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# The Assessment of the Technical Condition of the Water Distribution Systems

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**Abstract**

The paper deals with auditing the technical condition of the Water Distribution Systems (WDS) and its individual elements. The paper presents the methodology of determining the operating and technical indicators (TI) for a preliminary assessment of the technical elements of WDS (pumping stations, water tanks, transmission mains, water distribution networks) and its implementation in two pumping stations, the necessary data and system of TI evaluation using the multi-objective optimisation and FMEA method. The proposed methodology allows the selection and ranking of WDS critical elements for more detailed analysis and suggestions for the type of renewal, including the expected financial costs.



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*Keywords:* water infrastructure; asset management; technical audit; renewal

## 1. Introduction

The fundamental precondition for sustainable development of water infrastructure is its planned and continuous renewal. There is a number of methods and computer programmes available to support the water infrastructure renewal planning. These tools usually strive to estimate the future condition of the network; however, they only focus on planning the renewal and selection of rehabilitation technologies for the water supply mains. However, water infrastructure is not only made up of water mains. It is always a comprehensive system consisting of at least some of the following elements: raw water intake structures, raw water conduits, water treatment plants, pumping stations, water tanks, transmission mains, water distribution networks, etc. Comprehensive knowledge of the

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technical condition of the entire system should be in the best interest of each water supply system owner. This expertise and knowledge should serve as the basis for decision making on investment projects and water mains renewal planning.

The ageing water infrastructure has become a global issue. It is estimated [2] that over the next 20 years the investments required by the water infrastructure in the USA will amount to USD 77b. Furthermore, over the next 15 years, investments in the water supply systems in Canada will total USD 12.5b. It is also started [1] that 59 % of the Canadian water supply systems are in need of repairs and a total of 43 % of these systems is in a poor condition. In the Czech Republic, the renewal of the water of infrastructure calls for approx. CZK 16b every year [3]. Good knowledge of the technical condition of the water infrastructure is crucial to predict the performance of the water supply systems and optimise their maintenance and renewal. It is a standard practice to build only on practical experience to assess the condition of the water distribution system as there is no standardised evaluation scale to be employed in order to measure the technical condition of the water supply system [2]. Efficient evaluation of the technical condition calls for the deployment of a number of specialised staff, reliable databases, a great deal of time and equipment. Therefore, it is advisable to first carry out a fast efficient audit of the technical condition and then take a decision on whether it is necessary to undertake a more detailed assessment [4]. The proposed methodology presented in this article should serve as a tool for such a preliminary technical audit.

### *1.1. Legislative requirements in the Czech Republic*

The principal legal document governing water supply and sewer systems in the Czech Republic is Act No. 274/2001 Sb. on Water Supply and Sewer Systems imposing a duty on the owner of the WDS to develop and implement the water distribution system renewal financing plans. Requirements for these renewal financing plans are stipulated in Decree No. 428/2001 Sb. Annex No. 18 to this Decree provides the template of such a financial plan. The instructions for filling in the form are only defined as follows: „*The owner shall at its own discretion determine the deterioration rate for the specific group of selected data related to assets records or items. Determining the deterioration of a larger system is carried out on the basis of a weighted average based on the present value. The method of determining the rate of determination shall be described in the commentary as per item 8. The percentage expresses the condition which may also be derived from the service life duration according to §30 and 31of Act No. 586/1992 Sb., on Corporate Income Tax, as amended, taking into account other aspects, too, such as traffic load, surfaces and materials. The assessment may also be expressed as the result of impairment*".

The legislation of the Czech Republic does stipulate the duty to develop and implement the renewal financing plans related to water supply and sewer systems but this only concerns plans related to funds to be allocated for the renewal determined according to the percentage of assets impairment. The legislation does not set out any procedure for determining the percentage of impairment and leaves it up to the owner of the water supply system to decide on in what way it will be determined. On the contrary, Slovak legislation defines a simple method of assessing the technical condition of structures and equipment based on selected indicators (age, burst rate, capacity utilisation rate and compliance with the applicable law and the criterion according to which the individual civil structures are listed in the renewal plan.

