Environment Protection Engineering

Vol. 29 2003 No. 3–4

JANUSZ RAK*

A STUDY OF THE QUALITATIVE METHODS FOR RISK ASSESSMENT IN WATER SUPPLY SYSTEMS

In the paper, qualitative methods of risk assessment in operation of water supply systems have been reviewed. Problems concerning individual and group risks connected with consumption of drinking water have been presented. A method for assessment of risk involved in the work of the operator of water supply system has been proposed. The relationship between the risk and responsibility for decisions being taken has been presented.

1. INTRODUCTION

The awareness of risk has always accompanied man. In the ancient times, the highest risk connected with economic activity of man concerned transport and trade. In the Middle East, 1800 years B.C. there were agreements between the members of caravans who committed themselves to cover common damages due to the loss of goods or pack animals that each of them could suffer as a result of robbery. In the ancient Greece, there was a legal institution called in the Justinian code "the sea loan" connected with trade risk of the sea expedition, which was based on a financial loan with high interest. When the expedition ended successfully a borrower paid the loan back together with the interest. When the expedition failed (the ship sank, load was robbed) a creditor incurred the risk of the expedition (the loss of the sum he lent). People were looking for different ways to cope with the risk. The first methods of risk management, the so-called connection of goods subjected to risk, were used by the ancient Chinese merchants who carried goods along the River Yangtse. The point of it was that every boat took some amount of goods belonging to every merchant. In this way when the boat sank none of the merchants lost his whole property. The aim of that action was to minimize the losses of the individual merchant by transferring the risk to the community.

* Ignacy Łukasiewicz Technical University in Rzeszów, 35-959 Rzeszów, ul. Pola 2, Poland.

Nowadays the risk analysis is commonly used to estimate the safety of technological systems. In Poland, the act called "The Environmental Protection Law" passed in 2001 introduces an environmental duty to analyse the risk in plants with an increased or high risk of failure. The risk as a measure of the quality of water supply systems was introduced in Poland by KEMPA [1], [2].

2. QUALITATIVE NOTION OF RISK

Qualitative methods of risk analysis allow determination of the relative measure of risk that is the base for ranking risk connected with undesirable events.

In qualitative analysis of risk in technological systems, the following methods are used [3] :

- Failure Modes and Effects Analysis (FMEA).
- Hazard and Operability Study (HAZOP).
- Preliminary Hazard Analysis (PHA).
- Fault Tree Analysis (FTA).
- Event Tree Analysis (ETA).
- Human Reliability Assessment (HRA).

The analysis of risk is directly connected with its assessment, control and management, which is shown in figure 1.

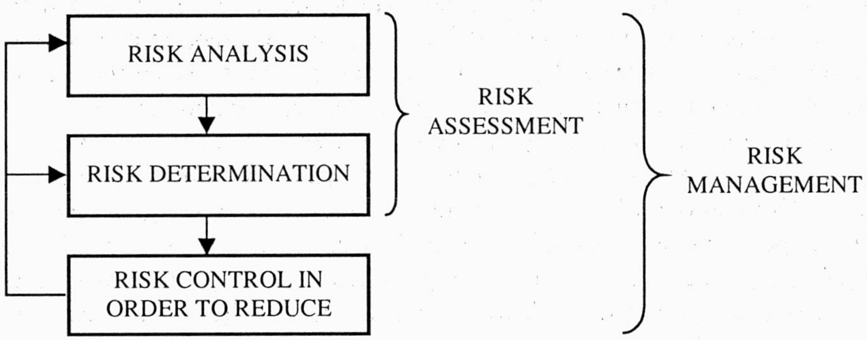

Fig. 1. The simplified diagram of relations in the process of risk modelling

The safety and risk management in municipal systems such as water supply system (WSS) forms the base for preventing the occurrence of some serious failures which, as everyday experience shows, can lead to economic, environmental and even human losses [4]. Within the developing research on safety some special techniques called *risk assessment* are being elaborated. Apart from the qualitative methods we can also use the quantitative methods that are based on the probabilistic risk assessment (PRA). They are not the subject of this work. Figure 2 illustrates the nature of risk.

