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METHODOLOGICAL PRINCIPLES FOR INFORMATIONAL AND TECHNOLOGICAL MONITORING OF THE STABLE OPERATION OF THE SEWERAGE NETWORKS

Monograph

Kharkiv
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The monograph has scientifically grounded and concluded its conclusions, directed at the top of the problem of the improvement of the exploitation of the longevity of the underground engineering measures of the sewerage state, which protect their constructive solutions, wash the operation of the technical station. The features of the repair and maintenance work on the working and hourly maintenance of the exploitation of the subdivisions and collectors are examined, which will ensure the minimum safety of the work with the possible minimization of the costs during the entry. Presented is an overview of materials, structures, machines and installations, which are required during repairs and renovation of pipelines, water supply and water supply. Introduced technical, technological and organizational solutions that improve the exploitation of the underground engineering facilities of the water supply and sewerage state. The information system for assessing the sustainability of the operation of engineering measures on the basis of indicative assessments has been developed.

The monograph is recognized to engineers, designers, who are responsible for repairs and installation of water supply lines and water supply lines. It may be worthwhile for graduate students and students of everyday specialties.

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INTRODUCTION

Extending the service life and ensuring the stable operation of sewerage networks and public utility facilities in Ukraine is the main issue to be addressed by operating companies in the context of reforming the housing and utility service system. Operating condition diagnostics and accident occurrence statistics show that the sewerage distribution system structures go out of working order before the end of the standard service life. The accident rate for sewerage networks and facilities in Ukraine is ten times higher than that in Europe, which is unacceptable in terms of the efficiency of their operation and material costs.

Investigations of the operating conditions of the sewerage networks and facilities shows that most accidents are due to corrosive processes, which amounts to about 80 to 90 % of the total number of accidents. Chemical reactions that occur in the free space of the sewer network form a corrosive environment towards the network's structures. The accident impact assessment indicates the environmental, economic and technical losses for the operating company and the population. The environmental component of the operation of the sewerage networks and facilities must be implemented in accordance with the current regulations of the European Union; however, hydrogen sulfide emissions to the atmospheric air during accidents exceeds the standard values, which is unacceptable under the European environmental requirements. The economic component of ensuring the efficient operation of utility networks and sewerage facilities imposes some material obligations on sewerage utility companies under conditions of insufficient funding for the industry.

The international environmental treaty known as the United Nations Framework Convention on Climate Change (UNFCCC, United Nations Framework Convention) to which Ukraine is a signatory is today in force. The primary objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the Earth's climate. These postulates must not be neglected when it comes to operating sewerage networks and facilities on the verge of emergency serviceability in the framework of of Ukraine's European integration.

To date, there is virtually no planned approach to determining the stable operation of the sewerage networks and facilities. An actual occurrence of an accident rather than its forecasting leads to the loss of the balance of serviceability and spot repair and remediation. The above approach to rehabilitation work results in material and technical losses of public utility services and as a result in the negative impact on the environmental and social components.

Therefore, this raises a sensitive issue of addressing a relevant scientific problem related to the methodological justification and development of a system of organizational and technological monitoring for the stable operation of the sewerage networks and facilities. This system should take into consideration the groups of indices that allow assessing the stable operation of the system as a whole at all stages of its life cycle and forecasting the performance of the sewerage networks and facilities in the future. As a result, an important outcome of implementing the monitoring system is that an operating company achieves economic, environmental, and social effects.

CHAPTER 1

REVIEWING CONSTRUCTION AND ORGANIZATIONAL AND TECHNOLOGICAL SOLUTIONS FOR THE SEWERAGE NETWORKS AND FACILITIES

1.1. Construction Solutions and Essential Requirements for Sewerage Networks and Facilities According to the Existing Building Regulations

An urban wastewater system is a sewerage system comprising a complex of sewerage networks and engineering structures for the collection and treatment of wastewater, the processing of waste from these structures and disposal of treated water into water bodies [1–3].

As stated in the regulatory document below, the structural designs, materials and equipment to be accepted must provide efficiency and effectiveness, reliability, durability and trouble-free operation of the sewerage networks and facilities during the estimated period of their operation [205–210].

The steady and reliable operation of the sewerage networks and facilities is determined by the consistency of receiving the estimated amount of wastewater, ensuring the degree of wastewater treatment and conditions of discharge into water bodies in normal and extreme conditions [205]. In case the operation of the sewer system or its individual elements cannot be shut down, measures must be taken to ensure their uninterrupted operation [205] (Table 1.1).

An urban sewerage system is a sophisticated engineering complex that dates back to antiquity. Wastewater disposal systems built in 2500 BC were discovered during the excavations in Egypt [81]. Similar structures had existed earlier in India. In the VI century BC in Rome, the Cloaca Maxima, a famous canal, was built, which is now partially used as part of the modern sewerage system in Rome. These structures required significant labor and material costs and mandatory water supply. In the XIX century Europe proceeded to actively build wastewater disposal systems. England was intensively developing the manufacturing sector; there was urban growth, as evidenced by the presence of a wastewater disposal system at the time of 1833 in more than 50 urban communities. The construction of the centralized sewerage system in Germany began later; it appeared in Hamburg in 1843, in Szczecin in 1862, in 1867 Frankfurt am Main, in 1873 in Berlin, etc. [47]. Sewerage in French urban communities developed slowly, although sewerage in Paris itself began in the second half of the 14th century. The building of sewerage systems in the US cities and towns was progressing more rapidly: by 1902, about 1,000 cities and towns had been sewered [32].

Table 1.1 — Measures to ensure the uninterrupted operation of the sewerage networks and facilities

Item No.	Measures
1	Providing reliable electric power supply (using two independent power supply sources, a standby stand-alone power plant, batteries, etc.)
2	Providing redundancy of utilities, designing switches, bypasses, bypass lines, etc.
3	Designing emergency reservoirs with their subsequent emptying when operating in normal mode
4	Sectioning the facilities operating in parallel with a number of sections to provide the necessary capacity without reducing the efficiency of wastewater treatment when disabling one section for repair or emergency work
5	Providing necessary redundancy of working equipment
6	Forecasting potential accidents and designing measures

In the period of the origin of wastewater dsposal systems, clay and wood served as materials for water pipelines (Figs. 1.1, 1.2) [79]. Later, with the development of civilization, stone materials, brick (Fig. 1.3), copper, lead, iron, reinforced concrete (Fig. 1.4), steel, and with the development of organic chemistry polymeric materials (Fig. 1.5) began to be used. Cast iron and forged iron pipes have been known to be used in Europe since the 15th century; In the 18th century, the first steel pipes appeared; they were made using forge welding, or the pipes were joined together with butt joints [205]. The evolution of the use of materials for making sewer pipes is shown in Fig. 1.6.