### *1.2. Situation in Czech water utilities*

In the Czech Republic there are more than 5,000 owners (26 of which own 61 % of the water-related assets) and over 2,000 operators (50 of which supplying 90 % of billed water) of the water infrastructure. Therefore, there is a large number of small owners and operators who may face limited possibilities when it comes to the renewal – in particular planning and availability of funds. The questionnaire survey we have conducted [2] shows that even larger companies need not necessarily have good knowledge of the technical condition of their infrastructure. The questionnaire was distributed to 50 largest water and sewerage utilities in terms of the volume of water produced for distribution. These 50 operators account for 90 % of drinking water supplies in the Czech Republic. We received 27 completed questionnaires back (54 %). Almost all the questioned operators (93 %) confirmed having renewal financial plans developed. However, the situation related to the renewal plans themselves. Only as little as 59 % of the utilities have short-term renewal plans in place, and even fewer companies have developed mid-term renewal plans and only

a small share of the contacted utilities have established long-term renewal strategies in the form of long-term renewal plans. More than half of the questioned utilities (59 %) carry out the assessment of the technical condition in certain frequency.

## 2. Employed methodology

The proposal for a uniform conception of a preliminary technical condition audit methodology for the water supply systems is based on the FMEA method. The FMEA (Failure Mode and Effects Analysis) method analyses reliability and makes it possible to determine failures with major consequences affecting the function of the system and its elements. To assess the water supply systems using the FMEA method it is necessary to determine the technical indicators (TI) for the specific drinking water supply subsystems. Determination methods, input data, physical dimension and presentation method are defined for each indicator. Based on the values of these technical indicators the system elements are classified into the following categories:

- **C1 (very good)** – optimal status of the relevant indicator, no measures needed to change the indicator values;
- **C2 (good)** – low level of risk of the relevant TI and no principal measures required;
- **C3 (average)** – average value of the relevant TI, no immediate solution required;
- **C4 (critical)** – critical values of the relevant indicator. Measures to address this condition should be implemented or planned;
- **C5 (non-complying)** – undesirable condition requiring immediate solution if feasible for the operator to achieve better values of the relevant indicator.

Compared to the FMEA method, this approach has been extended by another level - factors. The technical indicators are not assessed directly but for the sake of their more accurate assessment we use factors proposed for the specific indicators. The audit of the relevant element (transmission main, water tank, pumping station etc.) according to the proposed technical indicators is carried out on the basis of assessing the individual factors of each and every technical indicator. Each factor comes with a description of the point ranking method. The summary audit is carried out gradually starting at the lowest level (factors, indicators, parts) using the weighted sum method. The assessment of the individual water supply system elements is conducted in the following steps:

- **1st step**: Assessment of individual factors;
- **2nd step:** Calculation of the individual technical indicators based on the factor assessment;
- **3rd step:** Calculation of the individual parts of the element ( structural condition, technology);
- **4th step:** Calculation of the entire water supply system element assessment.

The audit of the technical condition of the individual elements of the water supply system is a multi-objective assessment. However, we do not strive to look for the optimal alternative (element), but to quantify the technical condition of all elements. The proposed methodology of auditing the technical condition is based on the weighted sum method. This means that each factor, technical indicators as well as their specific parts, are allocated a weight corresponding to their weight index in the conducted assessment.

To define the audit of the technical condition of the assessed water supply system, a division of the methodology into specific modules was proposed for the main elements (subsystems) of the audited system. The audit methodologies are proposed and developed for the following modules:

- **Module 1:** water intake structures;
- **Module 2:** water treatment plants;
- **Module 3:** transmission mains;
- **Module 4:** water tanks;
- **Module 5:** pumping stations;
- **Module 6:** water supply networks;

- **Module 7:**water mains.

The article also presents below an example of a pumping station module – TAPS module (Technical Audit of Pumping Station).

## 3. Methodology of assessing the technical condition of pumping stations – TAPS module

The character of the structure of the water pumping station is based on its division into the structural and technological parts. Technical indicators have been proposed for both parts.