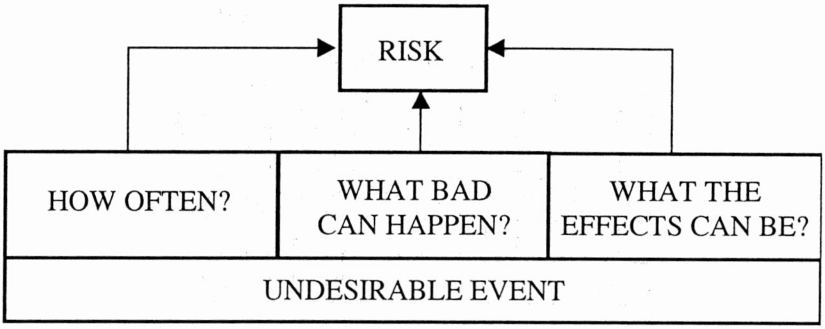

Fig. 2. The nature of the risk

From the mathematical point of view the following definition is obligatory in the qualitative risk analysis:

$$[\textit{measure of risk}] = \begin{bmatrix} \textit{measure of unreliability} \\ \textit{corresponding to the category} \\ \textit{of probability} \end{bmatrix} \times \begin{bmatrix} \textit{measure of consequences} \\ (\textit{damage}) \end{bmatrix} \quad (1)$$

3. GENERAL CHARACTERISTIC OF QUALITATIVE METHODS

In the most general case, when we do not have any data and know that the undesirable events happen at random we come to the conclusion that every event is probable. So, as an example, we propose to introduce the following categories of probability, that is, frequency of undesirable events and categories of the consequences of these events, as shown in table 1.

Table 1

The list of the categories of probabilities and consequences

Category of probability – frequency		Category of consequence	
A	Often	F	Catastrophic
B	Probable	G	Serious
C	Occasional	H	Significant
D	Little probability	I	Marginal
E	Improbable	J	Negligible

Using formula (1) we get the possible combinations of the undesirable events as presented in table 2.

Table 2

The matrix of the risk

A × F	B × F	C × F	D × F	E × F
A × G	B × G	C × G	D × G	E × G
A × H	B × H	C × G	D × G	E × G
A × I	B × I	C × I	D × I	E × I
A × J	B × J	C × J	D × J	E × J

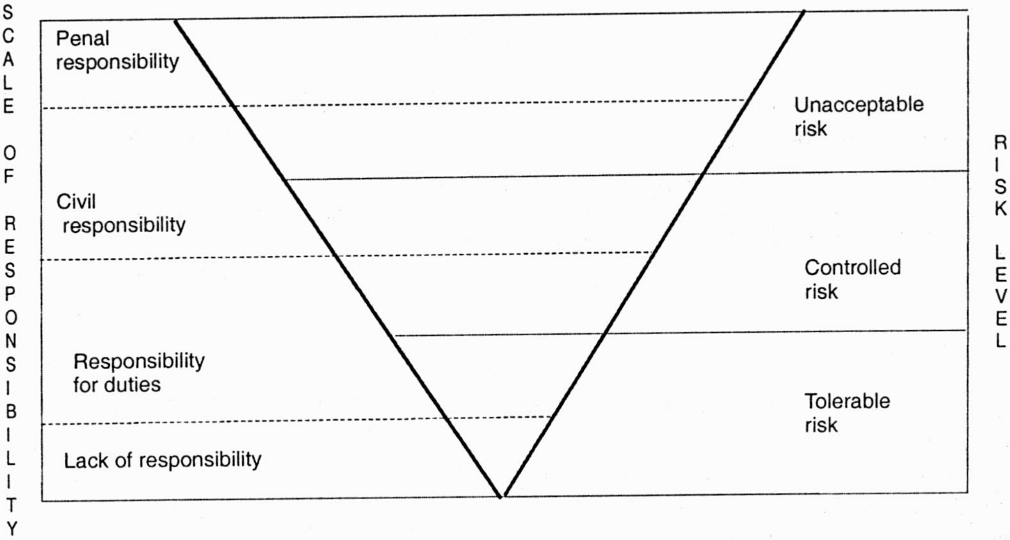

Fig. 3. The example of a scale of risk and responsibility

The procedure presented above generally characterizes the nature of the qualitative method for risk assessment [5].

