Planning risk management in case of a drinkable water tank facility operation

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Abstract. The continued assurance of the needs of drinking water and the proper quality is vital for ensuring good living conditions. As a result of this idea, the risk analysis of the technological process of providing drinking water in the case of water tanks and the creation of a risk management plan and its permanent pursuit can lead to a more efficient process. Water tanks are high importance facilities for communities and during their lifecycle, there are a lot of uncertainties that can occur and affect it. In order to have an efficient and correct facility management during the functioning period, performing a risk analysis of these events is mandatory for this kind of constructions. Creating a good risk management plan and keep following it during the objective lifetime keeps the qualitative indicators of the water into planned parameters and the low costs.

1. Introduction
In the case of special structures, such as water tanks, in order to obtain quality constructions, the achievement and maintenance of fundamental requirements (according to Law 10/1995) shall be compulsory fulfilled and maintained for the entire period of operation of the construction, as follows: Mechanical strength and stability; Fire safety; Hygiene, health and the environment; Safety and accessibility in service; Energy saving and thermal insulation; Sustainable use of natural resources [1]. Compliance with these requirements leads to the establishment of the quality assurance system. The quality system in construction is the ensemble of organizational structures, responsibilities, regulations, procedures and means, which competes in the realization of the quality of construction at all stages of conception, realization, exploitation and its post-using.

To this end, the quality system shall lead to the achievement and exploitation of appropriate quality constructions and shall be applied differently depending on the categories of building importance. An important component of quality management is risk management.

The risk is the “effect of uncertainty on objectives”, according to ISO 31000 [2]. Its effect can have a positive or negative deviation from what is expected.

A centralised public system exploiting a water source is a major responsibility that has implications for public health and safety in densely populated urban areas. Nowadays, drinking water is an absolute
necessity not only for consumption, sanitation, fire extinguishing, but also for industrial processes. The centralized water supply system consists in capturing and bringing water from the source, pumping stations, treatment stations, storage tanks (for creating an emergency reserve and the volume necessary to compensate for consumption variations) and the water distribution system to consumers.

Finding a sufficient source of water to be safely exploited and then distributed to consumers (with almost no interruption) requires reliable infrastructure.

In the period 1955 ÷ 1990, many water supply systems (capture and distribution networks, pumping stations, treatment stations, reservoirs, installations) have been executed in Romania, and which are currently at the end of the normed service period.

Water tanks are high importance facilities for communities and during their lifecycle, there are a lot of uncertainties that can occur and affect it. In order to have an efficient and correct facility management during the functioning period, performing a risk analysis of these events is mandatory for this kind of constructions. Creating a good risk management plan and keep following it during the objective lifetime keep the qualitative indicators of the water into planned parameters and the low costs.

For assuring a good quality of drinkable water, can be used the Stockholm framework, presented by the World Health Organisation conceived for assessment of risk for water-related microbiological hazards (figure 1).

![Figure 1](image_url)

**Figure 1.** Simplified representation of the Stockholm Framework (WHO2001) [3].

2. **Risk Management Processes**

According to PMI Practice Standard Project Risk Management [4] and PMBok 6th edition [7] the processes required to create a proper risk management for any project/structure.

a. **Plan risk management** is the process where are defined the scope and objectives of the risk management process. During this process are analysed historical data (in order to find previous risks and their data in similar structures), standards and documentation (to establish the parameters to measure and their acceptance level), tolerability criteria of the business to risks.

b. **Identify risks** is the process of identifying risks and the sources of risk and also documenting their characteristics; It is identified from the design, execution and, in particular, the exploitation phase, of the structure, as well as from the experience gained from the exploitation of similar structures.

c. **Qualitative analysis:** in the process where the risks are evaluated by the probability and impact and are ranked through risk index:

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\text{Risk index} = \frac{\text{expected loss/gain impact from an event}}{\text{probability of the event occurring}}
\]

It is well known that the first 20% of causes can determine 80% effects (according to Pareto principle)
so, it is important to analyse and find actions to avoid or mitigate it.

d. **Quantitative analysis** is the process of numerically analysing the combinations of effects of the identified risks and other sources of uncertainties.

e. **Plan risk responses**: Proposal for minimisation and/or avoidance/transfer of the identified risks and their possible effects, assign the risk owners (the persons that are accountable for any risk).

f. **Implement risk responses** is the process that follows the agreed-upon planned actions, only in case of risk occur.

g. **Monitor risks** is the process that tracks the identified risks, monitoring the agreed-upon risk responses, identifying and analysing new risks and if that risk process is efficient.

### 3. Case study

In Moldavian region of Romania, there is an important number of drinkable water tanks that due to lengthy exploitation and lack of a time-monitoring programme, in conjunction with the lack of maintenance/repair work (generated by minimum funds) has resulted in a significant decrease in sustainability characteristics.