Indicators of the **structural condition** of the pumping station:

- **TS1 Condition of the civil structure**
  The indicator is intended to assess the structural parts that may in particular effect the technology and safety of operation. Factors are used to assess the condition of the roof and ceiling structures, floors, doors and windows and metalwork such as ladders and railings.
- **TS2 Condition of the storage tanks**
  The technical condition of the storage tanks may have an adverse impact on water quality and operation of the pumping station. What is assessed is the condition of the structures, entrance to the tanks, pipes installed in the tanks and ventilation system.
- **TS3 Environment at the Pumping Station (PS)**
  Environment at the PS: unsuitable environment at the PS may contribute to the deteriorated condition of the technology and civil structure or may result in a risk of unauthorised entry or reduced safety of operation.

Indicators of the **condition of technology** at the pumping station:

- **TT1 Condition of pumping units**
  The purpose of the indicator is to assess the condition of the pumps based on indicators that may indicate a deteriorated technical condition or contribute to that. What is assessed is the age of the installed pumps, the maintenance demands and failure rate. Furthermore, attention is paid to characteristics that may indicate a poor technical condition or a failure. These characteristics include excessive noise level, vibrations, water seepage through glands.
- **TT2 Operating characteristics of the pumps**
  The pump as an energy-intensive piece of equipment also needs to be assessed in terms of the operating conditions and el. power consumption.
- **TT3 Condition of technology (except for pumps)**
  Besides the pumps it is also necessary to assess other technological elements of the PS such as pipes, valves, instrumentation, control elements and el. wiring.
- **TT4 Water hammer protection**
  Water hammer protection is an important element of the pumping station. This indicator assesses the risk of water hammer and the method and condition of water hammer protection at the pumping station.

Relevant factors have been proposed for each indicator through which these indicators are assessed. Table 1 shows the general structure of the indicators and their factors including recommended weights (importance of the assessed part, indicator and factor).

An evaluation scale has been proposes for the individual factors. The factors are rated on a scale of 0 - 3 (0 – not rated, 1 – best condition, 3 – worst condition) and the weighted sum covering all the factors of the relevant indicator is used to calculate the score based on which the relevant factor is classified under the relevant assessment category. Table 2 shows an example of the evaluation scale of factor F1- Condition of the roof structure – technical indicator TS1-Condition of the civil structure.

Table 1 Proposed parts, indicators and factors of the module

| Part / indicator / factor | Weight | Part / indicator / factor | Weight |
|---|---|---|---|
| **Structural condition of the PS** | **0,35** | **Condition of technology at the PS** | **0,65** |
| **TS1 – Condition of civil structure** | **0,40** | **TT1 - Condition of pumping units** | **0,30** |
| F1 – Condition of roof structure | 0,20 | F1 – Age of pumping units | 0,35 |
| F2 – Condition of ceiling structure | 0,15 | F2 – Frequency and demands on maintenance | 0,15 |
| F3 – Condition of floors | 0,15 | F3 – Pumping unit failure rate | 0,15 |
| F4 – Condition of walls | 0,15 | F4 - Signs of pump deterioration | 0,20 |
| F5 - Condition of doors and windows | 0,20 | F5 – Pump installation and fixing | 0,15 |
| F6 – Condition of metalwork | 0,15 | **TT2 – Operating characteristics of the pumps** | **0,25** |
| **TS2 – Condition of storage tank** | **0,40** | F1 – Average daily running hours | 0,20 |
| F1 - Condition of roof structure | 0,10 | F2 – El. power specific consumption trend | 0,20 |
| F2 - Condition of ceiling structure | 0,10 | F3 – Working point position | 0,20 |
| F3 – Condition of bottom | 0,20 | F4 – Pump delivery | 0,20 |
| F4 – Condition of walls | 0,20 | F5 – Installed power demand efficiency | 0,20 |
| F5 - Condition of entrance to the tank | 0,15 | **TT3 – Condition of technology** | **0,25** |
| F6 – Condition of pipes | 0,15 | F1 - Condition of PS pipes | 0,10 |
| F7 – Condition of ventilation | 0,10 | F2 - Condition of stop valves and other fittings | 0,30 |
| **TS3 - Environment at the PS** | **0,20** | F3 – Condition of instrumentation | 0,30 |
| F1 – Security | 0,30 | F4 - Pump control method and condition | 0,15 |
| F2 – Condition of ventilation | 0,20 | F5 – Condition of wiring | 0,15 |
| F3 - Condition of heating | 0,20 | **TT4 – Water hammer protection** | **0,20** |
| F4 – Hoisting system | 0,20 | F1 – Type of water hammer protection | 0,40 |
| F5 – Lighting | 0,10 | F2 – Shock occurrence and dampening | 0,60 |

