Environmental Engineering V

Editors

Małgorzata Pawłowska
Lucjan Pawłowski

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ENVIRONMENTAL ENGINEERING V

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Preface

Environmental Engineering V summarizes research carried out in Poland in the area of environmental engineering. The main goal of the book is to improve technology transfer and scientific dialogue in the time of economic transformation from a planned to a free market economy, thereby leading to a better comprehension of solutions to a broad spectrum of environmentally related problems.

Increased use of motor vehicles is one of the most serious problems in Poland today. No incentives or economic stimulation for buying pro-ecological cars have yet been introduced. In order to mitigate unfavorable environmental changes, especially one of the highest levels of air pollution, the new Polish government has taken actions to begin the production of electric cars in Poland.

Therefore, a presentation of scientific findings and technical solutions created by the Polish research community ought to be of the interest not only for Polish institutions, but also for international specialists, searching for solutions for environmental problems in new emerging democracies, especially those who plan to participate in numerous projects sponsored by the European Union. Finally, we would like to express our appreciation to all who have helped to prepare this book: Mr. Szymon Obrusiewicz for improving the linguistic side of the papers. Anonymous reviewers who not only evaluated papers, but very often made valuable suggestion helping authors and editors to improve the scientific standard of this book. And finally, last but definitely not least Mrs. Katarzyna Wójcik Oliveira for her invaluable help in preparing a layout of all papers.

Lucjan Pawłowski
Małgorzata Pawłowska
Lublin, September 2016

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About the editors

MAŁGORZATA PAWŁOWSKA

Małgorzata Pawłowska, Ph.D., Sc.D. (habilitation) was born in 1969 in Sanok, Poland. In 1993 she received M.Sc of the protection of the environment at the Catholic University of Lublin. Since that time she has been working in the Lublin University of Technology, Faculty of Environmental Engineering. In 1999 she defended Ph.D. in the Institute of Agrophysics of the Polish Academy of Science and in 2010 she defended D.Sc. thesis at the Technical University of Wroclaw and was appointed as associate professor and head of Engineering of Alternative Fuels Department at Faculty of Environmental Engineering Lublin University of Technology. Now she is working on biomethanization processes and application of selected wastes for remediation of degraded land.

She has publishes 59 papers, 2 books and is co-author of 7 polish patents, 1 European patent, 28 polish patent applications and 25 European patent applications.

LUCJAN PAWŁOWSKI

Lucjan Pawłowski, was born In Poland, 1946. Director of the Institute of Environmental Protection Engineering of the Lublin University of Technology, Member of the European Academy of Science and Arts, Member of the Polish Academy of Science, Deputy President of the Engineering Science Division of the Polish Academy of Science, honorary professor of China Academy of Science. He received his Ph.D. in 1976, and D.Sc. (habilitation) in 1980, both at the Wrocław University of Technology. He started research on the application of ion exchange for water and wastewater treatment. As a result, together with B. Bolto from CSIRO Australia, he has published a book "Wastewater Treatment by Ion Exchange" in which they summarized their own results and experience of the ion exchange area. In 1980 L. Pawłowski was elected President of International Committee "Chemistry for Protection of the Environment". He was Chairman of the Environmental Chemistry Division of the Polish Chemical Society from 1980–1984. In 1994 he was elected the Deputy President of the Polish Chemical Society and in the same year, the Deputy President of the Presidium Polish Academy of Science Committee "Men and Biosphere". In 1999 he was elected President of the Committee "Environmental Engineering" of the Polish Academy of Science. In 1991 he was elected the Deputy Reactor of the Lublin University of Technology, and held this post for two terms (1991–1996). He has published 19 books, over 128 papers, and authored 98 patents, and is a member of the editorial board of numerous international and national scientific and technical journals.

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Safety analysis of water supply to water treatment plant

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ABSTRACT: Collective water supply system safety analysis should include risk assessment of threats at each stage of water production, from the water intake through treatment, distribution to the point of delivery to consumers. The proposed method, using the definition of the expected value of water scarcity, enables to conduct the analysis and assessment of the risk of lack of water supply to the distribution subsystem, taking into account different combinations of reliability states. The paper analyses the operation of a water treatment plant. The analysis used data operational work of the water intake. The expected value is used as a measure of the risk of the lack of water supply. Calculations were carried out in two variants: for a nominal value, and for the theoretical increase in the demand for water, in which the nominal demand for water is two times higher than the current maximum water production.

