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MODERN MANAGEMENT OF THE UTILIZATION OF WATER SUPPLY AND SEWAGE DISPOSAL SYSTEMS

As it is known, water supply and sewage disposal systems constitute 60–90% of the value of water supply systems in water supply and sewage disposal enterprises. The process of the utilization of these systems is the longest period in the chain of realization actions (it is preceded by designing and contracting). Hence, a precise evaluation of relations between technical, research, organizational, and economic actions becomes necessary for a rational management of such big assets. The design of integrated management systems and their practical implementation in water supply and sewage disposal enterprises is aimed at increasing the standard of services in the field of the water supply and sewage disposal as well as at simultaneous increasing the capacities of the said enterprises to generate profits necessary for a systematic reconstruction of their assets.

1. INTRODUCTION

The main goal of the present paper was to develop the methods for managing the utilization of water supply and sewage disposal systems. Approaching to such a management from a system point of view and taking account of the role of science and practice in the contemporary utilization of the aforementioned networks shall create advantageous conditions for a rational utilization of such big assets which include the water supply and sewage disposal networks and may encourage a wide group of persons in charge of their utilization to further deepen the knowledge about it. In order to improve the efficiency of utilizing water supply and sewage disposal networks, an ordered system of management implemented in water supply enterprises ought to be established. A proper management of water supply and sewage disposal networks is the most efficient way to ensure an optimal utilization and thus an achievement of positive economic effects for the water supply enterprise.

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2. ANALYSIS OF THE MEANING SCOPE OF BASIC TERMS

The terms "water supply" and "sewage disposal systems" applied in the present paper are not defined either normatively or conventionally. The scope of the meanings of the above terms are connected with such terms as "water supply networks" or "sewage disposal networks". In other words, we have no uniform terminology, because of the customarily used terms in the qualification system of the area considered. Thus, they have to be made more precise for the needs of the present paper.

Many various phrases are applied to determine these terms in the professional bibliography. Their sense is similar, they do not exclude one another, but the semantic range of the phrases is different. It results from the assumptions adopted by the authors of professional literature and publications.

The following terms are the most frequently used in the available literature:

- water supply and sewage disposal networks,
- water supply and sewage disposal systems,
- water supply and sewage disposal units.

There can be also encountered very general terms, including "water supply pipes" or "sewage disposal" in source materials.

An analysis of the bibliography has indicated that "networks" and "systems" are the terms most frequently applied to the water supply and sewage disposal. In the case of the former, the semantic ranges of the terms "water supply networks" and "sewage disposal networks" are too narrow and general, as they contain, e.g., only the distribution or main conduits, while in the case of the latter, the semantic ranges are very wide and they usually cover elements including intakes, water treatment plants, water supply tanks, pumping stations of the 1^{st} and the 2^{nd} degrees, etc.

Because of the presented state of affairs referring to the nomenclature and semantic ranges of the aforementioned terms it has been decided to use the terms "water supply" and "sewage disposal systems". This is justified by the fact that "technical systems" are defined as ordered sets of elements arranged according to certain rules. Hence, water supply and sewage disposal systems have one common feature – each comprises three basic elements, namely:

- main conduits or sewers,
- distribution conduits or secondary canals,
- water intakes and sewers.

A characteristic feature that distinguishes a water supply system from a sewage disposal system is such an order of their elements that they perform their strictly defined tasks (i.e., water supply and sewage disposal).

3. BASES AND ASSUMPTIONS OF THE METHODS OF MANAGEMENT OF THE UTILIZATION OF WATER SUPPLY AND SEWAGE DISPOSAL SYSTEMS

Our basic goal was to develop the method for managing the utilization of water supply and sewage disposal systems based on an integrated know-how in the following scientific areas:

- reliability theory,
- replacement and maintenance theory,
- stock theory,
- mass servicing theory.