Since the sewer system includes facilities varying in engineering complexity and number, the dissertation research considers the sewerage networks and structures to be sewer networks, sewers, tunnels, inspection chambers, stilling chambers and pit shafts.

Closed and open inverts, channels of various shapes and cross-sectional areas are used for wastewater conveyance (Fig. 1.7) [21, 205].

Table 1.2 — Pipes for sewer pipelines

Item No.	System	Pipes
1	Gravity sewer system	Free-flow, reinforced concrete, concrete, ceramic, cast iron, asbestos-cement, plastic pipes and other pipes made of corrosion-abrasive-resistant materials or lined with the above materials. Free-flow, asbestos-cement, reinforced concrete and concrete pipes, tunnels, inverts must be protected from gas and biological corrosion. Methods of protection against gas and biological corrosion, including composite concrete compositions, materials, and so on are required [77, 95, 8]
2	Pressure sewer system	Pressure, reinforced concrete, asbestos-cement, cast iron, steel and plastic pipes and other pipes from corrosion-abrasion-resistant materials or with an internal protective lining made of the above materials. Steel pipelines must be protected externally with corrosion-resistant insulation. Cathodic protection of pipelines should be provided in areas of possible electrocorrosion

Table 1.3 — Design standards for inspection chambers

Item No.	Design	Standards
1	The working part of the chamber	Steps or hinged ladders (portable or stationary) should be arranged to descent into the inspection chamber; with a height of the working part of more than 1.500 mm, 1.000 mm high guardrails of the working platform should be provided. Steps, hinged ladders, and guardrails should be designed from corrosion-resistant materials
2	The neck of the chamber	The neck of the chamber should be at least 700 mm in diameter. The dimensions of the neck and working part of the chambers in the turning sections, and in the straight sections of pipelines with a diameter of 600 mm and more, located at distances from 300 m to 500 m, should be adequate to lower network cleaning tools
3	The design of the inspection chamber	The design should provide the operating conditions with regard to the load from general-purpose vehicles. For planned and preventive inspection and repair of sewer tunnels during operation, inspection pit shafts of round section (rectangular section is allowed at a depth of no more than 15 m) or holes with a diameter as a rule of no less than 1.5 m should be arranged. The minimum sizes of round and rectangular pit shafts are given in Table 1.5. The distance between the inspection pit shafts or holes should not exceed 500 m

Figure 1.1. A sewer pipe made of clay

Figure 1.2. A sewer pipe made of wood

Figure 1.3. Construction of a brick sewer

According to the current regulations in Ukraine, with regard to local conditions, pipes for sewer pipelines can be used, as shown in Tables 1.2, 1.3 [21, 205].

The design of the inspection chamber should provide the operating conditions with regard to the load from general-purpose vehicles. For planned and preventive inspection and repair of sewer tunnels during operation, inspection pit shafts of round section (rectangular section is allowed at a depth of no more than 15 m) or holes with a diameter as a rule of no less than 1.5 m

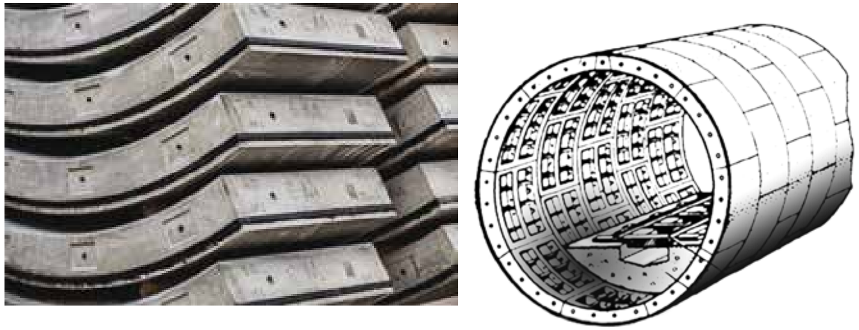


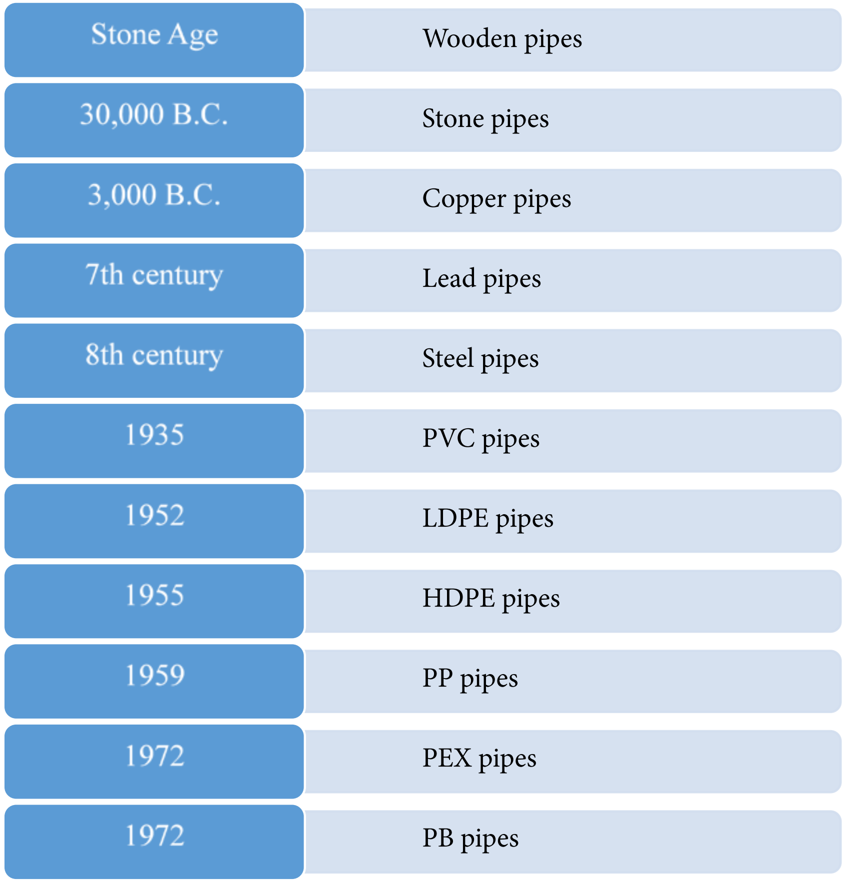
Figure 1.4. A sewer pipe made of reinforced concrete

Figure 1.5. Polyethylene pipes

should be arranged. The distance between the inspection pit shafts or holes should not exceed 500 m (Table 1.4) [21, 205]. The minimum sizes of the inspection pit shafts in the plan are given in Table 1.5.

Work platforms and removable shields for emergency and repair work should be provided in the inspection pit shafts [21, 205].