For an appropriate risk analysis, a water tank was proposed as a case study. The analysed construction is an overland water reservoir (figure 2) made of pre-stressed concrete, having 5000 m³ capacity. The construction was executed in the ‘80 and is still in operation, ensuring the water needs for the municipality of the Nicolina district of Iasi (RO).

![Figure 2. Water tank - Miroslava, Iași county.](image)

The water tank has a cylindrical shape, with an inner radius of 13.85 m and a useful height of 8.05 m. Inside there is a central reinforced concrete pillar with dimensions of 70×70 cm, supported by a continuous foundation (C18/22.5), with an upper chapter.

The wall of the tank is made up of prefabricated elements (C 25/30) of 17 cm thick, with a post-tensioned rub on the outside. At the top of the wall was made a reinforced concrete belt with 28 × 20 cm dimensions.

At the top, the tank was closed with prefabricated T-shaped roof elements (C 25/30), radially laid-down, supporting one end on the top of the wall and the other on the central pillar.

During the operation of the structure were carried out maintenance and repair work on the inside of the circular wall of the tank to diminish the corrosion process of the reinforcement. On the outside, periodic waterproofing works were carried out on the roof due to water infiltrations. The building also supported the effects of earthquakes during the exploitation period [9].

The list of the identified risks:

a. **Physical security** – operational risk in drinking water production: These risks could occur due to several unpredictable or accidental actions (like fire, blast, earthquake, containment loss, landslides), but could be avoided by a good structure’s protection (from designing and execution stages) and by positioning as an isolated structure (as is possible far from populated areas).

b. **Supplying water quality** – is given by the water treatment stations, were the procedures to improve
the water quality (exploited from natural sources) are applied in order to achieve the quality exigencies for drinkable water (standards requirements)

c. Resulted drinking water quality – Water must be checked under the microbial, chemical, radiological and acceptability aspects [3]. If the water does not qualitatively correspond to the requirements, it must be treated. The water treatment process is carried out using a complex set of structures and installations designed to improve qualitative parameters. In Romania, the most used method of water treatment is made by chlorination, for technical and economic reasons. Water chlorination (figure 3) [8] is carried out through various processes (additives with normed chlorine doses and over-chlorination with increasing chlorine dose), and this method applies to both centralized and local water supply systems. [5, 6]

Figure 3. Chart of the water treatment procedure by chlorination
1. Pumping raw water; 2. Pre-chlorination; 3. Coagulation/flocculation; 4. Decantation; 5. Pumping process; 6. Filtering on multi-layer quartz layers; 7. Filtration on active charcoal layer; 8. Post-chlorination.

d. Overflow/overfill – is a minimal risk, due to the sensor network which monitors 24/24 the water volume in the water tank, and also due to the procedure that imposes that the upper liquid level never success a safety level (figure 4).

Figure 4. Water tank section.
Blue zone – water; Red zone – air (safety level)

e. Piping / fitting failure – is a risk which could occur, but is a minimum one due to the permanent monitors’ activities (daily) and of the replacement services (stored in a nearby storehouse);

f. Internal / external corrosion
3.1 Internal corrosion action
It is caused by the attack of chlorine ions contained in water stored in the reservoir. The most common form of attack on the intimate structure of concrete is the action of chlorine in the treated water, the speed of the corrosion process being influenced by operating conditions, temperature, humidity, etc.

During the corrosion process produced by chlorine ions, the passive layer on the surface of the reinforcement is destroyed. Since the anodic area is reduced and the surface of the catheter is expanded over the entire surface of the reinforcement, there is a substantial reduction in the section of the reinforcement.

Due to the constant exploitation of the water tank, the operating environment promotes the triggering and evolution in various manners of the reinforcement corrosion in the structural elements (figure 5), thereby reducing the durability of the construction.

![Figure 5. Internal corrosion effects (degraded reinforcements).](image)

3.2 External corrosion action
At the wall’s bottom, the accelerated corrosion process of the post-stressed reinforcement (figure 6.a.) was caused by the continuous infiltration of the water resulting from precipitation and the detachment of the torch due to excessive moisture at the base (figure 6.b.), as well as the succession of frost-thaw cycles.

![Figure 6. Degradations at the tank wall’s bottom.](image)

In the case of post-stressed reinforcement, there was no need to carry out further tests to determine mechanical characteristics, as it was found during the visual inspection that it was significantly affected by the process of necessary to replace it completely.

On the outside, at the top of the perimeter wall of the tank was observed the corrosion of the reinforcement and, in some cases, the rupture of the post-stressed reinforcement (figure 7 a.) and the detachment of the torch on large surfaces (figure 7 b.).
a. **Structural failure**

Due to the action of aggressive environmental agents (water infiltrations resulting from precipitation, freeze-thaw cycles, acid rains, strong winds, etc.), degradation processes have been amplified over the last 5 years.