The determination of an acceptable level of risk is based on the criteria applied according to the rules shown in figure 3. The risk is always connected with responsibility of the WSS operator for his decisions. For fear of responsibility a multistage security system is used, which not always minimizes the risk (it generates passive, and not creative actions, with incompetence being connected with the risk zone). Responsibility, however, should be calculated. An example of responsibility scale is shown in figure 3.

4. THE INDIVIDUAL AND GROUP RISK

In this case, the division criteria include: source of risk, scope of its influence and scale of its consequences. The individual risk causes individual losses (failure of service water pipes for a given estate). The group risk has an impact on the whole communities (the lack of water supply in a city as a result of the lack of electricity caused by atmospheric discharge).

It is assumed that the group losses equal the sum of respective individual losses. Summation, however, should be performed separately for each category of losses (e.g. work losses, health losses, casualties).

If the risk concerns an individual person, we deal with the individual risk, when it concerns a group of people (community), we call it the group risk.

The group risk (r_g) can be calculated from the formula:

$$r_g = \frac{E(C)}{\Delta t}, \tag{2}$$

where:

Δt – time of exposure,

$E(C)$ – expected value of losses.

The individual risk when the number of people in the hazardous area is m is described by the formula:

$$r_i = \frac{E(C)}{m\Delta t}. \tag{3}$$

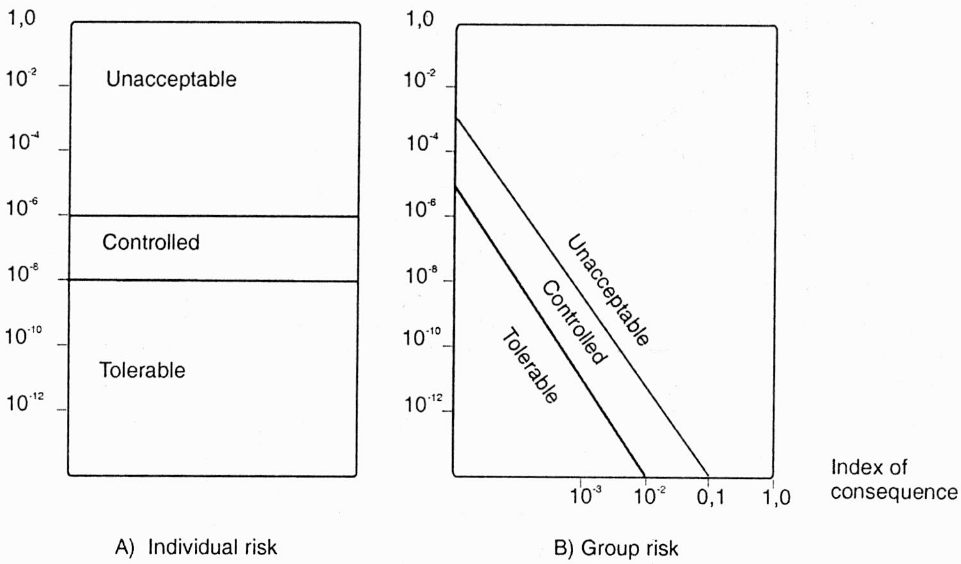

Fig. 4. Criteria of safety according to the Dutch recommendations

In a WSS, we should separate the individual risk (for a consumer of drinking water) from the group risk. As far as the reliability of WSS operation is concerned

WIECZYSTY [6] divided WSS into several categories according to the number of inhabitants, duration of an acceptable decrease in water supply for 0.7 Q_n and 0.3 Q_n and lack of water. The calculated indexes of the required reliability can be treated as the group quantity guarantees for water supply, where Q_n is the nominal demand for drinking water. The regulations in Holland [7] distinguish between the notion of individual and group risk. Their idea is illustrated in figure 4.

The recommendations concerning the group risk that are obligatory in Switzerland are shown in figure 5 [8]. It is worth noting that for the low values of frequency and consequence index the risk is not defined.