An intensive development of the technology observed in the past decade, ongoing changes in the approach to the management and improvement of the organization of work in water supply enterprises, the application of new materials and technologies, and all these against the background of the general restructuring of water supply and sewage disposal enterprises leads to far-reaching consequences in the process of the utilization of water supply and sewage disposal systems. There are first of all high requirements for the standard of the rendered services in the field of the water supply and sewage disposal, and the level of complexity of the said systems increases. The recipients' demands for a shorter and shorter time of breaks in the water supplies, i.e., a more efficient removal of failures or performance of modernization works in water supply and sewage disposal systems, with limited available human resources, or an assurance of the reliability of the functioning of such systems with a simultaneous reduction in utilization costs lead to the necessity of implementing contemporary methods of managing the network resources with some scientific elements.

During development of the methods of managing the utilization of water supply and sewage disposal systems the following assumptions have been taken into consideration:

- an interdisciplinary character of the know-how necessary for solving the aspects connected with the management of the aforementioned systems,
- a system-oriented approach facilitating the ordering of the management system elements, including its relations in the system in such a way that it is maximally effective [1].

4. STRUCTURE OF THE SYSTEM OF MANAGING THE UTILIZATION OF WATER SUPPLY AND SEWAGE DISPOSAL SYSTEMS

The following scientific disciplines are the basis for establishing the system of managing the utilization of water supply and sewage disposal systems:

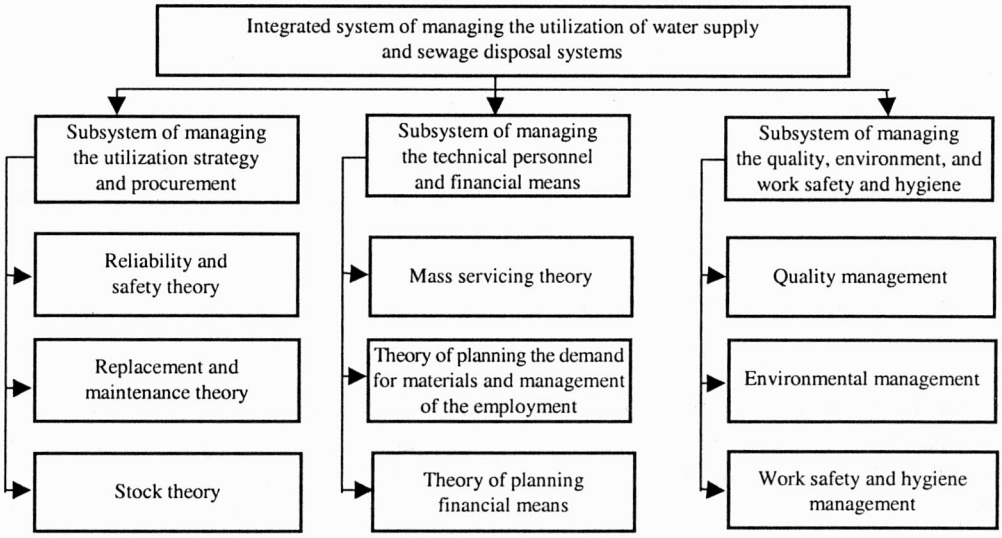

Fig. 1. Block scheme of an integrated system of managing the utilization of water supply and sewage disposal systems

- organization theory,
- functioning reliability and safety theory,
- replacement and maintenance theory,
- stock theory,
- mass servicing theory.

The block scheme of the system of managing the utilization of water supply and sewage disposal systems with individual scientific disciplines is presented in figure 1.

5. ANALYSIS OF THE INTEGRATED SYSTEM OF MANAGING THE UTILIZATION OF WATER SUPPLY AND SEWAGE DISPOSAL SYSTEMS

5.1. SUBSYSTEM OF MANAGING THE UTILIZATION STRATEGY AND PROCUREMENT

Adoption of the reliability theory in the process of the utilization of water supply and sewage disposal systems consists in the evaluation of the reliability of the functioning of the said systems and their elements. This method is based on the design of an appropriate reliability structure of the systems, which should render mutual connections of their elements from the point of view of the reliability of the functioning, i.e., the realization of the tasks assumed.

