DRINKING WATER QUANTITY AND QUALITY RISK MANAGEMENT

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This work establishes the ways of planning and developing the necessary processes for obtaining and distributing secure water to users with maintaining control over the risks regarding water quality. The basic hypothesis for planning and creating safe water is risk analysis which consists in identifying dangers and dangerous events, evaluating risks and determining their priority. The approach to risk management is based on Danger and Control of Critical Points Analysis, Safety Management System Principals, and requires the development and understanding of a method that ranks and prioritizes the dangers and risks, ensuring control measures in order to reduce them to an acceptable level.

Keywords: safe water production, drinking water quality and quantity, risk analysis

1. Introduction

The World Health Organization adopted the concept of safe water and recomends applying the principals of the Hazard Analysis and Critical Control Points System (HACCP) in the creation of drinking water.

Product safety is tied together with the presence of dangers in food products (water is considered a food product) during consumption. Due to the fact that dangers may occur during the technological flux at any stage, adquate control during the water route (starting from raw material – raw water, up to the supply of drinking water to the consumer), is essential. Thus product safety is ensured through the combined effort of all parties involved in the production and distribution of water to consumers. Communication during the technological flux is essential to ensure that all the significant dangers risks for product safety are identified and properly controlled at each step. This implies that internal as well as external communication (with clients and product and services suppliers). [1]

A risk evaluation plan means to identify risks, dangers, evaluate them, identifying control measures and monitoring them. Due to complexity, the afferent documentation to each step of the plan needs to be accurate and to reflect the

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characteristics of the water supply system. For each water supply system a risk evaluation plan needs to be drafted that can vary in complexity, according to the size and characteristics of the system. The approach of risk management is based on Hazard Analysis and Critical Control Points. Safety Management System Principles (which is a risk management prevention system) requiere the development and understading of a method that ranks and prioritises, the dangers and the risks, and at the same time ensuring control measures in order to reduce them to an acceptable level. The water supply systems may be considered as a serie of succesive steps that need to be followed and integrated in order to obtain a safe drinking water. In order to ensure safe drinking water, each step need a careful management that contains:

- Monitoring, prevention and control of water source polution;
- Management of water storage, where available;
- Proper water treatment and its monitoring before distribution;
- Safe distribution through: proper maintenance of the distribution system and additional water treatment where it is required;
- The monitoring of the drinking water distributed to consumers.

Each of these steps need to be taken into consideration before taking the necessary measures to ensure a clean and healthy drinking water. This is a large area, chemical and microbiological contamination agents may be present in the drinking water, some of these having effects on the consumer's health. The contamination agents can come from inconsistent sources, and in some cases even from the distribution process of drinking water.

2. Planning the actions and operations

In order to plan and ensure safe water, the following steps need to be went through: establishing a product safety team; evaluating and describing the water supply system; identifying dangers and dangerous events, evaluating risks and establishing their priority; determination, validation and monitoring of control measures for dangers and risks supervision; elaborating and periodic updating of specific documentation: danger analysis, operational preliminary programs, Hazard Analysis and Critical Control Points (HACCP) programs, risk evaluation, risk management plans; checking the efficiency of the established control measures.

The detailed description of the water supply system evaluation process needs to cover the entire system from the raw water source to the consumer's faucet, including the treatment technology. Drinking water quality varies along the system, so the evaluation needs to check the quality of the drinking water at the consumer's faucet, by comparing it to the limits set in the legal regulations in force. [1] Flux diagrams need to be elaborated in order to evaluate the water supply system. The clear identification of dangers requires the elaboration of a specific scheme of the supply system, which indicates the processes involved in each step of intake, treatment and distribution. In some cases, the water treatment process in order to make it drinking water, reduces itself to the disinfection stage, whereas in other situations the treatment is complex. Similarly, there are situations in which we cannot influence the source quality and the characteristics of the intake stuff. In other cases, there is access to detailed information regarding the water source and intake area. This is utilized to optimize the activities in the intake area and/or water transfer. In these types of cases, information regarding intake and water sources are part of the flux diagrams or can be shown in a geographical system (maps, traceability schemes). In order to identify dangers, all the possible threats need to be taken into consideration, biological, physical, chemical and radiological threats associated to the water supply system, starting with the water source and going through all the steps in the flux diagram. In Fig. 1, a flux diagram is presented for the Eforie Nord water supply system.