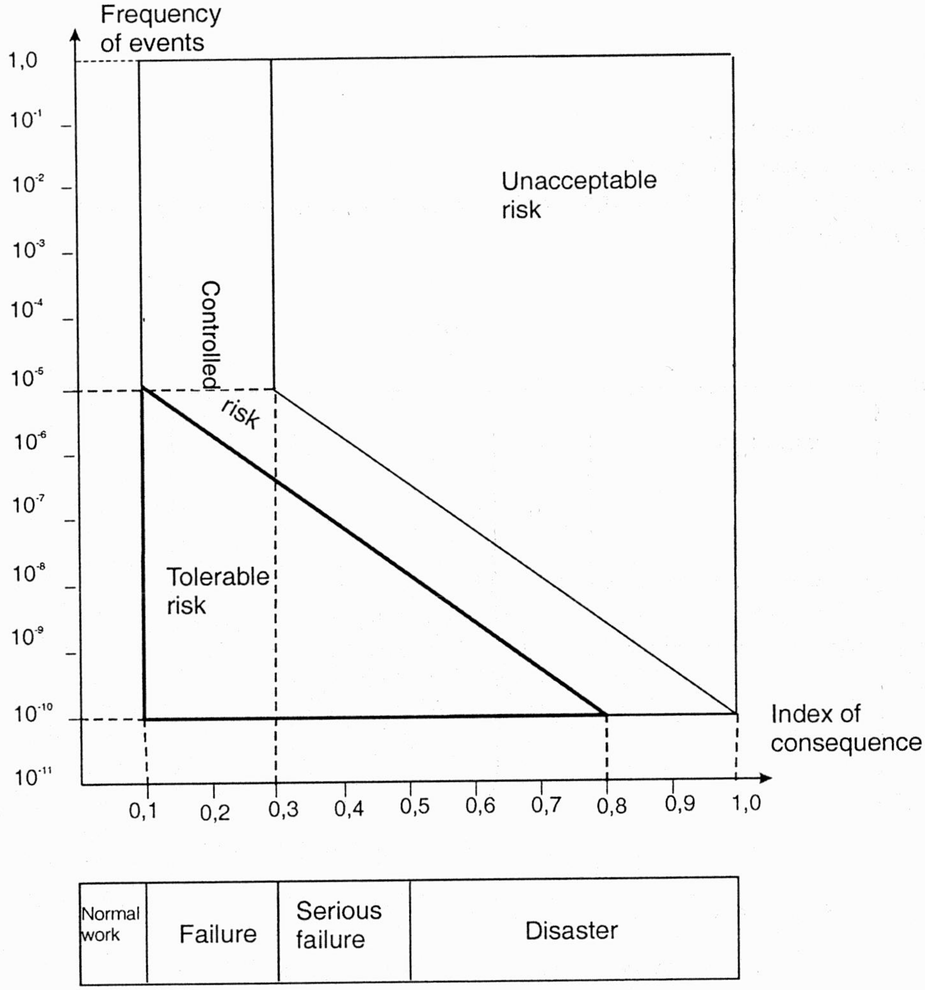

Fig. 5. Criteria of safety according to the Swiss recommendations

5. APPLICATION OF FMEA IN THE ANALYSIS OF DRINKING WATER QUALITY

In the FMEA method, the global assessment, taking into account the fact that the undesirable events occur at random, is carried out by using the number of risk priority (NRP) according to the formula:

$$\mathrm{NRP} = \mathrm{NPO} \,.\, \mathrm{NPD} \,.\, \mathrm{NPC}, \tag{4}$$

where:

NPO – the number of priority of the occurrence of a given index of drinking water pollution higher than the standard value – defines probability of occurrence starting from the very slight (impossible) to the very probable one,

NPD – the number of the priority of detectability – defines probability of pollution being detected; one should consider here the laboratory methods used, range and frequency of water analyses, monitoring (the early warning system – a protective station, the delayed warning system – analysis of raw water in the section of intake during the technological process of water treatment and analysis of the treated water, the late warning system – analysis of water quality at selected points of water pipe network),

NPC – the number of priority for a consumer – defines the probability of the intensity of effects for water receivers.

