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## **Failure risk analysis in the water supply sector management**

### **Keywords**

water supply, risk management, safety, critical infrastructure

### **Abstract**

The subject and main purpose of this study is to develop risk analytic model for the design and operation of water supply sector. A water supply system belongs to the critical infrastructure of cities, and it should be a priority task for waterworks and even for the local authorities to ensure the suitable level of its safety. A water supply systems (WSS) ought to be high reliable continuous operating system. Failure factors in WSS should be identified and prioritized, for example, the causing factors in the most frequent failures in water-pipe network. Drinking water supply utilities are responsible for providing a safe and reliable supply of potable water to their customers. Risk priority helps asset manager to target and refine maintenance plans, capital expenditure plans, investigative activities, and deal with potential failure before it occurs. In this paper, we present a review of classic risk analyses, risk management and new methodology for water supply networks management. This paper presents a framework for the analysis of performance risk in water supply that can be applied to the entire system or to individual subsystems. It is expecting that the methodology for the water supply performance risk analysis would provide the city leadership for decision making support.

### **1. Introduction**

Modern world standards say that every person has the right to get enough amount of proper quality water. The global problem is not only lack of water in the third world regions, but also the degradation of water resources in the developed countries. For many countries water recycling is not a choice but an urgent necessity. The other important problem is the exploitation of existing water supply systems (WSS) which should take into account the minimization of water losses, operational and safety reliability. Water supply providers seek to provide their customer with high-quality drinking water at all times. However this can sometimes be challenging because of changing raw water quality or problems with treatment and distribution. Opinions on WSS safety change along with the progress of science and technology.

Safety of the WSS means the ability of the system safely execute its functions in given environment. The measure of WSS safety is risk. The notion of

risk was introduced to European law by virtue of the instruction 89/392/EWG from 1989 on the adaptation of the state members regulations concerning machines.

The WSS safety management is an operator managerial activity to establish the aims (counteraction against lack of water or its bad quality, threatening health of municipal water pipe users) and to supervise their accomplishment using processes, information resources in the given operating conditions, in compliance with the valid law and with economic justification [26].

A special case of the WSS safety management is system management in a crisis situation. The transition to an explicit risk management philosophy within the water utility sector is reflected in recent revisions to the World Health Organization's (WHO) Guidelines for Drinking Water Quality [28].

In June 2004 the European Council asked to prepare an overall strategy for critical infrastructure protection. In December 2006 the European Commission presented a project (conclusion) of

Council Directive on identification and designation of an European critical infrastructure and evaluation of needs to enhance its protection, in order to elaborate the European Program for Critical Infrastructure Protection (EPCIP) and a Critical Infrastructure Warning Information Network (CIWIN).

A programme of critical infrastructure protection, which main purpose is to protect above mentioned infrastructure, should contain: procedures for determining the critical infrastructure, identification of functionally important elements of infrastructure, risk analysis based on the scenarios of serious threats, weak points analysis and potential consequences analysis, identification, selection and prioritization of countermeasures, dividing them into: permanent security measures (setting out the necessary investments and measures for safety, access control, supporting and preventive measures, procedures for informing of crisis management threats, improving social awareness, training and safety of information systems) and emergency safety measures, which are activated according to varying levels of risk threats, developed network of warning about the threats for critical infrastructure (e.g. multi barrier system, using GIS technology, emergency plans, e.g. alternative sources of water supply, water provided by means of water cart or bottled water, security funds and the establishment of expert groups to coordinate the implementation of EPCIP [25].

For purpose of this paper failure is defined as the event in which the system fails to functions with respect to its desired objectives. Safety of the WSS means the ability of the system safely execute its functions in given environment. The measure of WSS safety is risk [19], [25].

The main objective of this paper is to present the issue of risk management in the water supply sector. The paper explores the basic concepts related to water supply safety and presents a new method for risk analysis.

## **2. Risk management**

Under their current philosophy drinking water infrastructure decision-makers attempt to manage the risk of systems failure through deterministic trial and error approaches that provide inefficient solutions [18]. Decision-makers and engineers are increasingly using modeling software to determine the effect of human activities on water quality. There are many surface water quality modeling and algorithms software in the public and private domain.