The compressive strength design classes of concrete for sewer tunnel structures should be no lower than those specified in Table 1.6 from rock pressure only by primary facing. Secondary cladding is intended for water-



Stone Age	Wooden pipes
30,000 B.C.	Stone pipes
3,000 B.C.	Copper pipes
7th century	Lead pipes
8th century	Steel pipes
1935	PVC pipes
1952	LDPE pipes
1955	HDPE pipes
1959	PP pipes
1972	PEX pipes
1972	PB pipes

Figure 1.6. The evolution of the use of pipes

proofing and is not included in the calculation of the load from rock pressure [21,106, 205].

Sewer lining comprising primary precast lining (blocks or segments) and secondary cast *in situ* concrete or reinforced concrete lining should be designed to withstand the rock pressure load only by the primary lining. The secondary lining is designed for waterproofing purposes and not included in the design calculation of the rock pressure load [21, 106, 205].

Table 1.4 — The distance between the construction of pit shafts, safe entry and exit of personnel

Diameter, m	Distance between the construction pit shafts, m
2.1	550
2.6	750
3.2	150
4.0	2,000

Table 1.5. The minimum sizes of the inspection pit shafts in the plan

Diameter, m	Distance between the construction pit shafts, m
Round pit shafts	
2.1	4.0
2.6	5.5
3.2 and 4.1	7.5
5.2	9.5
Rectangular pit shafts	
2.1	3.5 × 4.0
2.6	4.0 × 5.0
3.2	4.5 × 5.0
4.0	5.5 × 7.0
5.2	6.0 × 7.0

Table 1.6. Compressive strength grade of concrete for structures

Type of structure	Compressive strength grade of concrete, no lower than
Solid or finned reinforced concrete blocks for lining	C25/30
Cast in situ reinforced concrete blocks for lining	C20/25
Cast in situ concrete linings	C12/15
Inner cast in situ concrete and reinforced concrete structures	C12/15
Inner precast reinforced concrete structures	C20/25
Prestressed reinforced concrete structures	C20/25

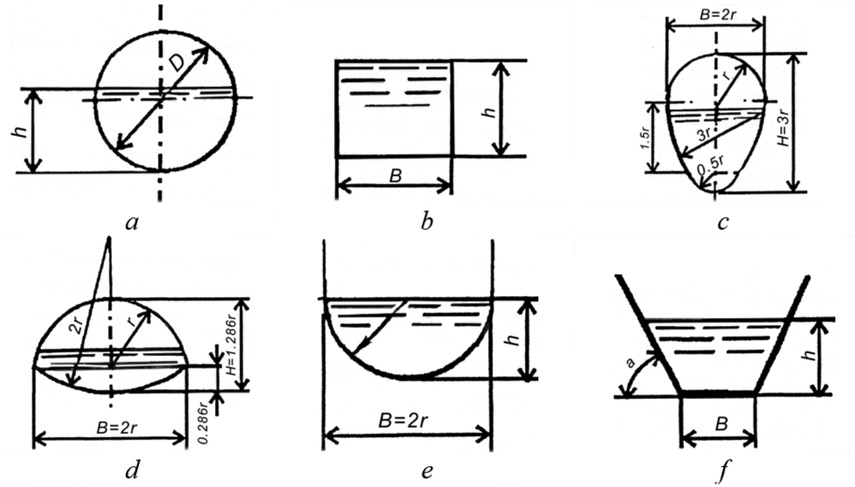


Figure 1.7. The cross-sectional area of sewer pipelines and sewers:
(a) round; (b) rectangular; (c) ovoid or oval;
(d) invert-type; (e) semicircular; (f) trapezoidal [21, 205]

As a rule, the sewer structure lining comprising primary precast lining (blocks or segments) and secondary cast in situ concrete or reinforced concrete lining should be designed to withstand the rock pressure load only by the primary lining. The secondary lining is designed for corrosion protection and waterproofing [21, 205, 317–324].

Concrete for the elements of the sewer tunnel lining structures should be specified by the project depending on the hydro-geological conditions in the area of construction, the potential internal pressure, and with regard to the protection measures for reinforced concrete and concrete structures against corrosion, but not below the grade in terms of water resistance, which is recommended to be W12 to W20 (not below W6). When designing, the freeze-resistance grade of concrete structures of sewer tunnels should be taken depending on the conditions of their operation, but not lower than F75 [21, 125–127, 155–156, 205].

The sewerage networks and facilities should be protected from surface and groundwater infiltration, along with wastewater exfiltration, by the following measures: by using waterproofing materials, by arranging metal insulation, by cementation of the soil mass,by claying, by silicification, etc. [21, 205]. The design of the external and internal waterproofing of the tunnel lining must ensure the structural integrity and watertightness in case of eventual deformations of the lining. The choice of the method to ensure watertightness should be determined by the lining design, engineering and geological and operational conditions [21,106, 205].

1.2. The Current State of the Sewerage Networks and Facilities in Kharkiv

As of July 2020, the total length of wastewater disposal networks in Kharkiv is 1,669.534 km, of which: 341.73 km of main sewers, 55.57 km of deep sewers, 104,112 km of pressure sewers, and 1,168.122 km of street and intrablock sewerage [21, 151, 158]. The review of sewers with a diameter of 600 to 1.500 mm by length, pipeline material, service life and degree of wear and tear is shown in Figs. 1.8 to 1.11, Tables 1.7 to 1.10. It should be noted that nearly 75 % of the total length of sewers are made of reinforced concrete, which were built more than 40 years ago, and the degree of wear and tear of which is more than 75 %.

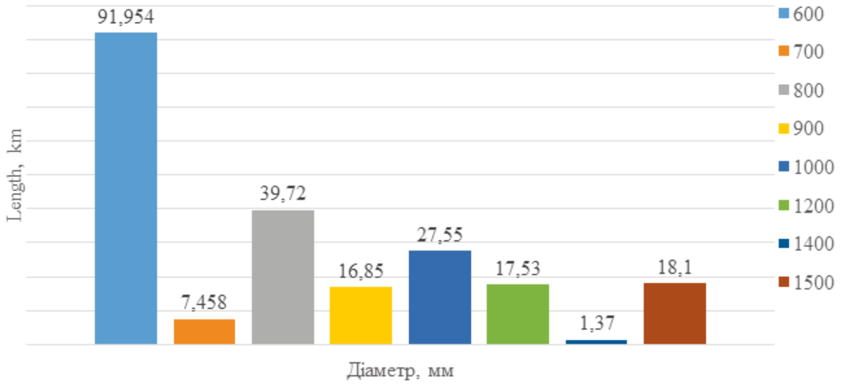


Figure 1.8. The length of sewers by diameter

Table 1.7. Data on the length of external sewerage networks, by pipeline diameters, as of July 01, 2020