To each of these three numbers of priority a weight from the scale 1 to 10 is assigned. In this way, NRP can take the values from 1 to 1000. The assessment of NPR is carried out by using some evaluation forms that comprise the existing state and the improved state. In table 3, one can see the suggested values of the particular priority numbers.

Table 3

The values of the priority numbers

NPO		NPD		NPC	
Improbable $<10^{-6}$	1	Very little probability $> 10^{-1}$	1	Little $> 10^{-1}$	1
Very little probability 10^{-5}–10^{-6}	2–3	Moderately probable 10^{-1}–10^{-3}	2–5	Noticeably significant 10^{-1}–10^{-3}	2–3
Little probability 10^{-3}–10^{-5}	4–6	Little probability 10^{-3}–10^{-5}	6–8	Large 10^{-3}–10^{-5}	4–6
Moderately probable 10^{-1}–10^{-3}	7–8	Very little probability 10^{-5}–10^{-6}	9	Large 10^{-5}–10^{-6}	7–8
Very probable $> 10^{-1}$	9–10	Improbable $< 10^{-6}$	10	Catastrophic $< 10^{-6}$	9–10

The high number of NPR means the high priority in the procedures of removing and minimization of hazard connected with undesirable events. It is assumed that for NPR $\geq$ 100 it is obligatory to take some precautions, and NPR reduced to 10% is treated as a negative result of actions carried out [9].

6. APPLICATION OF TESEO IN THE ASSESSMENT OF RISK CONNECTED WITH THE WORK OF THE WSS OPERATOR

The role of the operator as regards the functioning of WSS and risk connected with it have been presented in [10]. One of the methods arising from HRA is the TESEO method (in Italian – Technica Stima Errori Operatori).

The index of making a cognitive error is determined from the formula:

$$P(O) = K_1 \,.\, K_2 \,.\, K_3 \,.\, K_4 \,.\, K_5, \tag{5}$$

where:

K_1 – a degree of the task complexity,

K_2 – predicted time for routine and non-routine actions of the operator,

K_3 – preparation and professional experience of the operator,

K_4 – index of fear connected with seriousness of situation,

K_5 – operator–system interface.

This method can be used in the comparative analyses to assess the possibility of error made by the system operator.

The values of indexes K_i are given in table 4.

In [11], once can find recommended probabilities of an error being made by the operator:

- for routine actions performed automatically from 5.10^{-5} to 5.10^{-3} ,
- for actions connected with procedures of their performing from 5.10^{-4} to 5.10^{-2},
- for actions that are based on knowledge from 5.10^{-3} to 5.10^{-1}.

The interesting formula for the probability of error being made by the operator who acts under the time stress is given by the American Research Centre for the Safety of Nuclear Systems (US RSS).

The probability of making an error by the operator is [12] :

$$P(EO) = 2^{(n-1)} \,.\, P, \tag{6}$$

where:

P – primary probability of making an error,

n – number of previous unsuccessful trials to correct the wrong decision.

Table 4

The indexes K_i and description of procedures concerning TESEO

Index K_i		Index value	Description of procedure
Degree of task complexity K_1		0.1	Simple routine
		0.5	Routine required concentration
		0.5	Not routine
Predicted time for operator action K_2	Routine	2.0	2 minutes
		0.5	10 minutes
		0.1	20 minutes
	Non-routine	5.0	3 minutes
		3.0	20 minutes
		2.0	45 minutes
		1.0	60 minutes
Operator qualifications and professional experience		0.1	High qualifications, long experience
		2.0	Average knowledge, short experience
		5.0	Low qualifications, mediocre knowledge, lack of experience
Fear connected with seriousness of situation K_4		3.0	High probability of serious failure
		1.0	Probability of failure
		0.1	Normal functioning
Operator–system interface K_5		0.1	Perfect work conditions, very good interface
		0.5	Good work conditions, good interface
		1.0	Average work conditions, average interface
		3.0	Mediocre work conditions, weak interface

According to formula (6) the probability can reach the value 1.0, which means that the operator was completely disoriented and completely lost control over the system. In table 5, one can see the values of $P(EO)$ for $P = 0.0625$.