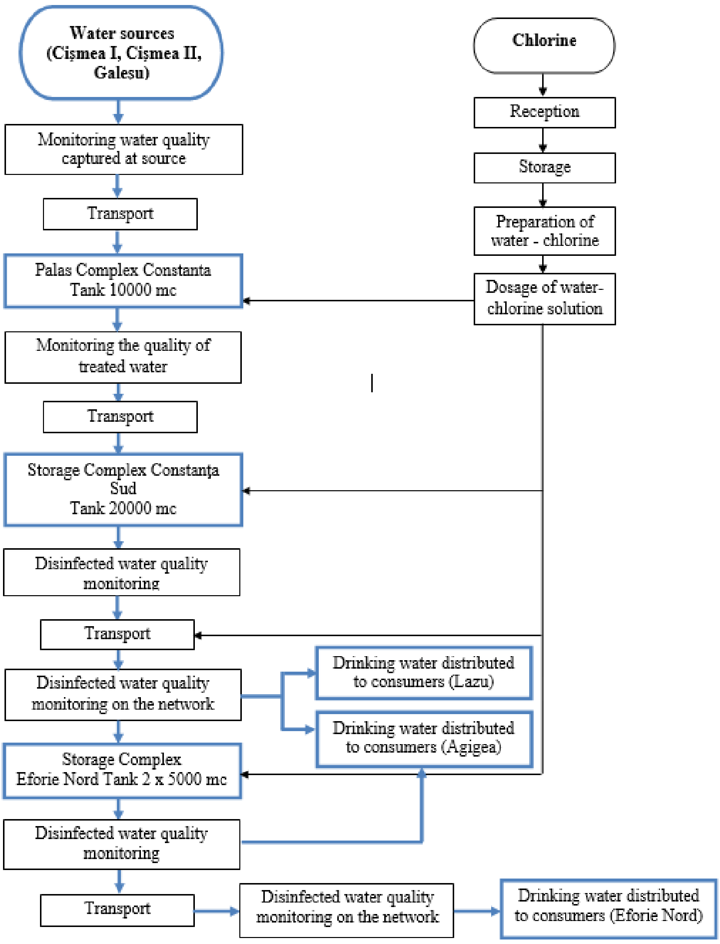

Fig. 1 Flux diagram

Each step of the danger identification process has two main objectives: Identifying the contamination source; and identifying control measures per each type of danger. [2] The drinking water distributed in the city of Eforie Nord comes from underground sources Cișmea I and II and from the Galeșu surface water source.

3. Risk evaluation for the Eforie Nord water supply system

Risk evaluation is the global process of identifying risk, risk analysis and risk estimation.

An organization needs to identify risk sources, impact area, events and causes of the risk as well as the possible consequences of such risks. The purpose of this stage is to generate a list of potential risks based on events that may create, intensify, stop, degrade or delay the accomplishment of objectives set. [3] Risk analysis supplies entry data for risk estimation, in order to make the decisions regarding treatment or non-treatment of risks and the most appropriate strategies to treat risks. Risk analysis also implies taking into consideration the causes and sources of risk, their consequences and also the probabilities of their appearance. [4]

Risk estimation implies comparing the risk level determined during the analysis process with the already established risk criteria. The purpose of risk estimation is to contribute, based on the risk analysis results, to make decision regarding the risks that require treatment and the prioritization of risk treatment implementation. [3] The preliminaries (Tables 1-3) and risk analysis [2,4] for the Eforie Nord water supply system (Table 4) are presented forwards.