Pipe diameter, mm	Length of networks, km
50	0.318
63	0.417
100	12.109
125	2.1
150	685.133
200	445.751
250	48.455
300	105.124
400	32.709
500	66.566
600	91.954
700	7.458
800	39.72
900	16.85
1000	27.55
1200	17.53
1400	1.37
1500	18.1
1840	22.94
2000	6.85
2500	5.1
3000	5.08
3400	8.15
2130*1410	2.20
Total:	**1669.534**
Including diameters up to 600 mm	**1398.682**
Diameters over 600 mm	**270.852**

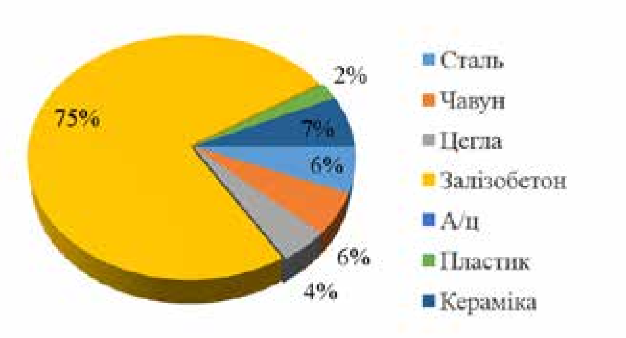


Figure 1.9. Sewers by material type

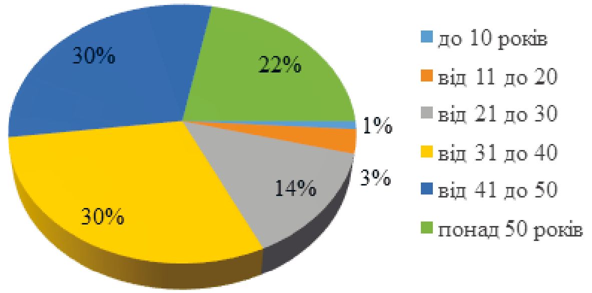


Figure 1.10. Sewers by service life, years

Table 1.8 — Data on the length of external sewerage networks, as of July 01, 2020

Item No.	Description	Length, km
1	Length of networks, in total	1,669.534
	of these, in disrepair	1,335.627
Including:		
1.1	Main sewers	397.3
	of these, in disrepair	317.84
1.2	Street sewer networks	902.556
	of these, in disrepair	722.045
1.3	Intrablock and courtyard sewer networks	369.678
	of these, in disrepair	295.742

Table 1.9 — Distribution of wastewater disposal networks by city districts

Item No.	District	Length, km
1	2	3
1	Shevchenkivskyi District	227.414
	including diameters up to 600 mm	198.612
	diameters over 600 mm	28.802
2	Kyivskyi District	182.825
	including diameters up to 600 mm	161.725
	diameters over 600 mm	21.1
3	Kholodnohirskyi District	164.858
	(including Pisochyn, Podvirki, diameters up to 600 mm)	61.269
	including diameters up to 600 mm	148.728
	diameters over 600 mm	16.13
4	Moskovskyi District	242.048
	including diameters up to 600 mm	206.948
	diameters over 600 mm	35.1
5	Industrialnyi District	153.464
	(including the village of Zatyshye)	0.8
	including diameters up to 600 mm	124.414
	diameters over 600 mm	29.05
6	Nemyshlyanskyi District	113.949
	(including the urban-type settlement of Kulinichi)	9.617
	including diameters up to 600 mm	95.579
	diameters over 600 mm	18.37
7	Slobidskyi District	176.551
	including diameters up to 600 mm	155.131
	diameters over 600 mm	21.42
8	Osnovianskyi District	166.951
	(including Kharkivskyi District, diameters up to 600 mm)	29.57
	including diameters up to 600 mm	147.121
	diameters over 600 mm	19.83
9	Novobavarskyi District	144.650
	including diameters up to 600 mm	131.430
	diameters over 600 mm	13.22
10	DERTK Section	67.83
	Including tunnel sewers	55.57
In total:		1,669.534
Including diameters over 600 mm		270.852

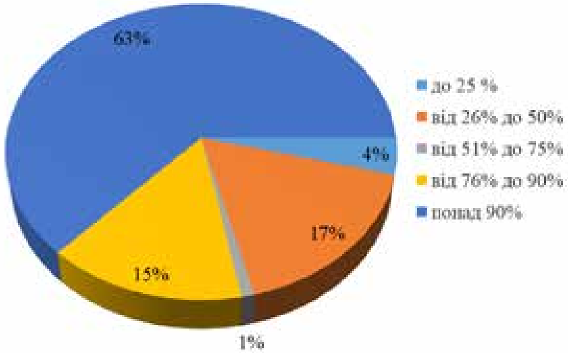


Figure 1.11. Sewers by the degree of wear and tear, %

Table 1.10 — Distribution of wastewater disposal networks by the coverage of influence areas

Wastewater disposal network	Networks in total		Dilapidated and being in disrepair	
	km	%	km	%
Main sewers	341.73	21	273.384	21
Pressure sewers	104.112	6	83.29	6
Deep sewers	55.57	3	44.456	3
Street sewer network	798.444	48	638.755	48
Intrablock and courtyard sewer network	369.678	22	295.742	22
Total:	1,669.534	100	1,335.627	100

Table 1.11 — Sewer tunnels in Kharkiv

Item No.	Tunnel Name	TBM Name	Bored, m		Year of Commissioning
			As of January 01, 1981	As of January 01, 1996	
1	Main	ПЩ-4,0	5205	5205	1971, 1973
		ПЩ-3,7			
		ПЩ-3,2			
2	KhTZ	ПЩ-2,6	7237	7237	1971, 1972
		ПЩ-2,1			
3	Saltivskyi	ПЩ-3,2	1423	1423	1971
4	Moskalivskyi	ПЩ-2,6	3246	3246	1971, 1974
5	Plekhanivskyi	ПЩ-2,6	3344	3344	1972–1974
6	Bezliudivskyi	ПЩ-3,2	1877	1877	1975
7	Ivanivskyi	ПЩ-2,6	3406	3406	1975 to 1980
8	Osnovianskyi	ПЩ-3,2; 2,6	1581	1581	1976
9	Frunzenskyi	ПЩ-2,1	1249	1249	1977
10	Zavoda KhEMZ	ПЩ-2,6	1932	2697	1978 to 1983
11	1st and 2nd Tsentralnyi	ЩМР-3,7	434	2594	1984, 1988
12	Avtozapchastyna	ПЩ-2,6	–	1434	1985
13	Lisoparkovyi	ПЩ-2,6	5079	6297	1989
14	3rd Tsentralnyi	ЩМР-3,7	–	1410	1993
15	Redundant (main)	ПЩ-3,3	–	398	–
16	Shevchenkivskyi	ПЩ-2,6	347	347	1974
17	on Zubareva Street	ПЩ-2,6	–	1619	1990
18	Rohanskyi	ПЩ-2,6	–	638	1992
19	Zavoda Budhidravlyka	ПЩ-2,6	–	961	1987
Total:			36360	46963	

The construction of the main sewer tunnels in Kharkiv was designed and carried out using tunnel boring machines (TBM) ПЩ-2,1; ПЩ-2,565; ПЩ-3,2; ПЩ-3,7 and ПЩ-4 (Table 1.11) [21, 106, 111-113]. Most of the tunnels are currently in disrepair.

