures.
6. Documentation and communication.
7. Feedback.

During the operation of a water safety system (Figure 2.) feedback ensures that the water safety system is fulfilling its objective, also this makes possible, that a continuous improvement can be realized in terms of risk mitigation, but also in many cases it results in water quality and service characteristics improvement. It has to be taken into account, that the improvement is quasi continuous only. Continuous improvement exist only in theory: after arriving at certain limit values no further improvement can be realized without changing the boundary conditions of operations (e.g. the applied treatment technology).

Water safety systems are prevention based risk management systems: the distinction between preventive and corrective measures are fundamental. As bacterial water quality testing methods still require several ours to find out their outcome, there is a significant response lag in the monitoring. Consequently, in disinfection processes prevention plays a key role, combining the best practices with technical indicators on the status of disinfection devices are to be combined.

Water safety plans have to deal with emergency situations that effect water quality. It means, that emergency response plans are integrated in water safety plans. This can result in a cohesive monitoring activity.

The elements of the water supply system are interdependent regarding to water quality. Drinking water quality deterioration in the distribution system is only partially effected by the characteristics of the distribution system itself: water production, raw water quality and the applied treatment technology are the fundamental factors in this process. Hence in order to mitigate water quality deterioration in the distribution system, corrective measures in network operation result only minor or temporary effects [5]. The effective corrective measures should address production and/or treatment: an integrated system approach ha to be applied. Water safety plans are an excellent tool to realize a system-wide approach for good drinking water quality.

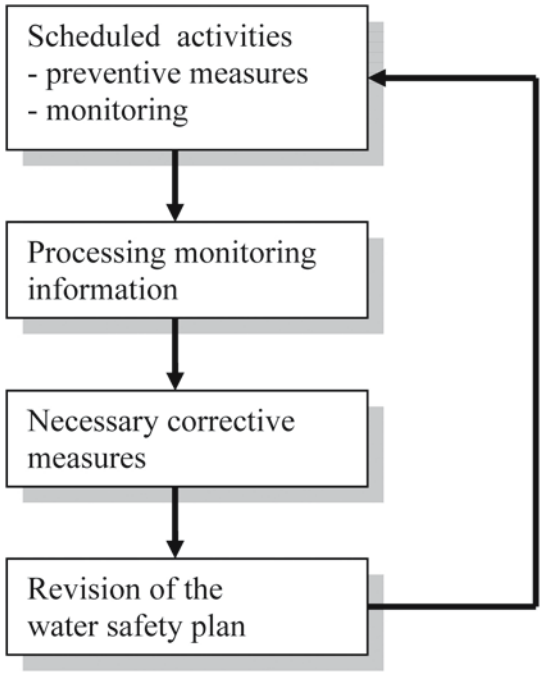

Figure 2. Basic scheme of water safety system operation

4. PRACTICALITIES OF WATER SAFETY PLANS

Water safety plans act as a framework, integrating all the procedures of the water system operation that effect directly or indirectly drinking water quality.

During the preparation of a water safety plan the first step is system assessment. It has to be a practical assessment, based on site visits: it is crucial to compare in detail the existing system facilities with the documentation - the water safety plan has to be built upon the existing system.

The following step is the revision of existing documentation: operational manuals, instructions, commands etc. have to be investigated, redundancies and inadequacies have to be healed, and un-detailed chapters have to be completed.

The first two steps might seem obvious, but it requires substantial expertise and thoroughness to clarify and unequivocally describe the properties of the actual supply system and its operation. If it is not done thoroughly, the water safety plan cannot be implemented successfully, the operational risks will not be mitigated.

The core of the water safety plans is the hazard management chart (Table 2.). The lines of the chart are the hazards that are taken into account in the plan. It is important, that even hazards with the least magnitude of risk are to be included in the plan. For each hazard its particular risk has to be quantified (with Eq. 1 and 2). The preventive action, the monitoring action (with parameters, methods and limit values), and the possible corrective measure have to be defined. All of this has to be integrated in the documentation structure of the system operation, with cross-references.

Process	Hazard	Risk evaluation	Preventive measure	Monitoring	Correctiv e measure
Intake - -	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..
Treatment - -	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..
Storage - -	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..
Distribution -- --	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..	……….. ……….. ………..

Table 2. Schematic hazard management chart

Water safety plans require a different view from operators than is used in water quality control. The role of monitoring in water safety systems is often misunderstood: water safety plans are not water quality control plans. The latter require regulation based monitoring activity, in compliance with the legal obligations and health authority requirements. The type and frequency of parameters monitored for the sake of water quality control are not necessarily adequate for water safety plans. For WSP requirements sampling frequency is usually higher, therefore there is a demand for on-line monitoring methods. The necessity of on-line monitoring implies the emphasised use of indicator parameters, such as turbidity, conductivity, free chlorine etc. The limit values are not necessarily the limit values set by the water quality standard. Limit values in water safety systems have to indicate not non-compliances according to the water quality standards but the occurrence of a specific hazard, which triggers a particular corrective measure. The determination of the limit values of the selected parameters is a statistical task, where the specific water quality properties, their range, and their changes in time have to be taken into account.