On the outside of the roof elements, the interaction with aggressive environmental agents (solar radiation, water infiltration, vapor exchange), coupled with some execution errors (waterproofing works), led to the amplification of the process of degradation (figure 8).

![Figure 7. Degradations at the tank wall’s upper zones.](image)

b. **Alarm failure**

Whereas most water storage constructions have an advanced state of degradation as a result of particular operating conditions (chemical aggressiveness environments, high humidity, technological processes, etc.), it is often necessary to provide maintenance and repairs on construction objectives. The monitoring of functional parameters shall be intermittent and may be included in an automated system together with other constructions and installations.

The operation of these water storage structures cannot be achieved without strict and permanent supervision. To this end, it is necessary to investigate and verify the structural elements, as well as the precise determination of the functional parameters and processes of the hydrotechnical structure and installations, in respect to the compliance with the safety criterion in the exploitation of drinkable water tanks.

c. **Impact to the business and financial penalties** – in case of occurring of an uncertainty event in water tank functioning this can affect the community and can’t assure the needed water capacity.

d. **Loss of equipment use / inventory** – failure of equipment used; represent a medium risk due to possibility to damage of the water tank’s services, which may result in periods of stopping the water supply (in case of repair necessity).

e. **Natural resource damages** – It may be possible only in the event of a miss-operation during exploitation of a water source, in which case can be hypothetically infested at the source. An
impossible risk due to the automation and processes specific to the operation that does not allow
the double-sense circuit (source → station and stations → source) but only one way (source → station).

f. **Criminal penalties** – in the event of a break-in, an attempt to destroy the facilities of a drinking
water tank or, even, the attempted infestation of the stored liquid is severely penalised by the laws
being considered by the jurisprudence of serious offenses. However, in practice, it is considered a
minor risk because these objectives (drinking water tanks) are considered the objectives of strategic
importance and are equipped with security and alarm devices, according to the laws of protection
for the particular importance objectives.

g. **Loss of life** – possible risk, which may occur only in the case of non-conform operation of existing
automation (very low risk) or possible workmanship accidents (falls from height, non-insurance,
lack of protection for dangerous manipulation, access to prohibited places, etc.)

### 4. Risk assessment matrix

The qualitative risk assessment is made using the risk matrix, for the classification of risks.

One of the versions of the risk matrix is the one based on the probability of producing the risk and
the impact of that risk in the event of its occurrence (in terms of the expenses necessary to solve the
consequences).

The estimation of the probability and the impact of the risk in the case of the realization of the risk
matrix is subjective and is usually performed based on an internal scale of the organization. The
organization establishes what each level of probability or impact represents based on the information
found in the database created from the previous works of the company.

In the proposed case study, the possible risks were evaluated in terms of probability and impact and it
was realised the risk matrix, as follows:

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| Probability   | Impact          | Risk  |
|---------------|-----------------|-------|
| 5 very high   | 1 no            | R.a.1 |
| 4 high        | R.a.2           | R.a.2 |
| 3 medium      | R.a.3           | R.a.3 |
| 2 low         | R.a.4           | R.a.4 |
| 1 very low    | R.a.5           | R.a.5 |
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- R.a.1 fire
- R.a.2 blast
- R.a.3 earthquake
- R.a.4 containment loss
- R.a.5 land slides
- R.b. supplying water quality
- R.c. resulted drinking water quality
- R.d. overflow/overfill
- R.e. piping / fitting failure
- R.f.1 internal corrosion
- R.f.2 external corrosion
- R.g. structural failure
- R.h - alarm failure
- R.i. impact to the business and financial penalties
- R.j. loss of equipment use/inventory
- R.k. natural resource damages
- R.l. criminal penalties
- R.m. loss of life
In the studied case, the interpretation of the risk matrix it turns out that there are no risks in the red zone, which means that there is no high risk in our analysis, in the functioning of the water basin. In the area of medium risk, we have the risks of an earthquake, of a landslide, of corrosion, both internal and external, nonconforming quality of water, supplying or resulted from the tank, containment loss from the tank and structural failure of it. All risks need to be monitored throughout the operating period of the water tank, as the status of each risk can be changed at any time.

5. Final remarks
The Risk Assessment Matrix analysis can conclude that:

- here are no risks in the critical area (red zone);
- there are current risks (yellow zone) that need to be managed by planning the responses corresponding to the risks assessed and also, constantly monitored;
- there have been identified as lower index risks (green zone), which has to be monitored.

Creating a strategy to assure a good function of water pump & treatment stations, water transportation systems and water deposits (drinkable water tanks) it is of vital local and national importance for ensuring the health of the population.

The continued assurance of the needs of drinking water and the proper quality is vital for ensuring good living conditions. So that the risk analysis of the technological process of providing drinking water in the case of water tanks and the creation of a risk management plan and its permanent pursuit can lead to a more efficient process.

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