The reliability structure of the systems is described by the so-called structural function. As far as two-state models of the utilization (the utility and non-utility states) are concerned in reference to the water supply and sewage disposal systems consisting of n elements, the structural function is determined as $\Phi[x(t)]$ function of the zero-one vector $x(t)$ states of systems, assuming that the states are fully determined by the states of their elements $x_i(t)$, namely:

$$\Phi[x(t)] = \Phi[x_1(t), x_2(t), ..., x_n(t)], \tag{1}$$

where $x_i(t)$, $i = 1, 2, \ldots, n$, is the binary function determining the state of the i-th element – it adopts the value of 1 when the element is utile and 0 when it is non-utile. The $\Phi[x(t)]$ function adopts the value 1 when the systems are utile and 0 when they are not utile [2].

Subsystems were selected in the presented simplified scheme of the reliability structures in water supply and sewage disposal systems, whose reliability influences the reliability of the said systems as a whole.

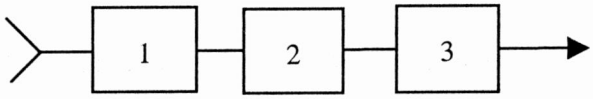

Fig. 2. Scheme of the simplified reliability structure of water supply and sewage disposal systems:
a) for water supply systems: 1 – subsystem of main networks,
2 – subsystem for distribution networks, 3 – subsystem for water supply connections;
b) for sewage disposal systems: 1 – subsystem of collectors,
2 – subsystem of secondary channels, 3 – subsystem of sewers

In the case of water supply and sewage disposal systems consisting of $n = 3$ subsystems with their series reliability structure, the value $K_w(n)$ required for each of them can be determined as $\sqrt[3]{K_w}$. The reliability of the said systems is determined in the following way in terms of the readiness index:

$$K_q = \prod_{i=1}^{3} K_i \cdot K_1 \cdot K_2 \cdot K_3, \tag{2}$$

where:

$i = 1, 2, 3$ – number of elements,

K_1, K_2, K_3 – readiness index of individual subsystems in water supply and sewage disposal systems,

K_w – required value of the readiness index.

From the above relations it is evident that the readiness indexes of water supply and sewage disposal systems of series structures are the products of readiness indexes of their subsystems.

In the process of the utilization of water supply and sewage disposal systems, the results of reliability tests allow us to decide whether their individual elements should be repaired or should be rather replaced (replacement and maintenance theory). Determination of the number of spare parts of subsystems of water supply and sewage disposal networks (stock theory) may be a practical result of the aforementioned tests.

The planning carried out during the process of the utilization of water supply and sewage disposal systems is aimed at preparing utilization tasks and their realization in such a way as to achieve optimal economic results at minimal financial inputs. It also entails the planning of the demand for materials.

Reliability characteristics are the basis for planning the demand for materials and spare parts. The stock in warehouses of utilization units can be checked on the basis of the theoretical equation presented below [4]:

$$\sum_{i=0}^{SM_{\max}} \binom{n}{i} \left(1-\frac{RZ}{n}\right)^{n-1} \left(\frac{RZ}{n}\right)^{i} = SO, \tag{3}$$

where:

$SM_{\max}$ – value of the maximal state of a given item of utilization materials,

$\binom{n}{i} = \frac{n!}{i!(n-i)!}$ – binomial coefficient,

n – number of demand places,

RZ – average demand in terms of the time between orders (pieces),

SO – servicing system.

5.2. SUBSYSTEM OF THE MANAGEMENT OF TECHNICAL PERSONNEL AND FINANCIAL MEANS

Pursuant to the results of utilization tests of the water supply and sewage disposal systems, the number of repair teams in individual subsystems of the aforementioned systems can be calculated based on the mass servicing theory according to the following formula [3]:

$$b = b_{\min} + b_{\text{add.}}, \tag{4}$$

where:

$b_{\min}$ – the number of basic teams (determined as $b > \rho$) with ρ being the MSS (mass servicing system) utilization ratio $\rho = \lambda_{MSS}/\mu_{MSS}$, λ_{MSS} – intensity of the inflow of reports to MSS, μ_{MSS} – intensity of servicing (renovation),

$b_{\text{add.}}$ – number of additional teams on condition that the mass servicing system will have the required reliability K_w.