As it is clearly indicated in Table 2. preventive and corrective measures and monitoring are distinct, they have different roles in water safety. Unfortunately this is not evident every time in practice, and their roles are often misunderstood. Water safety plans have to be set up to create a prevention-based system. Monitoring is not prevention. Monitoring is only a tool which enables the activation of corrective measures when it is needed. If only monitoring and correction is incorporated in the plan, than the objective of the water safety plan, which is risk mitigation, cannot be achieved. This leads to an operation where health hazards are meant to be controlled by monitoring and intervention, but there is no action taken to inhibit their occurrence.

The role of feedback is crucial in risk mitigation. The continuous revision of the system, the modification of limit values, sometimes even procedures and methods not only reduce health related risks, but also can improve drinking water quality. If WSP limit values were set to the limits of the water quality standard, it could never be realized.

In practice, water safety plans are not only risk management tools, but tools for the operators which:

- clarify roles and responsibilities of every participant in water supply system operation;
- eliminates outdated, incorrect or inaccurate operational instructions;
- results in a detailed and up to date documentation and archiving system;
- can improve drinking water quality;
- can improve consumer satisfaction;
- can serve as a decision making tool and supporting documentation for necessary developments and investments;
- can be incorporated in the reconstruction strategy for priority making.

5. RISK MITIGATION IN OPERATION

Drinking water quality is primarily effected by the characteristics of the water resource and the applied treatment technology, and secondarily effected by the distribution system. To prevent the outbreak of water born diseases the water utility operator has a limited number of tools, namely

- water resources protection;
- applying adequate treatment with adequate operation;
- optimal operation of the distribution system.

Water resources protection is a preventive measure. In Hungary, in case of operation intake facilities on vulnerable water resources there is a legal obligation (123/1997. (VII. 18.) Governmental Decree for operators to create and implement a water resources protection plan. This plan becomes an integral part of water safety plans.

Applying adequate water treatment is a complex question which is addressed here only from the disinfection's point of view. The role of disinfection is the inactivation of pathogenic micro-organisms. It serves as the ultimate tool for operators to prevent the outbreak of epidemics. As it was mentioned in the previous chapter, microbiological water quality takes time to assess: if there is an unidentified problem during disinfection, such as a physical deficiency of the disinfection device, the sudden increase of turbidity of the water etc., infectious water may be distributed unnoticed for a certain amount of time. To overcome this hazard, in addition to monitoring the disinfection device, the concept of two-stage protection can be applied: prior to disinfection the physical removal of micro-organisms is to be carried out by nanofiltration. Nanofiltration can play the role of a barrier for pathogens, although due to the high cost of this technology, presently this alternative is not viable: this is an application for the future water supply.

The distribution system plays an interesting role in water quality and in associated hazards. The major water quality changes in the distribution system can be summarized as follows [5]:

- deterioration of organoleptic parameters;
- deterioration of bacterial water quality;
- chlorine decay;
- nitrification;
- corrosion;
- scaling and precipitation;
- THM formation.

Some of these phenomena (e.g. chlorine decay) can be mitigated by optimal network operation, trying to reduce residence times for instance – but in reality there are fairly limited opportunities in this field. The key for solving these water quality problems, and to reduce the induced health related risks in some cases is in water treatment. This shows the necessity of the prevention based approach from another perspective.

In the short term, the operator can intervene in the distribution systems condition by changing the pump schedule, installing additional chlorination stations, shutting off unnecessary reservoirs, water tanks, and implementing extensive network cleaning on a repetitive basis. In the medium tern technological modifications, the extension of the treatment technology is viable. In the long term, water quality concerns can be incorporated in reconstruction strategies.

Whatever time scale is in focus, water safety plans can be used as tools to support decisions. This way water quality objectives and public health risks can be treated in a systematic and integral way.

6. CONCLUSIONS

The application of water safety plans has different aspects. From public health point of view, it is a risk management and mitigation system. From the operator's point of view water safety plans can support operation by providing a unified operational framework, which is water quality oriented, and which clarifies every practical aspect of adequate operation. It is beneficial for consumers, and can serve as a decision support tool of technical developments, reconstruction strategies.

In order to fulfil all these requirements, it is crucial that water safety plans are to be correctly implemented: hazards and risks, their evaluation, preventive measures, monitoring and corrective measures have to be taken into account as they meant to be. Water safety systems are dynamic systems, enabling improvement and quasi continuous risk mitigation. It is the responsibility of the engineer to utilize their potential.

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