Table 2. Factor 1 evaluation scale – Condition of the roof structure

| **Evaluation scale** | **Grade** |
|---|---|
| Not rated | 0 |
| Condition as new. Roof structure with no defects, or only minor defects, no signs of leakage. | 1 |
| The roof structure is functionally without defects. Minor defects due to the aging materials. | 2 |
| Poor condition. Leakage in the roof structure, structural damage to the civil structure (due to the age of materials, wind, human factors …). | 3 |

## 4. Case studies

The proposed methodology of auditing the technical condition of the pumping stations has been tested in a number of water pumping stations operated in the Czech Republic. The methodology requires a visual inspection of the PS as well as the acquisition of operating data, i.e. data from the control room. The methodology testing has been validated in cooperation with selected water utilities. As an example we provide below two assessments of two selected pumping stations.

Fig. 1 Technology at PS No.1.

### *1.3. Pumping station no. 1*

This PS constructed in 1987 is supplied with water from the supply main DN 200 and delivers water to the water tank via a transmission main DN 250. The flow rate is approx. 17 l/s, the head of delivery is over 200 metres. The pumping station was partly reconstructed (reconstruction of the pipe system) in 1997.

The result of the pumping station assessment is presented in Tab. 3. On a scale of C1 - C5, the pumping station was classified under category C4, i.e. the second worst category. During the reconstruction, the original pumps were kept. These are now outdated, achieving inadequate operating parameters, which has a negative impact on the final assessment.

### *1.4. Pumping station no. 2*

This PS constructed in 1996 is supplied by a gravity main from the water tank by a pipe diameter DN 100 and it pumps water to a water tankvia a transmission mainDN 100. The flow rate is approx. 1.5 l/s, the head of delivery is 70 metres. The result of the pumping station assessment is presented in Tab. 3. The PS was placed under category C3 (average). The assessment was mainly affected by the worse condition of the technology installed at the pumping station.

Fig. 2 Technology at PS No.2

Table 3 Assessment of the technical condition of PS No.1 and PS No.2

| | PS No.1 | PS No.2 |
|---|---|---|
| **General assessment of the PS** | **C4** | **C3** |
| **Structural condition of the PS** | **C2** | **C2** |
| TS1- Condition of the civil structure | **C2** | **C2** |
| TS2- Condition of the storage tank | **N/A** | **C2** |
| TS3- Environment at the PS | **C1** | **C2** |
| **Condition of technology at the PS** | **C4** | **C3** |
| TT1 - Condition of pumping units | **C4** | **C3** |
| TT2 - Operating characteristics of pumps | **C4** | **C3** |
| TT3 - Condition of technology (apart the pumps) | **C1** | **C3** |
| TT4- Water hammer protection | **C3** | **C3** |

## 5. Conclusion

Although the law of the Czech Republic lays down the duty to determine the technical condition of the water infrastructure (rate of deterioration for the purposes of the renewal financial plans - PFO), there is no uniform binding methodology in place for assessing the technical condition of the individual parts of the public water supply systems. In the Czech Republic there are several large water utilities as well as a number of smaller utilities where a lack of qualified staff to perform the assessment of the technical condition is expected. This is where the presented methodology of assessing the technical condition of the water supply systems should be of assistance.

The presented methodology aims to outline a simple but efficient approach to assessing the technical condition of the water infrastructure including specific civil structures such as water tanks and pumping stations. The methodology makes it possible to categorise the technical condition assessment of the individual components of the assessed system.

The outputs of the methodology may serve as the basis for a comparative analysis, repairs planning, renewal planning, development of renewal financial plans required under the water supply and sewer systems act or as supporting data fora detailed structural-technological survey of the individual elements of the assessed system. The presented examples of assessing the technical condition of the water pumping stations indicate the possibility of the methodology to interpret the technical condition of the pumping station, detect its critical points and make a comparison of the assessed pumping stations according to their technical condition. Its disadvantage may lie in its seeming demands on the acquisition and processing of the input data.

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