In 2004 in the third edition of directives concerning drinking water quality (Guidelines for Drinking-Water Quality) the WHO presented the directives for developing the so-called Water Safety Plan (WSP)

[27], intended for drinking water supply systems. The main element of the WSP is the developing system risk analysis for all the WSS subsystems, i.e. water intake and treatment, pumping and storage, as well as distribution, in order to ensure water consumers safety. The safety plan is a key element of a strategy which aim is to prevent the undesirable events in the WSS. It should consist of a descriptive part and an analytic–implemental part.

The aim of water consumers threat identification is to show the type of substance existing in drinking water, however the evaluation of threat level should be based on showing its harmful impact on human health and classifying the substances on the basis of all the available data. The impact of the particular substances on human health is determined by appropriate experts (doctors, chemists, biochemists, and microbiologist) on the basis laboratory and clinical studies, as well as from their experience [13]-[14]. Decisions on managing risk, if they are to be effective, need to be active rather than reactive and well structured. Risk management frameworks set out the relationship between the processes of risk identification, evaluation and management. They can be regarded as ‘route maps’ for decision makers [1].

Among the most important components of sustainable management strategies for WSS is the ability to integrate risk analysis and asset management decision-support systems, as well as the ability to incorporate in the analysis financial and socio-political parameters that are associated with the networks in study [4]-[5], [16]-[18].

Risk management in waterworks responsible for right water-pipe network operating is a formal program containing internal procedures which main purpose is to protect water consumers, environment, as well as waterworks interests (financial and personal). The water industry is undergoing a significant shift in its approach to risk management to one that is increasingly explicit and better integrated with other business processes. Risk management strategies and techniques traditionally applied to occupational health and safety and public health protection are now seeing broader application for asset management, watershed protection and network operation [7], [21]-[24].

This process should consist of the following components:

- risk control: risk analysis (threat identification, determination of the possibilities of undesirable events, determination of negative consequences, risk assessment, risk evaluation), decision making (response to risk: acceptance, elimination or reduction),
- risk administration: documentation of failures and all the negative events in the WSS, developing of

emergency response plan, developing of the WSS elements maintenance and modernization schedule, etc.

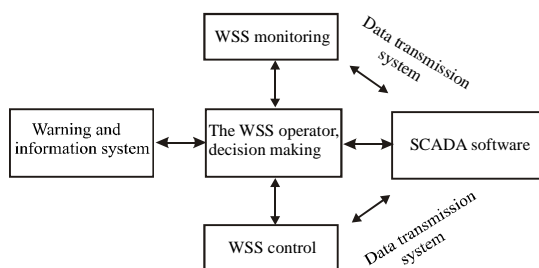
- risk monitoring: revision and updating of risk analysis methods, as well as all the data necessary for such analysis, taking into account the dynamics of the WSS development and changeable external factors, risk audit.

- risk financing: the financial means necessary to cover the expenses connected with execution of mentioned above processes, as well as to finance insurance systems, must be guaranteed in waterworks budget.

It is very important for waterworks to identify risk correctly and to divide it into consumer risk and water producer risk. It allows choosing the right method for calculating different types of risks. The correct WSS risk management process should contain suitable organizational procedures within the framework of regular waterworks activity, the WSS operation technical control and supervisory system, a system of automatic transfer and data processing about WSS elements operation. The key role in this process is played by a system operator, whose main purpose is:

- to implement the reliability and safety management system,
- to operate the WSS according to valid regulations and in a way which ensures its long and reliable operation,
- to execute a program of undesirable events prevention,
- to develop failure scenarios for water supply in crisis situations,
- to develop a complex system of information about the possible threats for water consumers.

Such type of WSS risk management optimises an operation of particular WSS devices (e.g. parameters of operation of water pipe pumping stations which cooperate with network tanks), and the work of the whole system. In *Figure 1* the diagram of WSS information and risk management is presented.