Today, the experience of operating of sewers indicates the difficulty of ensuring the working order and steady operation without the implementation of the latest methods of accident prevention and elimination [21, 32–39, 64, 184, 203, 205, 219–226]. The dynamics of the occurrence of accidents shows that over the past 5 years the number of accidents in the linear sections has increased almost 5 times compared to the same parameter in 2014. Most of these accidents were registered in sewers with a diameter of more than 600 mm. The economic component of ensuring the stable operation of the sewerage networks and facilities is of particular concern in the context of limited financial resources of the operating companies in Ukraine [3].

1.3. The Main Definitions Used in the Study of the stable operation of the Sewerage Networks and Facilities. Setting the Purpose and Objectives of the Dissertation Research

The dissertation research will be based on the works of domestic [1–218] and foreign scientists [219–329], dealing with both the complex approach to maintaining the stable operation of sewerage networks and facilities, investigating the existing technologies of restoration of underground utilities, and the features of conducting work for a particular facility. The works by D. F. Goncharenko[21, 32–63, 243–249], I. A. Arbramovich [1–3], I. V. Korinko [64, 117–123], O. M. Kovalenko [111–113], O. V. Starkova [20, 27, 173–181, 309, 310], S. A. Zabelin [23, 89–91], S. V. Khramenkova [191] and others are concerned with the issue of the operational life of wastewater disposal networks. The subject of the work includes categories such as “system”, “steady operation”, “monitoring”, “the sewerage networks and facilities”, “corrosion processes”, “advanced methods of rehabilitation of the sewerage networks and facilities”, etc., which are studied in detail in the relevant chapters , and the current direction of research by domestic and foreign scientists in the specified areas is provided.

Much attention is paid to modeling the processes of repairing and operating pipelines. Researchers from Canada [322–324] proposed models of failure of the stable operation of distribution networks for further forecasting. The experience of American scientists on the basis of long-term statistics data has allowed developing regression models that can forecast the structural and operational conditions of pipelines [325–326, 280–283]. As for studies of factors affecting the operational life of the sewerage networks and facilities and technical and economic indices of work performance the following research should be noted: the study by V. Kaushal focuses on the protection of reinforced concrete sewers from corrosion [263]; the paper presents a numerical study of longitudinal bending in pipes subjected to lateral ground movements, which plays an important role in construction work [265].

It should be noted that studies by scientists from Germany of the operational stability and reliability of the sewerage networks and facilities show that today preference is given to trenchless (NO-DIG) rehabilitation technologies [296, 298, 311, 323], which are more cost-effective than traditional (involving earthwork). The work by G. Rosher consolidates the results of many years of research on the reasons of failure of distribution networks, the impact of their technical condition on the quality of service and ways to increase their service life [296]. K. Kökmäjär considers the issue of rehabilitating sewers from precast reinforced concrete structures using multicomponent building materials [261]. S. Praetorius and B.Schößer pay particular attention to filling the annular gap with a multicomponent mixture to reduce surface friction and soil consolidation when repairing utilities, especially using Relining technology [292]. The work [291] investigates the application of polyethylene pipes, polymer liners to rehabilitate pipelines during their subsequent operation. Foreign scientists are constantly improving the methods of trenchless rehabilitation of pipes to improve their efficiency. The work by J.Jeyapalan et al. deals with spot repair of pipelines using Quick Lock polymer mechanical sleeves [259]. The work [303] by S. Sendesi et al. indicates the improvement of the environmental component of the use of trenchless technologies.

Despite the described improvements, the implementation of most of these advanced technologies for Ukrainian operating enterprises is inaccessible due to their high cost. According to the author, it is promising to improve the stable operation of the sewerage networks and facilities by developing alternative repair technology in terms of cost-effectiveness, which will ensure their operability in an environment of limited funding.

The issue of the stable operation of the sewerage networks and facilities is planned to be considered comprehensively and variably, in particular, from the design (design load, longitudinal profile and section of the pipeline), operational (pipeline operation conditions), resource-saving (implementation of technological recommendations, competitive building materials, domestically produced vs. high-priced foreign fasteners), environmental (environmental impact assessment of the accident and repair work), and innovative (development of cost-effective methods of work in comparison with the existing ones) points of view. That is, when considering various options, a comprehensive assessment will be provided for a particular case. This is an innovative practice, which confirms the non-triviality of the dissertation research as a whole.

Therefore, the purpose of the dissertation research is a theoretical justification of methodological principles and development of organizational and technological monitoring for the stable operation of the sewerage networks and facilities, which is based on a system approach using groups of indicative assessments for operation and allows obtaining and investigating the optimum operation indices. To achieve the purpose, the following research objectives have been identified, particularly:

- Review the operating characteristics of the sewerage networks and facilities: design, technical, and organizational and technological features; regulatory requirements for operation.
- Review the main causes of the collapses of the sewerage networks and facilities, including laboratory and field studies of corrosion processes.
- Study the categories of monitoring and stability in the area of the operation of the sewerage networks and facilities. Justify and develop the basic principles of the system approach to monitoring the sewerage networks and facilities.
- Form the topology of consequences of the occurrence of accidents in the sewerage networks and facilities and develop a technique for defining a rank of consequences of the occurrence of an accident.
- Develop a methodology for forecasting environmental risk to assess the level of environmental hazard of the sewerage networks and facilities.
- Develop a system of organizational and technological monitoring for the steady operation of the sewerage networks and facilities, which is based on indicative assessments.
- Develop software tools for monitoring the stable operation of the sewerage networks and structures.
- Develop technical, and organizational and technological solutions for rehabilitating the sewerage networks and facilities.
- Implement and forecast the effectiveness of the system of organizational and technological monitoring for the stable operation of the sewerage networks and facilities.

Conclusions to Chapter 1:

1. The construction solutions and the main requirements fot sewer networks and facilities according to the existing building requirements were investigated.

2. The current state of the sewerage networks and facilities in Kharkiv was reviewed.
3. The basic definitions used in the research of scientists regarding the stable operation of the sewerage networks and facilities were studied.
4. The purpose and objectives of the dissertation research were determined.