Keywords: water supply system, safety analysis, water treatment plant

1 INTRODUCTION

State, level and area of population using Collective Water Supply System (CWSS) are a measure of the level of civilization. Water quality, quantity and availability should be a priority for the sustainable development of a local community. In accordance with The European Programme for Critical Infrastructure Protection, collective water supply system belongs to critical infrastructure. The identified critical infrastructure must have a protection plan including identification of key resources, risk analysis based on major threats scenarios and vulnerabilities of resources, as well as identification, selection and procedures prioritization and protection measures. CWSS safety has its own international legal regulations, the source of which are primarily the guidelines of the World Health Organization (WHO). The primary and basic subject the notion of water safety is concerned with is a consumer (Tchórzewska-Cieślak 2007, Tchórzewska-Cieślak 2009, Boryczko & Tchórzewska-Cieślak 2015, Olkiewicz et al. 2015, Mrozik et al. 2015).

The secondary subject is a supplier, i.e. a manufacturer of water. In this respect, one can consider the risk of the consumer and the producer. The important elements in this regard also include the environmental aspects and the principles of sustainable development in water management. The environmental aspect and the principles of sustainable development in the widely understood water management are relevant as well. Operational reliability of the CWSS is the ability to supply a constant flow of water for various groups of consumers, with a specific quality and specific pressure, according to the users' requirements in the specific operational conditions, at any time (in which case we use the readiness indicator K) or in the specific time range (then we use reliability function R(t)) (Rak 1993, Rak 2005, Kwietniewski et al. 1993, Tchórzewska-Cieślak & Rak 2010).

The definition of the CWSS safety, including technical, economic and environmental aspects, is the following: "safe CWSS operation means ensuring continuity of water supply to the consumer while the following criteria are met" (Rak 2005, Tchórzewska-Cieślak 2011, Nowacka et al. 2016):

- system reliability (in terms of quantity and quantity),
- socially acceptable level of prices per m^3 of delivered water, taking into account aspects arising from the requirements for public safety, natural aquatic environment protection and standard of life quality.

CWSS safety analysis should include an analysis and risk assessment of threats at each stage of water production, from the water intake through treatment, distribution to the point of delivery to consumers (Hrudey & Hrudey 2004). In most studies regarding the analysis and assessment of CWSS safety it is assumed that the measure of CWSS safety is risk associated with the possibility of different threats occurrence (Haimes 2009).

One of the most common ways to conduct threat analysis is the study of threats using data from:

- previous safety analyses, conclusions—drawn from undesirable events and their causes,
- the experience of experts from—the operation of existing systems of water-pipelines.

Risk identification involves selecting the representative emergency events that may occur during the operation of the system, including the initiating events, which may cause the so-called domino effect (Pollard et al. 2004, Rak 2009, Rak 2003, Rak & Tchórzewska-Cieślak 2013).

Risk assessment is the process of qualitative and quantitative analysis using methods adequate for the given type of risk, with the determination of the criteria value for the assumed risk scale (Zio 2007) or in the form of failure prediction (Tchorzewska-Cieslak et al. 2016). For example, a three-step scale distinguishing tolerated risk, controlled risk and unacceptable risk, or a five-step scale, in which the area of neglected risk and absolutely unacceptable risk is also distinguished (Apostolakis & Kaplan 1981, Michaud & Apostolakis 2006).

The determination of risk acceptability criteria should primarily take into account the aspect of water consumer safety, as well as technical and economic analysis. The risk acceptability criteria are used in making decisions concerning the operation of the system (e.g. repairs, modernization and allowing to be used). The system can be considered safe if the risk level created during system operation does not exceed the limit values.

It is very important for waterworks to identify risk correctly and to divide it into consumer risk and water producer risk (Boryczko & Tchórzewska-Cieślak 2015). It allows to choose 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 (Zimoch 2007). The key role in this process is played by a system operator, whose main purpose is (Ezell, Farr & Wiese 2000, Iwanejko 2009, Królikowska 2011, Rak 2005, Sadiq, Kleiner & Rajani 2004):

- 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 emergency situations,
- to develop a complex system of information about the possible threats for water consumers.

In practice, the WHO recommends the development of the so called Water Safety Plans (WSP) and the new Water Cycle Safety Plan (WCSP) approach, based on analyses and risk assessment. It is important for the entire water cycle in urban catchments and the impact of rainfall on the functioning of water supply system (Kazmierczak & Kotowski 2015). At the same time there are still risks such as floods, droughts, failures of electrical power, accidental pollution of water sources, and even terrorist and cyber terrorist attacks, which are often the cause of serious disruption in CWSS subsystems functioning and thus contribute to the loss of water consumers' safety.