The planning in the process of the utilization of water supply and sewage disposal systems is aimed at the performance of utilization tasks in such a way as to achieve optimum economic results with minimum financial inputs. It also covers the planning of the demand for materials and employment with its scope.

On the other hand, the employment planning is realized on the basis of utilization tasks with a simultaneously fixed analysis of the current employment state and process capacities. In this scope, the following cases may occur:

$$Z \leq S - N_{ad},$$

$$Z = S - P,$$

$$Z > S - N_{ie},$$

where:

Z – demand for processing capacities,
S – current employment,
N_{ad} – employment surplus,
P – employment,
N_{ie} – lack in servicing.

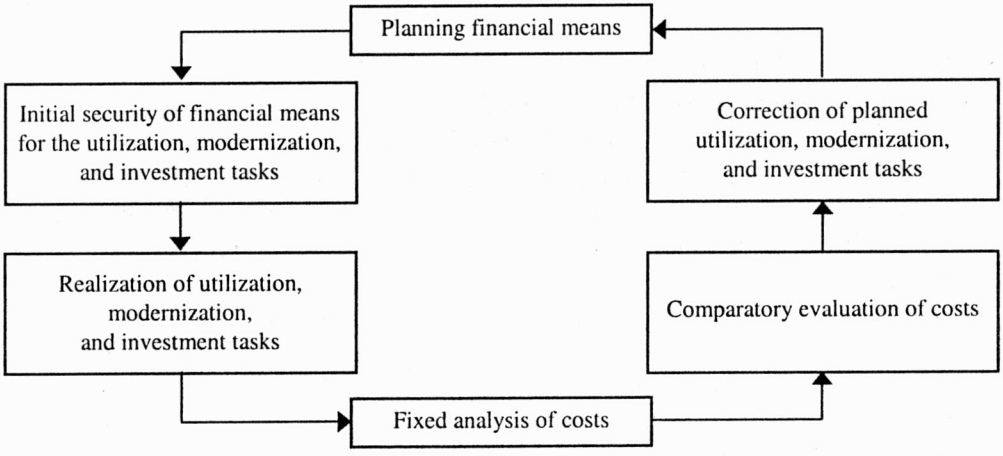

Fig. 3. Idea scheme of the planning, verification, and control of costs

The most important goals of the planning and control of processing capacities in utilization of water supply and sewage disposal systems are the following:

- guaranteeing the realization of the necessary maintenance activities and the functioning of these systems,
- an equal load and utilization of processing capacities,
- assurance of a rational utilization of the servicing personnel,

• guaranteeing an appropriate supervision over the realized tasks to achieve a high utilization efficiency.

The planning of financial means is considered to be the last element of the planning of the utilization of water supply and sewage disposal networks. Generally speaking, it entails the security of appropriate funds for realizing the planned maintenance works. A regular registration, analysis, verification, and control of financial means are the most important actions here. Figure 3 presents a block scheme for the verification and control of costs in the field of the planning of financial means.

Application of the rule of generating profits obligatory in the market economy (generally speaking, it is a difference between revenues and costs) appears to be a basic element in water supply and sewage disposal enterprises. Hence, the financial management is aimed at ensuring a good financial condition of water supply and sewage disposal enterprises and at organizing a correct functioning of the financial and managerial accountancy.

5.3. ANALYSIS OF THE MANAGEMENT SUBSYSTEM OF THE QUALITY, ENVIRONMENTAL AND OCCUPATIONAL SAFETY

It becomes indispensable at the present moment to implement management systems in the processes of the utilization of water supply and sewage disposal systems. The systems are as follows:

• quality management according to ISO 9000,

• environmental management according to ISO 14000,

• work hygiene and safety management according to PN 18001 [5].

The construction and implementation of the said management systems in the process of the utilization of water supply and sewage disposal systems can be made in several ways, namely by:

• construction of a complex system covering all aforementioned management elements,

• construction of individual management systems and their gradual integration,

• construction of independent management systems covering individual tasks, namely the quality, environment and occupational safety.

The first method is quite difficult and time-consuming, but it has many advantages, including:

• a complex approach to the process of the utilization of water supply and sewage disposal systems in the field of the quality, environment, and occupational safety management,

• a common documentation containing the elements which are necessary for construction of the system,

• smaller inputs.