Table 5

The probability of making an error by the operator with the number of unsuccessful trials to repair it equals n according to (6)

n	$P(EO)$
1	0.0625
2	0.125
3	0.250
4	1.0

As follows from the data given in table 5 after the fourth unsuccessful trial to correct the error the operator completely loses control of the system.

6. CONCLUSIONS

It follows from the definition of risk that the assessment of losses without taking into account the probability of their occurrence is not precise enough to measure system's safety.

Qualitative methods of risk assessment are based on the rule that actions taken under uncertainty conditions can generate losses and are based on the two categories:

- expected value of possible losses,
- possible fluctuation of the size of these losses.

As a rule, an increased risk can lead to higher expected losses.

The analysis carried out using qualitative methods for risk assessment in the case where risk is considered unacceptable gives the following possible directions of actions:

- prevention of undesirable events,
- counteracting hazards,
- elaboration of rescue scenario.

The qualitative methods of risk assessment have a character of specialist's evaluations. In most cases connected with hazard to WSS, it is not possible to conduct experimental research (due to the lack of physical possibilities, the ethical aspects, etc.). One can use statistical sets of events that occurred in the past (e.g., failures of water pipelines, incidental pollution of water source, floods, draughts, etc.).

The qualitative methods of risk assessment described in this paper have a character of so-called matrix methods in which the risk is being estimated on the basis of the scales of the levels of hazard and unreliability with the division into the categories.

REFERENCES

[1] KEMPA E.S., *Analiza ryzyka w systemach oczyszczania wód*, Ochrona Środowiska, nr 3(50), Wydawnictwo PZITS O/Dolnośląski, Wrocław, 1993, 5–10.

[2] KEMPA E.S., *Ryzyko w procesach i obiektach inżynierii sanitarnej*, Ochrona Środowiska, nr 2(57), Wydawnictwo PZITS O/Dolnośląski, Wrocław, 1995, 43–48.

[3] PN-IEC 60300-3-9, *Analiza ryzyka w systemach technicznych*, 1999.

[4] RAK J., *Metoda szacowania ryzyka zagrożenia systemu zaopatrzenia w wodę*, Ochrona Środowiska, nr 2/2003, Wydawnictwo PZITS O/Dolnośląski, Wrocław, 2003, 33–36.

[5] RADKOWSKI S., *Podstawy bezpiecznej techniki*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2003.

[6] WIECZYSTY A., *Niezawodność systemów wodociągowych i kanalizacyjnych*, Skrypt Politechniki Krakowskiej, cz. II, Kraków, 1990.

[7] VERSTEEG M.F., *External Safety Policy in Netherlands. An Approach to Risk Management*, Technical Committee of Status, Experience and Future Prospects for the Development of Probabilistic Safety Criteria, Vienna, 1986.

[8] SCHNEIBER J., *Risiko und Scherhbeit Technischer Systeme*, Birkhäuser Verlag, Bazylea, 1991.
[9] Menager Jakości; RWTŰV Akademie Westfalen GmbH, Materiały szkoleniowe, Katowice, 2002.
[10] RAK J., *Ryzyko w funkcjonowaniu operatora SZW – analiza ergonomiczna*, GWiTS nr 6, Wydawnictwo SIGMA, Warszawa, 2003, 211–214.
[11] HANNAMAN G.W., SPURGIN A.J., *Systematic Human Action Reliability Procedure (SHARP)*, EPRI NP.-3583, 1984.
[12] SWAIN A.D., GUTTMANNN H.E., *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application*, US-NRC-NUREG/CR-128, 1983.

STUDIUM METOD JAKOŚCIOWYCH OCENY RYZYKA W SYSTEMACH ZAOPATRZENIA W WODĘ

Dokonano przeglądu jakościowych metod oceny ryzyka w funkcjonowaniu systemu zaopatrzenia w wodę. Podjęto problematykę ryzyka indywidualnego i grupowego związanego ze spożywaniem wody do picia. Zaproponowano metodę oceny ryzyka związanego z pracą operatora systemu zaopatrzenia w wodę. Przedstawiono związek między ryzykiem a odpowiedzialnością za podejmowane decyzje.