2 MATERIAL AND METHODS

The risk assessment is concerned with what can go wrong, as well as its likelihood and consequences. Risk is a measure of the probability and severity of adverse effect (Haimes 2009).

Kaplan and Garrick introduced the theory of scenario and the triplet questions in the risk assessment process (Kaplan & Garrick 1981, Kaplan 1997):

- what can go wrong?
- what is the likelihood?
- what are the consequences?

They introduced that the risk is the function: $r = f(S_i, L_i, C_i)$, where S_i = denotes the i-th risk scenario (initiating events scenarios); L_i = denotes the likelihood of that scenario; C_i = denotes resulting consequences.

In order to perform effective risk assessment and management, the analyst must understand the system and its interactions with its environment, and this understanding is a requisite to modeling the behaviour of the state of the system under varied probabilistic conditions (Boryczko & Tchórzewska-Cieślak 2015).

A factor determining the risk of lack of water supply may be a scarcity of water production during the failure of the particular subsystems of water production. It is assumed that the absolute risk of lack of water supply is a product of the probability of water scarcity and the losses related to it.

This relation can be determined using the so-called expected value of water shortage $E(\Delta Q)$ (Rak 2005, Tchórzewska-Cieślak 2011; Kwietniewski et al. 1993):

$$r_a = E(\Delta Q) \tag{1}$$

and

$$E(\Delta Q)=\int_{0}^{\infty}\Delta Q f(\Delta Q)d(\Delta Q)=\sum_{i=0}^{i=n}\Delta Q\cdot P_i \qquad (2)$$

where r_a = the absolute risk of lack of water supply (m^3/d); $E(\Delta Q)$ = the expected value of water shortage; i = a number of operating state; n = a maximum number of the possible states of reliability; $n = 2^m$ (m = a number of all water sources); ΔQ_i = deficiency of water sources in the given state of unreliability; P_i = probability of the i-th state of the water production subsystem operation.

The value of the deficiency of water sources ΔQ is calculated as the difference between the required capacity of water sources and the capacity of sources in the i-th state, according to the (Rak 2005, Tchórzewska-Cieślak 2011, Kwietniewski et al. 1993):

$$\Delta Q = Q_n - \sum_{i=1}^{k_i} Q_{ik} \qquad (3)$$

where Q_n = the required water demand, the required system capacity during the normal operation (usually the value of Q_n is assumed to be the maximum daily demand for water Q_{maxd} or the design value of water production); k_i = a number of faulty water sources in the i-th state; Q_{ik} = production of the particular water sources in the i-th state with k_i failures.

Probability value P_i is determined by the following formula (Kwietniewski M. et al. 1993):

$$P_i = \prod_{j\in S} K_j \cdot \prod_{j\in N}(1-K_j) \qquad (4)$$

where K_j = the availability index of the j-th water supply subsystem; $j\in S$ = the set of those subsystems of delivery (or their components) that are efficient in the i-th state, marked with the symbol (+); $j\in N$ = the set of those subsystems of delivery (or their components) that are inefficient in the i-th state, marked with the symbol (–).

In order to assess the risk of lack of water supply, the relative risk of lack of water supply to the CWSS is defined, referring the expected value of water scarcity (the absolute risk) to the nominal value of water supply, which also allows to determine the criteria values. In order to better illustrate the relative risk, its value can be expressed as a percentage, according to the formula (Tchórzewska-Cieślak 2011):

$$r_r = \frac{r_a}{Q_n} \qquad (5)$$

Table 1. The safety criteria values for levels of the relative risk of lack of water supply.

Water supply system	r_r [%]	Safety level
large supply system,	≤2	TSL
number of inhabitants	(2÷5)	CSL
>500 000	≥5	USL
medium supply system,	≤ 4	TSL
number of inhabitants	(4÷9)	CSL
50 000 ÷ 500 000	≥9	USL
small supply system,	≤5	TSL
number of inhabitants	(5÷9)	CSL
<50 000	≥9	USL

where r_r = the relative risk of lack of water supply [%]; Q_n = the nominal value of the water demand (consumption) [m^3/d].

If the sum of the capacity of all sources is higher than the required capacity, then so called water reserve occurs (scarcity is equal to zero).