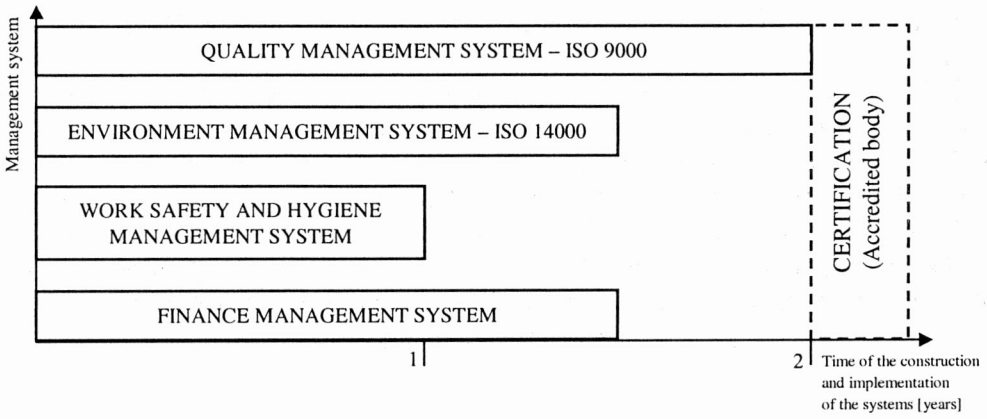

Fig. 4. Graphic illustration of the order of implementing individual management systems of a water supply and sewage disposal enterprise

The second one is the most popular method of construction of separate systems, and then their gradual integration aimed at an optimization of the system on the basis of a strategy of activities of water supply and sewage disposal systems.

The third method entails a construction of the management systems of separate quality, environment, and occupational safety and their integration over a longer period of time. It is a time-consuming, long-lasting method in terms of the final effect, i.e. the integration. However, it creates advantageous conditions for the management of independent systems up to the moment of their optimal co-operation.

The order of the construction and implementation of individual management systems of quality, environment, security, and finances is presented in figure 4.

6. SUMMARY

An introduction of scientific elements into the aspects connected with the management of the utilization of the water supply and sewage disposal systems is very important in terms of their functioning under normal, difficult conditions (internal and external influences upon their functioning). Pursuant to the analysis of the developed method of the management of the utilization of water supply and sewage disposal systems, the following conclusions can be formulated:

1. The presented method of the management from the system point of view facilitates the consideration of the problem as a set of the following subsystems:

- subsystem of the management of the utilization strategy and procurement,
- subsystem of the management of the technical personnel, employment, and financial means,

• subsystem of the management of the quality, environment, and work safety and hygiene.

2. The analysis of the integrated system of the management of the utilization of water supply and sewage disposal systems performed herein proves that the consideration of the structure of the construction of individual subsystems and goals that the system should achieve are the basis for its implementation.

3. Pursuant to the above considerations it can be stated that there has been developed a general, applicable method for the management of the utilization of water supply and sewage disposal systems that facilitates a rational management of network resources of water supply and sewage disposal enterprises.

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Jak wiadomo, układy wodociągowe i kanalizacyjne stanowią od 60% do 90% wartości systemów zaopatrzenia w wodę przedsiębiorstw wodociągowo-kanalizacyjnych. Proces eksploatacji tych układów jest najdłuższym okresem w łańcuchu działań realizacyjnych (poprzedzony projektowaniem i wykonawstwem). Dlatego też, aby racjonalnie gospodarować tak dużym majątkiem, należy dokładnie ocenić relacje między działaniami technicznymi, badawczymi, organizacyjnymi i ekonomicznymi. Tworzenie i wprowadzanie do praktyki eksploatacyjnej przedsiębiorstw wodociągowo-kanalizacyjnych zintegrowanych systemów zarządzania eksploatacją układów wodociągowych i kanalizacyjnych ma na celu podniesienie standardu usług w zakresie dostawy wody i odprowadzania ścieków i jednocześnie zwiększenie zdolności wspomnianych przedsiębiorstw do generowania zysków niezbędnych do systematycznego odtworzenia ich majątku.