*Figure.1.* Diagram of the information system for the WSS risk management

### 3. Risk analysis methodology

#### 3.1. Failures in the WSS

A failure in the WSS is a complex problem, every time it occurs, the primary reasons behind it must be analyzed carefully. Failure can be grouped into either structural failure or performance failure. The failures of the WSS which occur most often are the following [3], [6], [11], [25]:

- incidental contamination of water intakes, eg. chemical, biological contamination,
- failures in water treatment stations, eg. disturbances in the technological process of water treatment,
- failures in transit, main and distributional pipelines, which can result in the secondary water contamination in water-pipe network, as well as breaks or lack of water supply to the receivers, or the drop of water pressure in the network,
- deterioration in water quality in water-pipe network as a result of unfavourable hydraulic conditions (low speed of water flow, pipelines technical conditions ),
- failures in power supply, which can cause a lack of the possibility to operate the particular subsystems and elements of the WSS and even the whole system. The factors which form the probability that the negative consequences occur are, among others, the following:

- the probability that the undesirable event occurs,
- frequency and a degree of exposure,
- the possibility of avoidance or minimization of the negative consequences.

Risk assessment is a process consisting of a number of the systematic steps, in which the study of different kinds of threats connected with the WSS operating is carried out. The basic purpose of this kind of activities is to collect the information necessary to estimate the safety of the system. Risk assessment should contain:

- establishment of a ranking of the undesirable events,
- determination of the level (value) of risk,
- proposal of the activities aimed at risk minimisation,
- establishment of time after which the risk can obtain its critical value as a result of different processes, eg. materials ageing.

Risk assessment includes the so called risk analysis, which is the process aimed at the determination of the consequences of failures (undesirable events) in the WSS, their extend, sources of their occurrence and the assessment of the risk levels [2], [15], [29]. Haines (1998) [8]-[9] suggests that risk assessment concerns its reasons, as well as its likelihood and

consequences. Hastak and Baim (2001) [11] define infrastructure risk as a product of the probability (likelihood) of system failure (p) and costs associated with its repair (economic-value) (C).

Drinking water infrastructure system uncertainty or risk is defined as the likelihood or probability that the drinking water service fails to provide water on-demand to its customers [25].

The purpose of this paper is to present the risk analysis method for drinking water infrastructure.

Risk (r) is a function of three parameters [19], [25]: the probability  $P_{Si}$  that  $i$  representative emergency scenario  $S_i$  occurs, the magnitude of losses  $C_{Si}$  caused by  $i$  representative emergency scenario  $S_i$  and the consumers protection  $O_{Si}$  against  $i$  representative emergency scenario  $S_i$ ,  $r = f(P_{Si}, C_{Si}, O_{Si})$ . In this way risk can be calculated from the equation (1):

$$r = \frac{P_{Si} \cdot C_{Si}}{O_{Si}} \quad (1)$$

where:

- $P_{Si}$  is the probability of  $S_i$ ,
- $C_{Si}$  is the degree, or point weight, of consequences connected with  $S_i$  for water consumers,
- $O_{Si}$  is the level, or point weight, of protection of water consumers against  $S_i$ .

For every situation, a score is assigned to the parameters  $P_{Si}$ ,  $C_{Si}$  and  $O_{Si}$ , according to the following point scale:

- low (L)=1,
- medium (M)=2,
- high (H)=3.

In this way, we obtain risk matrix and a point scale to measure risk: tolerable, controlled and unacceptable, in a numerical form, within the range [0.33÷9], according equation 1.

Failures in the WSS can be a consequence of errors made during design, construction and operation, what in the *Table 1* was presented.

For each stage of the process of creating the water-pipe network (design, construction and operation) matrixes for risk assessment were proposed. The final step is to define the integrated risk and to determine limits of its individual levels:

- tolerable,
- controlled,
- unacceptable.

*Table 1.* The errors made during design, construction and operation.

design	
errors	<ul style="list-style-type: none"> <li>• errors in water-pipe network layout (ground conditions wrongly examined, an incorrect route for the water pipeline, the economic activity of a third party was not taken into account), wrong conception of water-pipe network geometry and structure,</li> <li>• errors in network hydraulic calculations (an incorrect water-pipe diameter, incorrect pressure in network, wrong layout of water-pipe tanks), errors in a conception of the whole WSS control.</li> </ul>
construction	
errors	<ul style="list-style-type: none"> <li>• deviations from the design and the rules of correct construction, according to valid regulations, as concerns the technology of pipe laying, connections of the individual pipe sections; covering pipes for the passages going under and through the obstacles are not installed, improper anticorrosion protection (passive and active), badly performed pressure test and other procedures</li> </ul>
operation	
errors	<ul style="list-style-type: none"> <li>• incorrect operating procedures, a lack of water pipeline operation monitoring,</li> <li>• the scenarios for the emergency water supply were not taken into account,</li> <li>• incoherent protecting and warning system for water quality,</li> <li>• lack of programme to classify the network segment requiring the repair, lack of programme to obtain, process and storing the data on failures, their causes and consequences and records of data about failures.</li> </ul>