Table 1

Gravity of potential consequences and probability of appearance of consequences

GRAVITY (G)		GRAVITY OF POTENTIAL CONSEQUENCES
1	NEGLIGIBLE	Consequences: no impact
2	SMALL	Consequences: minor lesions and/or sickenings, the absence of effects or minor effects, or consequences that appear only after exposure to high value doses in long periods of time
3	MEDIUM	Consequences: minor diseases
4	LARGE	Consequences: substantial prejudice and/or rarely serious disease
5	SERIOUS	Consequences: fatal, serious diseases, incurabile prejudice, that manifest themselves immediately or after a long period
PROBABILITY OF APPEARANCE (P)		PROBABILITY OF APPEARANCE OF CONSEQUENCES
1	VERY RARE	Negligible: P < 1/an
2	RARE	Small: P = 1/an
3	MODERATE PROBABILITY	Medium: P = 1/lună
4	PROBABILE	Large: P ≥ 1/lună
5	FREQUENT	Serious: P > 1/săptămână

Table 2

Risk level

Gravity (G)	Risk level (RL)				
Serious	5	10	15	20	25
Large	4	8	12	16	20
Medium	3	6	9	12	15
Small	2	4	6	8	10
Negligible	1	2	3	4	5

Table 3

Risk class

Risk level (RL)	Risk class (RC)
1 - 2	No action required
3 - 5	Keep under observation / consider the water source control or water treatment measures
6 - 10	It is necessary to control the water collection or the treatment process / a possible intervention is necessary if the treatment is not appropriate
12 - 16	Emergency control of water abstraction or treatment and investment if treatment is not appropriate
20 - 25	Emergency control of water abstraction or treatment and investment if treatment is not appropriate

Table 4

Risk analysis for the Eforie Nord water supply system

No. crt.	Potential Risk	Causes of risk appearance	Potential consequences	G	P	RL	Security measures	Rezidual RL proposed	Responsabile	Risk re-evaluation term
1. **PROCESS: Capture and transport of raw water**										
Stage: Capture and transport of surface raw water/ groundwater										
1.	Surface / underground raw water contaminated with oils, lubricants, pesticides, animal waste	- Discharges bilge ships - Improper disposal of waste - Unrecorded failure of hydraulic equipment at pumping stations and locks - Insufficient staff awareness - Unreported equipment failures	- Contamination of raw water - Faults in equipment from the water treatment plant	3	1	3	- Monitoring the quality of raw water - Stopping water supply from contaminated drilling and exclusive water supply from uncontaminated drilling - Stopping water supply if total source contamination is found and an imminent epidemiological risk - Informing authorities and population - Training and awareness of staff	3	Workstation Chief Manager Laboratory	The end of the current year
2.	Insufficient drinking water distributed to consumers	- Filling of water sources - Decrease in surface water due to drought	- Lower users' health and hygiene	3	1	3	- Ensuring the quantity of drinking water required in relation to the variation in the number of consumers - Permanent monitoring of water sources	3	Responsible for water production	The end of the current year
3.	Sabotage, vandalism	- Social - political reasons - Revenge - Actions of people with mental disorders	-Contamination of raw water	4	1	4	- Monitoring the quality of raw water - Stopping water supply if an epidemiological risk is found	3	Workstation Chief Manager	The end of the current year

No. crt.	Potential Risk	Causes of risk appearance	Potential consequences	G	P	RL	Security measures	Rezidual RL proposed	Responsabile	Risk re-evaluation term
							and the authorities and the population are informed - Ensuring workplace guard		Laboratory	
					2. PROCESS: WATER TREATMENT					
					Stage: The first chlorination					
4.	Sub-dosing of chlorine concentration / Overdose of chlorine concentration	- Awareness and inadequate training of staff - Undefined failure of chlorine dosing equipment	- Water Disinfection Inefficiency / Exceeding the residual chlorine content	2	2	4	- Training and awareness of staff - Regular checking of the chlorine dosing equipment - Monitoring of water quality	2	Workstation Chief Manager Laboratory	The end of the current year
5.	Chlorination plant failure	- Awareness and inadequate training of staff	- The inefficiency of water disinfection	2	2	4	- Training and awareness of staff - Regular checking of the chlorine dosing equipment	2	Workstation Chief Manager	The end of the current year
					Stage: Coagulation treatment					
6.	Coagulation inefficiency due to under-dosing of the coagulant solution	- Awareness and inadequate training of staff	- Inefficient water treatment	3	1	3	- Training and awareness of staff - Monitoring of water quality	3	Workstation Chief Manager Laboratory	The end of the current year
					Stage: Decantation					
7.	Decanters improperly sanitized	- Awareness and inadequate training of staff	Contamination of water	3	1	3	- Training and awareness of staff - Supervision by the workstation chief - Monitoring of water quality after sanitation	3	Workstation Chief Manager Laboratory	The end of the current year
8.	Short decantation time	- Awareness and inadequate training of staff	- Insufficient sedimentation	3	1	3	- Training and awareness of staff - Supervision by the workstation chief - Monitoring of water quality after sanitation	3	Workstation Chief Manager Laboratory	The end of the current year
9.	Pest control	- No failure to report infrastructure damage - Failure to comply with the pest control program	Contamination of water	4	1	4	- Preventing infrastructure damage - Realization of pest control program according to established schedule	4	Workstation Chief Manager Responsible pest control	The end of the current year
					Stage: Filtration					
10.	Filters improperly sanitized	- Awareness and inadequate training of staff	Contamination of water	3	1	3	- Training and awareness of staff - Supervision by the workstation chief - Monitoring of water quality after sanitation	3	Workstation Chief Manager Laboratory	The end of the current year
11.	Failure to comply washing	- Awareness and inadequate training of staff	Contamination of water	3	1	3	- Training and awareness of staff - Supervision by the workstation chief	3	Workstation Chief Manager	The end of the current year