CHAPTER 2

THEORETICAL FUNDAMENTALS OF THE STABLE OPERATION OF THE SEWERAGE NETWORKS AND FACILITIES

2.1. Theoretical Justification of a Sewerage Utility Operating Company as a Comprehensive System

To elaborate methodological principles of the organizational and technological monitoring for the stable operation of the sewerage networks and facilities, the sewerage networks and facilities should be considered as a production and technological element of the sewerage utilityoperating company, which is designed to perform a specific function in providing centralized wastewater disposal to the population [70–73, 75, 197]. This approach is called in scientific circles a system approach, the essence of which is to consider the object of study as a single entity, consisting of interconnected and interacting parts, when the properties of the system are not identical to the properties of its individual elements. This modeling of the object allows, when considering the problem, providing a comprehensive approach to its solution, assessing how the change of any element (subsystem) will affect the activities of all other elements, and as a result the properties of the system as a whole. In the system approach, the central place is taken by the category of system [70–73, 75, 197]. However, it should be noted that in the scientific literature today there is no generally accepted concept of the category of system, which is due primarily to its extreme commonality and fundamentality. The pages of scientific publications give numerous definitions of system, most often the alternative ones, which indicates that this area of methodological analysis is in constant motion and development.

Meanwhile, the authors generally focus their attention on certain properties that characterize the phenomenon of system [70–73, 75, 197].

Thus, for instance, S. M. Nikeshin considers the system as a set of interconnected and interdependent elements that form a certain unity and expediency. The system has properties that are absent in its constituent elements. In complex systems "… the whole is greater than the sum of the parts... in the important pragmatic sense that from the given properties of the parts and their interactions one cannot properly draw conclusions about the properties of the system as a whole" [70–73]. In their turn, G. Chernov and L. Moses consider the function or functions that a system is capable of performing based on the association and interaction of its constituent elements to be the main criterion for defining a system: "A system is a harmonious unity of associations united by a common function"[70–73]. Here the authors focus their attention on the most important, in our opinion, property of any system, fulfillment of a certain function. Any system in this world, both of natural origin and of artificial nature, is designed to implement a certain target function. Otherwise, its existence in the surrounding world is meaningless and unnecessary.

Some scientists who define the category of system focus their attention on its structural component. Specifically, N. P. Buslenko defines a complex system as a multilevel structure of interdependent elements that are combined into subsystems of different levels [70–73]. V. G. Shorina notes that a system is "… a set of objects with a set of connections between them and between their properties, i.e. everything that consists of parts connected with each other". Therefore, any system has a certain structure, that is, it is characterized by levels and connections between the elements forming it to perform a function.

In addition, as defined by W. Ashby [70–73], the most important for any system is its integrity, which lies in the fact that as a result of the interaction of its elements new properties of the system are born, which are absent in its subsystems separately. The integrity of a system is determined, on the one hand, by the strength of the links between the elements of the system, on the other hand, by their flexibility in the functioning of this system. The emergence of this property of integrity allows the target function of this system to be implemented in the surrounding external world.

A number of scientists [70–73, 75, 197], when defining the concept of system, focus their attention on such an important property of the system as self-organization or adaptability, i.e. the ability of the system to reconstruct its structure (organization) under the influence of internal and external environment factors, that is, to adapt to them to fully implement its target function. Closely related to the concept of self-organization of the system is the category of system stability. Stability of the system is understood as its ability to find the optimum variant of connections and relations between elements of the system, which allow maintaining its important parameters at a given level. It can be argued that the stability of the system is a consequence of its ability to self-organization.

The concept of organization is very close in meaning to the category of system. Specifically, when describing the meaning of the word "organization", the founder of organizational science A. A. Bogdanov wrote: "It is organization, which is an organized whole in the most general abstract form, that is the ultimate extension of any system. The concept of "organization" as an ordered state of the whole is identical to the concept of "system" "[70–73]. V. G. Aliev holds a similar point of view: "a system is nothing other than organization in statics, i.e. some state of order fixed for the moment. This does not deny at all the system dynamics as the development of the system itself in time. It is known that systems can be divided (with a sufficient degree of conventionality) into deterministic and stochastic ones. They can maintain or change their properties. But in the latter case, from the organizational point of view, they will be other systems, with a different structure, connections, functions, we can say - another organization"[70–73].

As is known, in terms of the economic sphere, the scientific literature often uses the concepts of "economic system", "production system", "socio-economic system".

When considering the company as an economic system, L. L. Tonppeva writes: "The basis for the creation and functioning of the organization as an economic system is the active activity of people who run their public economy. The interaction between the elements of the economy is carried out in the established order, determined by opportunities and constraints, inherent and set by the general properties of the system. Any economic system consists of a finite number of interacting elements, each of which represents a certain totality, some whole, unity of carriers of decision-making processes, people and objects, to which these decisions are directed, with the former acting as managers, the latter as resources" [70–73].

A. P. Gradov considers the company in the market environment as a production system and gives the following definition: "a production system is a separate part of the production process as a result of the social division of labor, able to independently or in the interaction with other similar systems to meet certain needs, needs or requests of potential consumers with the goods and services produced by this system" [70–73]. It seems to us that this definition fully reflects the features of the company as a system. First of all, this interpretation ignores the researcher's variety of relationships (except for production) that the company has with the external environment. For example, the definition does not take into consideration the social component of the company's activity.

Thus, one can say that in order for any object, process or phenomenon to be regarded as a system (complex), it is necessary to have a certain number of elements or components (subsystems), interconnected and interacting in a certain way to implement its target function. To ensure its normal functioning and development, the system must have the property of stability. Thus, one can formulate the following major principles of the system: elementarity, integrity, development, systemicity, hierarchicity, formalization, optimality, normativity, stability (Table 2.1).

In a number of the specified properties of the system, in our opinion, particular attention should be paid to the nature of the relationship between the system and the external environment [70–73, 75, 197]. It is its content that determines the content of other system properties (Fig. 2.1). As V. D. Mogilevsky notes on the issue "… the environment itself is not only the progenitrix of the system, but any system lives and functions in the surrounding of the environment, it feels the effects of the environment and, in its turn, exert an effect on the environment. Often the system is created only to change the properties of the environment. For this reason, the relationship between the environment and the system can be considered as one of the main features of the functioning of the system, an external characteristic of the system, which largely determines its properties, i. e. internal characteristics" [70].