### 3.2. The risk of design

The two-parameter matrix for risk assessment was proposed. The risk of design ( $r_d$ ) can be calculated from the modified equation (1), we obtain equation (2):

$$r_d = P_d \cdot C_d \quad (2)$$

where :

$P_d$  – point weight related to the probability of design error,

$C_d$  – point weight related to the size of possible losses.

Point weights associated with  $P_d$  are the following:

- $L = 1$  – a renowned design office with a quality certificate, having completed projects in the list of reference, a design is made by means of tested computer programs,
- $M = 2$  – a design office having the required license to design and the list of references,
- $H = 3$  – a person with experience in designing segments of water pipe network.

Point weights associated with  $C_d$  are the following:

- $L = 1$  – financial loss up to  $10^4$  EUR,
- $M = 2$  – financial loss from  $10^4$  EUR to  $10^5$  EUR,
- $H = 3$  – financial loss above  $10^5$  EUR.

In *Table 2* the two-parameter risk matrix was presented.

*Table 2.* The two-parameter risk matrix at the stage of water-pipe network design.

$C_d$	$P_d$		
	$L = 1$	$M = 2$	$H = 3$
$L = 1$	1	2	3
$M = 2$	2	4	6
$H = 3$	3	6	9

The individual risk categories are the following:

- tolerable [ $1 \div 2$ ],
- controlled [ $3 \div 4$ ],
- unacceptable [ $6 \div 9$ ].

### 3.3. The risk of construction

The three-parameter matrix for risk assessment was proposed. The risk of construction ( $r_c$ ) can be calculated from the modified equation (1), we obtain equation (3):

$$r_c = \frac{P_c \cdot C_c}{O_c} \quad (3)$$

where:

$P_c$  – a point weight related to the probability of error made at construction,

$O_c$  – a point weight related to the probability of the detection of error,

$C_c$  – a point weight related to the size of possible losses.

Point weights associated with  $P_c$  are the following:

- $L = 1$  – a building company is certified ISO 9000 and has completed investments in the list of reference, procedures associated with the receipt of

investment are obeyed, laying pipes according to the best available technology,

- $M = 2$  – a building company has completed investments in the list of reference, verification of the specification of materials and procedures for the receipt are performed,

- $H = 3$  – a building company enters the market of water-pipe network construction, lack of experience in this field.

Point weights associated with  $O_c$  are the following:

- $H = 3$  – procedures for pressure tests are scrupulously obeyed with the use of modern equipment, there are no derogations in relation to implementing the project, execution is supervised by an investor,

- $M = 2$  – procedures for the receipt of investment are implemented,

- $L = 1$  – questionable quality of the trials connected with the receipt of investment, frequent derogations from the design assumptions.

Point weights associated with  $C_c$  are the following:

- $L = 1$  – a financial loss up to  $10^4$  EUR,
- $M = 2$  – a financial loss from  $10^4$  EUR to  $10^5$  EUR,
- $H = 3$  – a financial loss above  $10^5$  EUR.

In *Table 3* the three-parameter risk matrix was presented, According to equation 3. The weights of individual parameters presented above were established on the basis of works [19], [20].

*Table 3.* The three-parameter risk matrix at the stage of construction

$C_c$	$P_c$								
	$L = 1$			$M = 2$			$H = 3$		
	$O_c$								
	H	M	L	H	M	L	H	M	L
$L = 1$	3	2	1	3	2	1	3	2	1
$M = 2$	0.33	0.5	1	0.67	1	2	1	1.5	3
$H = 3$	0.67	1	2	1.33	2	4	2	3	6
	1	1.5	3	2	3	6	3	4.5	9

The individual risk categories are the following:

- tolerable [ $0.33 \div 2$ ],
- controlled [ $3 \div 4$ ],
- unacceptable [ $4.5 \div 9$ ].