No. crt.	Potential Risk	Causes of risk appearance	Potential consequences	G	P	RL	Security measures	Rezidual RL proposed	Responsabile	Risk re-evaluation term
	steps and washing times						- Monitoring of water quality after sanitation		Laboratory	
12.	Pest control	- No failure to report infrastructure damage - Failure to comply with the pest control program	Contamination of water	4	1	4	- Preventing infrastructure damage - Realization of pest control program according to established schedule	4	Workstation Chief Manager Responsible pest control	The end of the current year
Stage: Chlorination										
13.	Failure to comply the established chlorine concentration	- Awareness and inadequate training of staff - Failure of the chlorine equipment	Microbiological contamination of water - Illness of users	4	3	12	- Training and awareness of staff - Regular checking of the chlorine dosing equipment - Monitoring of water quality	4	Workstation Chief Manager Laboratory	The end of the current year
3. **PROCESS: WATER STORAGE**										
Stage: Cleaning										
14.	Inadequately sanitized tank	- Awareness and inadequate training of staff	Contamination of water	4	1	4	- Training and awareness of staff - Supervision by the workstation chief - Monitoring of water quality after sanitation [10]	4	Workstation Chief Manager	The end of the current year
15.	Sanitized residues	- Awareness and inadequate training of staff	Contamination of water	4	1	4	- Training and awareness of staff - Monitoring of water quality after sanitation [10]	4	Workstation Chief Manager Laboratory	The end of the current year
16.	The hygienic behavior of the staff	- Poor inspection of staff by the heads of the work points - Inadequate awareness of staff in applying hygiene principles to avoid drinking water contamination	Contamination of water	3	1	3	- Training and awareness of staff - Supervision by the workstation chief	3	Workstation Chief Manager Laboratory	The end of the current year
4. **PROCESS: WATER DISTRIBUTION**										
Stage: Drinking water transport through the distribution network										
17.	Badly resolving a fault on a water distribution network [9]	- Awareness and inadequate training of staff	Contamination of water	4	1	4	- Compliance with the applicable procedures / instructions for each type of damage encountered - Washing and disinfecting the pipe section at the end of the work - Monitoring of water quality after work on the water distribution network [10] - Training and awareness of staff	4	Workstation Chief Manager Laboratory	The end of the current year
18.	Sabotage, vandalism	- Social - political reasons - Revenge - Actions of people with mental disorders	- Contamination of water - Equipment failures	5	1	5	- Monitoring water quality in the network [10] - Securing manholes - Periodic inspection of the manholes in accordance with the Valve Maintenance Program	5	Workstation Chief Manager Laboratory	The end of the current year

4. Case Study: Risk analysis of insufficient drinking water distributed to consumers for the Eforie Nord water supply system using the Analytica software