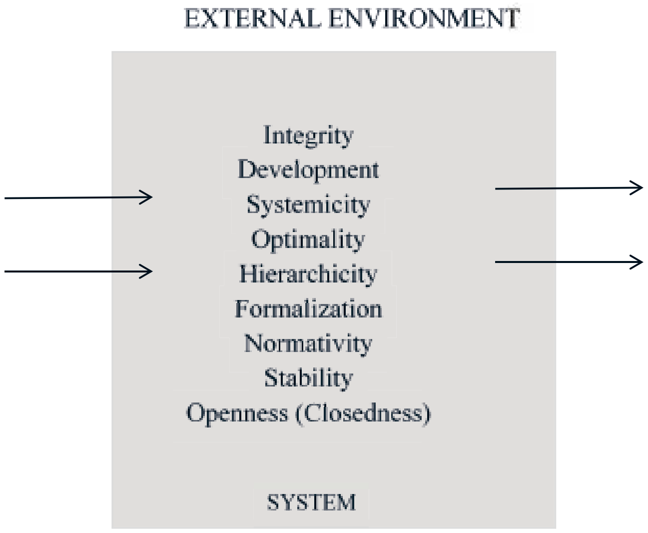


Figure 2.1. Main properties of the system

Table 2.1 — Characteristics of the principles of a production system

Item No.	Principle	Characteristic
1	Elementarity	A system is a set of interrelated elementary components that act as a manifestation of the universal interaction of objects and phenomena
2	Integrity	Consideration of any object, system in terms of internal unity, separation from the environment
3	Development	The system is in development, goes through the stages of emergence, formation, maturity and top-down development
4	Systemicity	Consideration of objects as a system, i.e. as a whole that is not reduced to a set of elements and connections
5	Optimality	Any system can be brought to the state of its best functioning in terms of a certain criterion
6	Hierarchicity	A system is a a collaterally subordinated entity
7	Formalization	Any system with more or less correctness can be represented by formal models, including formal-logical, mathematical, cybernetic, etc.
8	Optimality	Any system can be brought to the state of its best functioning in terms of some criteria
9	Normativity	Any system can be accepted for understanding only if it is compared with some normative system
10	Stability	Adherence to some dynamic equilibrium, which guarantees the maintenance of parameters in a certain range, which determines the existence of the system
11	Openness (Closedness)	Features of interaction with the external environment of the system (the order of influence of the system on the environment and vice versa)

Depending on the nature of the interaction with the environment, there are closed systems that are isolated from the external effects relative to the system or where the external effects are regulated, and open systems that interact with the external environment in any aspect (information, energy, material, etc.), and are steady only when maintaining this interchange [70–73, 75, 197].

In the dissertation research, we take the view that sewerage networks and facilities should be considered as a production subsystem of the sewerage utility operating company, which somehow interacts with the external environment, as it was found that the nature of this interaction would determine the parameters of their stability. If we consider the sewerage of Ukraine, where operating companies are in operation (in particular, those that operate sewerage networks and facilities), as a supersystem, we can say that, toward the subjects, it acts as an external surrounding or external environment with common problems and vectors of development to one extent or another [70–73]. Therefore, one may note that there is a vital need for the formation of an adaptation mechanism that allows maintaining the stability of their functioning and development over time under the effects of the unstable environmental factors.

The presence of an adaptive mechanism should form the property of self-organization in the system [70–73, 75, 197]. (Table 2.2).

Table 2.2 — Methodological approaches to the theory of systematicity combining a set of techniques and methods of systemic activity formed in the practice of analytical activity

Item No.	Approach	Feature
1	**2**	**3**
1	System	Irreducibility of the properties of the whole to the sum of the properties of the elements. The behavior of the system is determined by both the features of individual elements and the features of its structure. There is a relationship between the internal and external functions of the system.
2	Structural and functional	The system is in interaction with the external environment, possesses its appropriate internal environment. The system develops as a whole.
3	Constructive	Identification of the structure (or functions) of the system. Establishing a relationship between the structure and functions of the system. Construction of the functions (or structure) of the system accordingly.
4	Comprehensive	Realistic analysis of the problem. Analysis of all possible solutions to the problem. Construction of the system, the action to solve the problem.
5	Problem	Consideration of all aspects, properties, variety of structures, functions of the system, and its relationship with the environment. Consideration of these taken in unity. Clarification of the level of significance of the characteristics of the system taken in unity in its essence.
6	Situational	Isolation of the problem as a contradiction between any aspects of the object that determine its development. Determining the type of problem; assessing the problem.
7	Innovative	Statement of the innovation-related problem. Elaborating an innovation model that provides a solution to the problem. Introducing an innovation. Managing the innovation; developing and implementing the innovation.
8	Normative	Statement of the system-related problem. Establishing the sound standards of the system. Transforming the system according to the standards.
9	Goal-oriented	Defining the goal of the system. Decomposing the goal into simple components; justifying the goals. Construction of the "goal tree". Expert assessment of all "branches" of the "goal tree" in terms of time and resources for achievement.
10	Activity	Defining the problem. Defining the object of activity. Formulation of the goals and objectives of activity. Defining the subject of activity. Elaboration of the model of activity. Implementation of activity.
11	Morphological	Defining the problem in a most accurate way. Searching for the largest number within all possible solutions. Implementation of the system by combining the main structural elements or features. Application of the morphological modeling methods: system field coverage; negation and construction; morphological box; comparison of the perfect with the defective, generalization, etc.
12	Program- and goal-oriented	Defining the problem. Formulating the goals. Building a program to achieve goals.

The development of issues related to the self-organization in complex systems originates in cybernetics. Scientists began their study in the middle of the last century. W. Ashby, H. Pascoe, and J. Neumann can be considered as the ancestors of this area of research. This area was further developed in the research of I. Prigogine, P. Glensdorf, H. Haken and many others [70–73, 75, 197].

We note that there is currently no unambiguous interpretation of the concept of self-organization. Specifically, M. D. Mesarovic considers self-organization "… as a process of changing the structure of the goal-oriented process, i. e. the functions that determine the goal-oriented system..." [70]. That is, the author considers self-organization as a certain process. A similar position is held by T. M. Konoplyanyk, who emphasizes that the outcome of self-organization is the formation or improvement of the organization of a dynamic system. The specific feature of the processes of self-organization is their goal-oriented, but at the same time natural, spontaneous nature; these processes, which function in the interaction of this system with the external environment, and are relatively independent of it [73].

In his turn, E.A. Smirnov [72] defines self-organization in two ways, both as a process and as a phenomenon. According to the author, the essence of self-organization as a phenomenon is the presence of a set of elements that are meant to implement a program or a goal and act on the basis of internal rules and procedures. The characteristic feature of self-organization as a phenomenon is defined: self-organization is not a characteristic of a special class of objects, but is a moment in the development of any complex system that corresponds to its steady state. In the presence of strong imbalance, these same systems can become objects, the functioning of which is controlled by the environmental factor. In this context, they lose the property of self-organization. Self-organization as a process is the formation of a set of actions that lead to the creation of steady reactions in the system. Self-organization is a complex process, the outcome of which is the creation, reproduction, perfection of the organization of a complex dynamic system.