### 3.4. The risk of operation

The four-parameter matrix for risk assessment was proposed. The risk of operation ( $r_o$ ) can be calculated

from the modified equation (1), we obtain equation (4):

$$r_o = \frac{S_o \cdot I_o \cdot U_o}{O_o} \quad (4)$$

where:

$S_o$  – a point weight associated with a type of water-pipe network,

$I_o$  – a point weight associated with the failure rate  $\lambda$  [failure/km year],

$U_o$  – a point weight associated with the difficulty to repair damages,

$O_o$  – a point weight related to protection of water-pipe network operation.

Point weights associated with  $S_o$  are the following:

- L = 1 – household connections,
- M = 2 – distributional network,
- H = 3 – main network.

Point weights associated with  $I_o$  are the following:

- L = 1 – the failure rate  $\lambda < 0.5$  failure./km year,
- M = 2 –  $0.5 \text{ failure/ km year} \leq \lambda \leq 1.0 \text{ failure/ km year}$ ,
- H = 3 –  $\lambda > 1.0 \text{ failure/ km year}$

Point weights associated with  $U_o$  are the following:

- L = 1 – failure in the pipeline in not urbanized area, repair brigades are organized and equipped appropriately and they are in full readiness for 24 hours,
- M = 2 – failure in the pipeline in the pedestrian lane, basic equipment to repair a failure, one shift work.
- H = 3 – failure in the pipeline in the vehicles lane (streets), lack of mechanized equipment to repair a failure.

Point weights associated with  $O_o$  are the following:

- H = 3 – special, above standard, full monitoring of water pipe network by measuring the water pressure and flow rate of water, possession of a specialized apparatus to detect water leaks by acoustic methods, unrestricted communication with the public through the phone line active 24 hours, monitoring of water quality in water network by means of protection and warning system. The network is fully inventoried, an exploiter has numerical maps of water-pipe network,
- M = 2 – standard, simplified monitoring of water-pipe network with the use of pressure measurement, inability to respond to small water leaks, water quality tests in water- pipe network are conducted,
- L = 3 – none, lack of monitoring of water-pipe network and water quality. There are no current inventory of water-pipe network.

In *Table 4* the four-parameter risk matrix was presented. The individual risk categories are the following:

- tolerable [0.33 ÷ 3],
- controlled [4 ÷ 8],
- unacceptable [9 ÷ 27].

The integrated risk is a sum of the risks at the stages of design  $r_d$ , construction  $r_c$  and operation  $r_o$ . To get the individual risks compatible with each other we should multiply them by the weights  $W_i$ , whose values are shown in table 5.

The integrated risk is determined from the modified equation (5).

$$r = W_i \cdot r_d + W_j \cdot r_c + W_k \cdot r_o \quad (5)$$

It is included in the range [1.0 ÷ 81].

The individual categories of integrated risk are the following:

- tolerable [1.0 ÷ 9.0],
- controlled [12.0 ÷ 24],
- unacceptable [27 ÷ 81].

*Table 4.* The four-parameter risk in matrix at the stage of water-pipe network operation

$U_o$	Type of water-pipe network – $S_o = 1$								
	Household connections – $L_o = 1$								
	Failure rate – $I_o$								
	L = 1			M = 2			H = 3		
	Protection – $O_o$								
	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1
L=1	LLLH 0.33	LLLM 0.5	LLLL 1	LMLH 0.66	LMLM 1	LMLL 2	LHLH 1	LHLM 1.5	LHLL 3