Analytica software offers an integrated risk and sensitivity analysis for uncertainty-entry models and powerful facilities for time-dependent dynamic simulations. Analytica embodies the idea of using a white board for problem solving. Using a visual, point-and-click approach, by drawing nodes and arrows to depict the relationships between model components, allows to describe the essential qualitative nature of the problem without getting lost in the details. As the model develops and the understanding of the problem becomes clear, it can be can defined the exact quantitative details of the model. A key feature of Analytica is its ability to create hierarchies of models. By grouping related components of a problem into separate sub-models, a multi-level organization of the model is available. This helps to manage complex relationships. Each node, or object, in an Analytica model has a window that displays the node’s inputs and outputs, and allows you to enter definitions, descriptions, units of measure, and other documentary information. This self-documenting capability, combined with hierarchical models and Intelligent Arrays, makes it easier to understand and communicate how models work. Analytica features fully integrated risk and sensitivity analysis for analyzing models with uncertain inputs; powerful facilities for time-dependent, dynamic simulations; powerful graphing capabilities; and over 200 financial, statistical, and scientific functions for calculating just about any type of mathematical expression. [6]

Ideally, in times when raw water has a constant quality and quantity, a water supply system will operate continuously, without changes in flow or other operating conditions for individual treatment processes. In this way, an optimized system will have the best opportunity to constantly produce safe drinking water. However, ideal conditions do not always apply with various factors that influence the quality and quantity of water required. [5,6]

Drinking water distributed in Eforie Nord (Fig.2 - elaborated in Analytica software) is derived from the underground sources of Cișmea I and II and from the surface water source Galeşu, so the risk of insufficient drinking water distributed to consumers is due to the clogging of water sources or the decrease of the surface water level due to drought, and/or lack of precipitation. A potential consequence of this risk may be the lowering of the level of health and hygiene of the users and the security actions that can be taken are: ensuring the quantity of drinking water required in relation to the variation of the number of consumers and the permanent monitoring of the water sources. [7] At present, the amount of surface water used is up to 20% of the total amount of water.

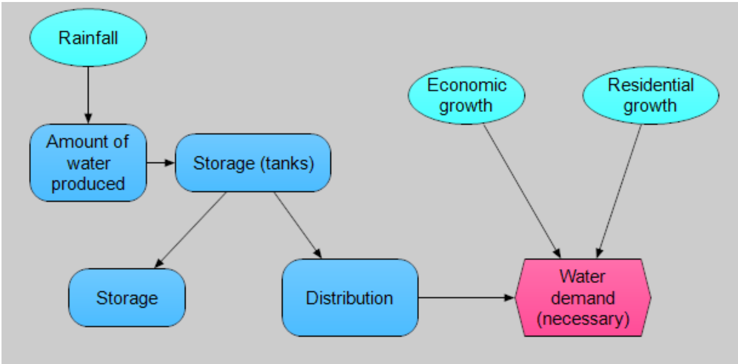

Fig.2 Analytica diagram for water demand in Eforie Nord

Drinking water supply is a continuing concern, and if underground water supply is relatively stable, in the case of surface water an important factor that influences the amount of water are precipitations. Supply of surface water is vulnerable to decreasing the amount of water during periods of low rainfall. In this case, the uncertain key variable is rainfall, which varies with the season [8], (Fig.3).

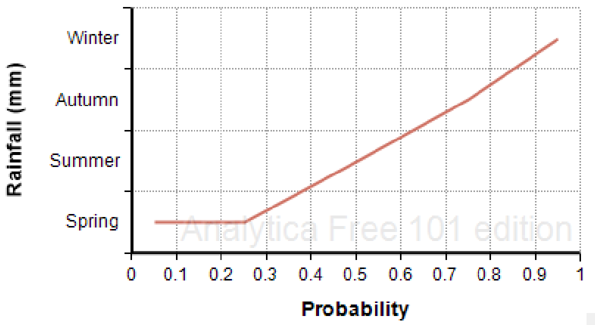

Fig.3 Seson probability of rainfall in Eforie Nord

Water storage (Fig.4) is provided in a tank of 20000 mc (Storage Complex Constanța Sud) and in a tank of 10000 cubic meters (2 cuvettes of 5000 mc of Eforie Nord).