Criteria for the assessment of the safety of CWSS on absolute risk are the following:

- Tolerable Safety Level (TSL),
- Controlled Safety Level (CSL),
- Unacceptable Safety Level (USL), and are presented in Table 1 (Tchórzewska-Cieślak 2011).

If the calculated values indicate that safety level is:

- TSL—one can assume that the subsystems of water production fulfils its functions in the satisfying way,
- CLS—an improvement in the work of some elements of water production subsystems or alternative water sources should be considered,
- USL—the subsystems of water production does not fulfil its functions and should undergo a complete modernization and alternative sources of water are needed.

3 RESULTS AND DISCUSSION

The paper analyses the functioning of the Water Treatment Plant (WTP) for a town located in the eastern Poland and supplying water for about 80 000 residents. Water Treatment Plant takes water from the unconfined quaternary aquifer from a depth of about 15 m.

The quaternary aquifer level within which there is a water intake is part of the Main Groundwater Reservoir. Wells, due to their location, are divided into two intakes I and II. Water is directed to the collective well (retention time 24 hours, depending on the current water production). The weak side of supply is connecting the intake wells I and II by means of one transmission pipeline with WTP.

It is compensated by a store of water in the collective well; however, it is a weak point of the intake.

Water facilities for water intake are pump intakes:

- I—which includes 5 pieces of drilled wells (Q_{emax} 183 m^3/h).
- II—which includes 22 pieces of drilled wells (Q_{emax} = 715 m^3/h).
- the maximum daily water consumption (2013/2014) is on average Q_{maxd} = 6 958.5 m^3/d.

Table 2 lists the values of water production for intakes I and II and adopted values of reliability indexes K (Kwietniewski M. et al. 1993; Rak J. 1993).

Calculations were carried out in two variants:

- for a nominal value, accepted on the base of the average maximum water production, Q_n = 7 000 m^3/d, was assumed.
- for the theoretical increase in the demand for water, in which the nominal demand for water is two times higher than the current maximum water production, $Q_n = Q_{maxd}$ = 14 000 m^3/d, was assumed.

Table 3 presents the results of calculations of the absolute risk according to the formulas (1) ÷ (4) for the nominal value of the water demand, adopted on the base of the average maximum water production: Q_n = 7 000 m^3/d and we have to assume:

- The state of reliability is marked with "1", the state of unreliability with "0".

For the two water sources the number of the possible states is: $2^2 = 4$, i = 1,2,3,4.

Table 2. The reliability indexes K for water intake I and II.

Intake	Q [m^3/d]	K
I	2 976	0.984
II	15 797	0.995

The absolute risk of lack of water supply:

r_a = 20.35 m^3/d.

The relative risk was calculated using the formula (5) for the demand for water: $Q_n = Q_{maxd}$ = 7 000 m^3/d (adopted for the current maximum water consumption), which is approximately 40% of the maximum operational capacity of intakes I and II.

It is stated that the system has excess production capacity. The relative risk for the lack of water supply is:

r_r = 0.3%.

According to the data contained in table 1, the relative risk of lack of water supply to the water supply system of the city, for a variant with an excess (real state) is at a tolerable level—TSL.

In order to analyse the risk of lack of water supply in case of a theoretical increase in the demand for water, the risk of lack of water supply for a hypothetical state in which the nominal demand for water is two times higher than the current maximum water production, was calculated.

$Q_n = Q_{maxd}$ = 14 000 m^3/d was adopted, which represents approximately 75% of the maximum operational capacity of intakes I and II.

Table 4 summarizes the results of calculation of the absolute risk according to formulas: (1) ÷ (4) for a nominal value adopted for the hypothetical variant.

The absolute risk of lack of water supply:

r_a = 55.36 m^3/day.

The relative risk was calculated using the formula (5) for the demand for water:

$Q_n = Q_{maxd}$ = 14 000 m^3/d

The relative risk for the lack of water supply is:

r_r = 0.4%.

Table 3. Analysis of the risk of lack of water supply (I and II) for the existing state.

	Characteristics of operating states		Capacity m^3/d]		Total m^3/d]	Deficiency m^3/d]	Probability of i state	
i	I	II	Q_I	Q_{II}	Q	ΔQ	P_i	$P_i \cdot \Delta Q$
1	1	1	2976	15797	18773	0	0.9791	0
2	1	0	2976	0	2976	4024	0.0049	19.79
3	0	1	0	15797	15796	0	0.0159	0
4	0	0	0	0	0	7000	0.00008	0.56
				Σ				20.35