M=2	LLMH 0.66	LLMM 1	LLML 2	LMMH 1.33	LMMM 2	LMML 4	LHMH 2	LHMM 3	LHML 6	
H=3	LLHH 1.5	LLHM 1.5	LLHM 3	LMHH 2	LMHM 3	LMHL 6	LHHH 3	LHHM 4.5	LHHL 9	
U <sub>o</sub>	Type of water-pipe network – S <sub>o</sub> = 2									
	Distribution – M <sub>o</sub> = 2									
	Failure rate – I <sub>o</sub>									
	L = 1			M = 2				H = 3		
	Protection – O <sub>o</sub>									
	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1	
L=1	MLLH 0.66	MLLM 1	MLLL 2	MMLH 1.33	MMLM 2	MMLL 4	MHLH 2	MHLM 3	MHLL 6	
M=2	MLMH 1.33	MLMM 2	MLML 4	MMMH 2.66	MMMM 4	MMML 8	MHMH 4	MHMM 6	MHML 12	
H=3	MLHH 2	MLHM 3	MLHL 6	MMHH 4	MMHM 6	MMHL 12	MHHH 6	MHHM 9	MHHL 18	
U <sub>o</sub>	Type of water-pipe network – S <sub>o</sub> = 3									
	Main – H <sub>o</sub> = 3									
	Failure rate – I <sub>o</sub>									
	L = 1			M = 2				H = 3		
	Protection – O <sub>o</sub>									
	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1	H = 3	M = 2	L = 1	
L=1	HLLH 1	HLLM 1.5	HLLL 3	HMLH 2	HMLM 3	HMLL 6	HHLH 3	HHLM 4.5	HHLL 9	
M=2	HLMH 2	HLMM 3	HLML 6	HMMH 4	HMMM 6	HMML 12	HHMH 6	HHMM 9	HHM 18	
H=3	HLHH 3	HLHM 4.5	HLHL 9	HMHH 6	HMHM 9	HMHL 18	HHHH 9	HHHM 13.5	HHHL 27	

Table 5. Values of weights

Risk	r <sub>d</sub>			r <sub>c</sub>			r <sub>o</sub>		
	W <sub>i</sub>			W <sub>j</sub>			W <sub>k</sub>		
	low	high	medium	low	high	medium	low	high	medium
tolerable	0.33	1.5	0.9	1.0	1.5	1.25	1.0	1.0	1.0
controlled	1.33	2.0	1.67	1.33	2.0	1.67	1.0	1.0	1.0
unacceptable	1.5	3.0	2.25	2.0	3.0	2.5	1.0	1.0	1.0

#### 4. Discussions

The presented work is a result of the five-year cooperation with water authorities as part of research grants. At present authors are processing a development research project, a result of which will be a program of the risk management in the waterworks company. Suggested methods, will constitute the basis for so-called Water Safety Plans of (recommended by WHO) which will be compulsory in waterworks practice. The risk analysis

in Water Safety Plans is the basis of ensuring water consumers safety.

Data received from water authorities are derived from exploiters of the water supply system. Criteria of the risk assessing suggested in the work were based on the mentioned above information. Water Safety Plans, and methods of the risk management in water supply system are included in works: [3]-[5], [12], [14], [16], [19], [24], [27]-[28].

An important challenge is to define the tolerable risk level, the so-called ALARP (As Low As is Reasonably Practicable), which means that risk level

should be as low as it is reasonably practicable. The ALARP principle was first introduced in Great Britain, where the unacceptable (impermissible) value of risk of death for the individual worker was determined to be  $r=0.001$  and the risk of death for the public was determined to be  $r=0.0001$ . Risk reducing process should take into account a cost benefit analysis. Such risk level should be determined at which costs of its further lowering are disproportional high. Health and Safety Executive, directives introduce a notion “the cost for preventing a fatality” which is estimated, according to the mentioned above directives, at about 1mln GBP [10]. Danger and hazard are the factors that determine the magnitude of the risk. Danger is considered a cause of loss. It is characterized by some kind of arranged time sequence of successive phases. In the first phase threat appears, which creates danger (e.g. an incidental water pollution in a source). In the second phase danger becomes real (e.g. polluted water appears in the distribution subsystem). In the third phase the effects of real danger are revealed (e.g. water consumers’ gastric problems). Hazard is identified as a set of conditions and factors that have a direct impact on the second phase of danger. The scales of parameters that describe risk on the different levels of its occurrence should be simple, which allows risk assessment and classification for every discussed case. The method has an expert character and is used to pre-estimate the risk associated with the WSS operation. In relation to specialist expertise made by experts, describing the

identified water-pipe failures, which are superior, this method should be regarded as preliminary material. The detailed analysis of the risk associated with different stages of the WSS operation is important. Determination of the size of the risk associated with the design, construction and operation and its sum allows the appropriate reaction at each stage, and consequently contributes to reducing the risk of the WSS operation. A lot of experience gained from the analysis of risk associated with the WSS operation can be already generalized at the level of research and passed in the form of publication. The knowledge about risk does not have to be achieved by means of individual trial and error method. Risk management requires its identification, is directly associated with the control of quality and reliability of technical systems. The latter includes all actions which result is a product (article, object, subsystem, system) of the required quality and reliability. We still deal with the mistaken stereotype that the technical control in execution phase will ensure the required quality and reliability. Modern and perspective becomes a trend that the quality control and reliability control from the design phase, through construction, to operation of technical systems lead to a reduction of risk associated with their operation [12].