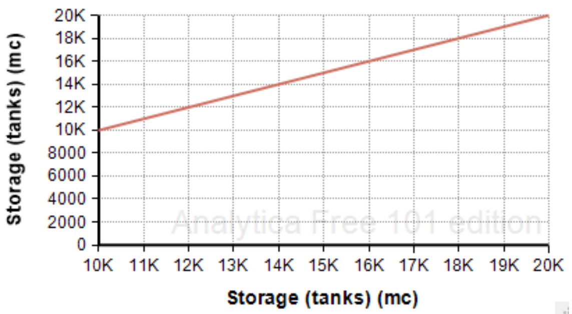

Fig. 4. Water storage

An important issue to keep in mind is economic growth through the development of area tourism [9], (Fig. 5) and automatic residential growth [9], (Fig.6). Typically, during the summer season, the number of users is four times higher than during the cold season, and the drinking water requirement is four times higher.

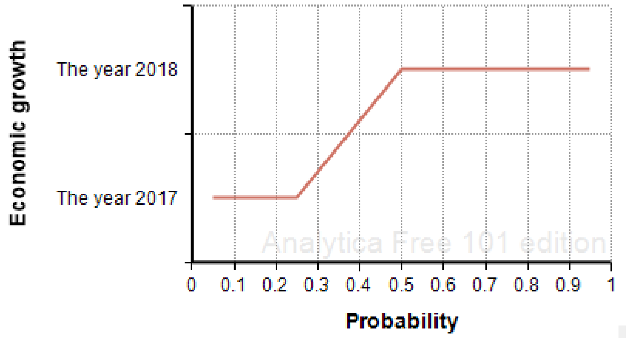

Fig. 5 Probability of economic grows in Eforie Nord

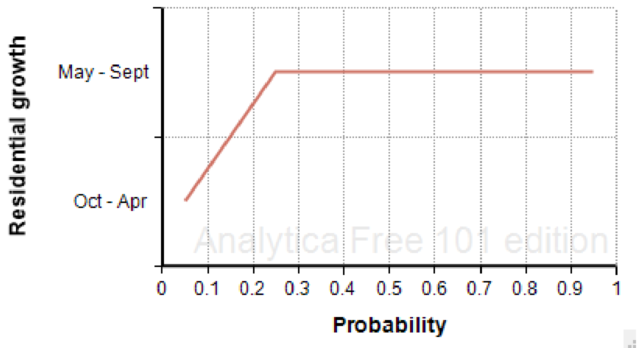

Fig. 6 Probability of residential grows in Eforie Nord

If during the cold season (October - April) the volume of water billed is about 41000 mc per month, during the summer season (May - September) at the level of 2017 it was about 184000 mc per month and it is expected to increase to 2018 up to 200,000 mc per month thanks to the development of the area's tourism In Fig. 7 is represented the main result from Analytica diagram (Fig. 2), respectively from the node Water demand – (necessary).

Fig.7 Evolution of water demand in Eforie Nord

This analysis can allow water operators to understand probabilities and potential impacts on water resources. It can be used as input to analyse water storage emergency procedures, to create a new water allocation process and monitorise in real-time water resources conditions.

5. Conclusions

We need to treat risk assessment as a preventive management to ensure safe drinking water quality and quantity, taking into account the following main elements:

- Evaluation of the management system,
- Establishing as the primary objective of user health concerns,
- Operational phased monitoring, from raw water extraction to the distribution of drinking water to users, control measures (security actions) established,
- Elaborating, documenting, communicating and periodically reviewing management system monitoring plans, risk assessment plans, describing actions, measures to be taken under normal operating conditions and potential incidents, including upgrading and improving.

By developing and following compliance with a risk assessment plan, it is ensured that distributed drinking water complies with the legal requirements in force.

Control measures (Security actions) must have a clearly defined monitoring regime that validates efficiency and monitors performance against established limits. Following periodic evaluations, non-compliance reports should be initiated, and take corrective action to eliminate the causes of non-compliance. Operational monitoring actions are carried out on planned intervals and on time of planned or unplanned changes to the water supply system.

Developing a risk assessment plan is not an end of itself but a means for a goal. A risk assessment plan is only useful if it is implemented, monitored and reviewed periodically. [10]

R E F E R E N C E S

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