In *Table 6* the quantitative and qualitative categories of the consequences connected with the three level risk gradation are presented.



Table 6. The quantitative and qualitative limits of risk connected with poor drinking water quality in public supply systems, related to 1 year

Consequence category	Description of consequences	Tolerable risk	Controlled risk	Unacceptable risk
Insignificant	Incidental difficulties that are not a threat to health, lack of consumers complaints	$<10^{-3}$	$10^{-1} \div 10^{-3}$	$>10^{-1}$
Marginal	Perceptible organoleptic changes, individual consumer complaints	$<10^{-4}$	$10^{-2} \div 10^{-4}$	$>10^{-2}$
Significant	organoleptic changes are significant, numerous consumers complaints, reports in local media, water can be used after 10 minutes boiling	$<10^{-5}$	$10^{-3} \div 10^{-5}$	$>10^{-3}$
Serious	mass gastric problems, relevant sanitary inspector turns off water pipe, toxic effects in pollution indicators, large number of reports in local media, general information in national media	$<10^{-6}$	$10^{-4} \div 10^{-6}$	$>10^{-4}$
Catastrophic	mass hospitalisation as a result of health complications, deaths, front news in national media	$<10^{-7}$	$10^{-5} \div 10^{-7}$	$>10^{-5}$

In crisis situation drinking water supplied to water pipes should be taken, if possible, from the underground water intakes. The other intakes become the reserve intakes. Water pipe should have the possibility to cut off water intakes with the operational possibility and to use the whole system or its fragments, e.g. water pipe network, water intake, transit water pipes, activate alternative water treatment technology (e.g. periodical dosage of active carbon in a powdery form), increase dosage of disinfecting agent, supply water bypassing Water Treatment Plant. If water pipe is inactivated and in the areas without water pipe network, water is supplied from emergency wells. When a number of the emergency wells is too low or their layout is unfavorable one should predict water delivery by tanks or water-carts. Water pipes and emergency wells should be prepared to get energy from generators, they should be equipped with generators which can start pumps and water supply during the limited deliveries. Fuel reserve should be enough for 400 hrs, however for not less than 200 hrs of generating sets operating. Water requirement in crisis situation should be established for all the municipal water pipes and for villages without water pipe network. It should be assured from water pipes and emergency wells, and also from industrial intakes, if necessary.

One can distinguish two kinds of water requirements in crisis situation [19]:

- necessary water quantity (for a few weeks time): population -  $15 \text{ dm}^3/\text{person, day}$ ,
- minimum water quantity (for a few days time): population -  $7.5 \text{ dm}^3/\text{person, day}$ .

#### 4. Conclusions

A water supply system is one of the most basic technological underground systems and is highly important for the livelihood and health of humans. In WSS operations, we deal with events that can cause breaks in water supply or water pollution. The procedures of correct designing, construction and operating of the WSS should be completed by the analyses of risk connected with the possibility that different undesirable events that have a significant impact on the level of the WSS safety occur.

The opinions and assessment made by the exploiters and the experts play a very important role in the procedures of risk analysis. The important problem is also to establish the criteria values of risk levels, which should be made by cooperating teams of experts in the field of methods of risk assessment and experienced engineers, based on the up-to-date scientific and technological knowledge, as well as based on the statistic data on the WSS operating.

If the calculated risk values (according to equation 5) indicate the category is tolerable, then one can assume that the WSS fulfils its functions satisfactorily, with regard to both operational reliability and safety. If the risk values indicate the

category is controlled then an improvement in the work of some elements of the system (e.g. network monitoring, protective stations) or repair of some sections of the water-pipe network should be considered. If the risk values indicate the category is unacceptable, this means that the WSS does not fulfil its functions, with regard to both operational reliability and safety.

Risk grows as the level of threat increases and from the so called “ergo-dynamic rule” we know that if failure is possible then the probability of its appearance approaches one (event is certain), when time of expectancy approaches infinity. Safety procedures in the present WSS are distinguished by the fact that risk reduction is made by technical means as well as by the organizational means

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