The concept of self-organizing system is connected with the category of self-organization. N. P. Buslenko [70–73] defined a system as self-organizing when it is able on the basis of assessing the impact of the external environment by consistently changing its properties to reach a steady state, where environmental impacts are found to be within acceptable limits. As noted by A. B. Pozdnyakov, whatever the conditions, the processes in self-organized systems are aimed at self-preservation, self-reproduction, at improving the mode of development, at reducing entropy [70–73]. According to O. M. Galimova, the formation of self-organizing systems are based on two reasons: one is related to the establishment of a certain order, the emergence of self-organization and a certain steady structure; the other consists in the disruption of the former order of the emergence of disorder, which is characterized by an increase in entropy. To effectively solve the problems of the development of the system (for example, a company) both trends should be taken into consideration [70–73].

The central idea of the concept of self-organization of complex systems is the goal-oriented use of internal sources and internal reserves in the process of overcoming external disturbances, in the process of removing, eliminating external causes. The internal preferences determine the mechanism of action, the logic of the activity of the system, according to which the system is organized and configured to overcome the impacts that outrage the environments [70–73, 75, 197]. Certainly, external conditions, external causes are important in choosing the behavior of the system: they determine, in particular, the level of activity of the system in achieving goals. However, it is not possible to explain the logic of the behavior of a self-organizing system, based only on external causes as the defining principles of functioning. According to synergetics, self-organization is due to the interaction of the elements of the system being in an excited nonequilibrium state. Self-organization is not imposed on the system from the outside, although the root cause may be also found in external impacts [70–73, 75, 197].

Therefore, to ensure the stable operation of sewerage networks and facilities as a subsystem of the sewerage utility operating company and consequently increase its in-service life, sewerage networks and facilities should be considered as part of a self-organizing system [70–73]. This is due primarily to labor resources, which with their knowledge, experience and tools for managing production subsystems, provide a basis for the self-organization of the sewerage utility operating company. Besides, modern sewerage utility operating companies have some properties that provide rationale for this kind of approach according to the author. These properties include.

- — Openness, which is shown in a close interaction with the external environment.
- — Complexity, which is manifested in the presence of many levels of subsystems, as well as their relationships that form the desired organizational and technological structure.
- — Nonlinearity of development, which consists in their ability, when reaching a certain point of change in the external environment, to change their structure accordingly.
- — Self-sufficiency, which allows transforming the internal organization according to the requirements of the external environment, and its operation.
- — Controllability, which consists in their ability to submit to goal-oriented actions that ensure their steady operation [70–73].

The methodological task is, in the author's opinion, to improve the mechanism of self-organization of the sewerage utility company through automated tools and monitoring to support management decisions, which is a basis for providing the technical, organizational and technological, and consequently economic stability of the production system. It is necessary to form appropriate methodological principles of organizational and technological monitoring, which will be the basis for effective management on the principles of self-organization of the sewerage utility operating company. Achieving this issue is possible by increasing the stability of its elements, primarily sewerage networks and facilities [72].

Given the above provisions, in the author's opinion, sewerage networks and facilities can be defined as a production subsystem of a complex, self-organizing system, and is a set of technical and technological interrelated elements, the interaction of which creates the internal organization of a complex sewerage utility, which provides the full possibility of its steady operation and development in order to obtain a certain planned result, aimed at uninterrupted provision of the population with the service of centralized wastewater disposal [70]. To form an effective system for managing the sewerage utility operating company, the scientific background of which should be, in our opinion, the methodological principles of monitoring the stable operation of the sewerage networks and facilities, one needs, first of all, to define the concept of "steady operation of the sewerage utility operating company" and "steady operation of sewerage networks and facilities", along with the factors influencing thereof.

2.2. The Essence and Factors of the stable operation of the Sewerage Utility Operating Companies

In the current conditions of the operation of sewerage utility operating companies an important scientific task in the field of management is to improve the mechanism of stability. Considering the issues related to the category of stability is relevant, both at macro- and microlevels of the operating company [15, 69, 70, 115, 189]. The study of the life cycle of the production system involves the need to cover in a comprehensive manner and in all interconnections both the production process as a whole, and the individual elements that provide the design, creation, operation and development of a system such as a sewerage utility operating company. Design and production represents the stage of system design, and functioning and development — the stage of its vital activity. This study considers functional aspects of the study of production systems at the stage of life activity, the most important of which include organizational and technological reliability of their operation in the process of achieving the purpose, ensuring uninterrupted service of centralized sewage disposal. In this regard, one should agree with A.A. Gusakov that "… in functional construction systems only one element, the result, should be reliable, still other elements can and should be able to rebuild and change in the course of system functioning, if it is necessary for the final result" [70–73].

Research of a problem of the steady existence of systems of different origin is one of the most popular and demanded areas in a modern science. In this connection, to formulate the category of "the stable operation of the sewerage networks and facilities", we consider it appropriate to consider the established system of views on such concept as "stability" in general, which is used in many areas of modern society, and on the concept of "the stable operation of sewerage utility operating companies" as a global concept.

The authors have reviewed [15, 69, 70, 115, 189] the existing scientific works; four main approaches to the consideration of the concept of "stability" existing today in science can be identified (Table 2.3).

Table 2.3 — Consideration of the concept of stability

Approach	Interpretation
1	2
1	Using the term of "Steady state" (steady state, state of stationary stability) introduced by R. Solow and reflecting the conditions of dynamic equilibrium of the system. V. Yachmeneva believes that "... stability in general terms is due to the capabilities of the internal energy-material forces of the elements of the organization, which are able to maintain it within its characteristic equilibrium and accordingly give the organization the opportunity to maintain the structure and perform its functions steadily, reliably in changing environmental conditions." A number of scientists, in particular S. Anokhin, I. Blank, A. Zagorulkin, B. Kolas, A. Kolodizev, K. Nuzhny, V. Roshchin, Y. Simekh, V. Sumin and others refer to the concept of steady state, equilibrium when studying "economic stability". However, it should be noted that the term of "stability" describes the process associated with equilibrium
2	The second approach to the consideration of the problem of stability of the industrial enterprise is held today by the majority of Western scientists. Economist researchers such as V. Dergacheva, D. Kovalev and T. Sukhorukova, Z. Korobkova, Ye. Korotkov, A. Sheremet, Yu. Maslenko and N. Kulbaka, I. Nedin, andI. Senko identify the company's stability with its financial condition. According to representatives of this approach, financial stability is formed as a result of the stable income of the enterprise, which creates opportunities for free maneuvering and effective use of funds and contributes to the rhythm and reliability of the processes of logistics, production and sales. However, today in Ukraine, a lot of sewerage sector companies operate with losses, but are not bankrupt and continue their activities

1	2
3	The third approach in assessing the stability of the system is based on the provisions of the concept of sustainable development ("sustainable development"), the starting point for the development of which is the report of the UN International Commission on Environment and Development in 1987. The new strategy of the development of society is based on the priorities of the future, and it can be defined as a strategy of survival and continuous development of civilization (and the country) in conditions of environmental conservation. A. Derkach, L. Melnik, A. Semyonov and A. Fadeeva adhere to these views and describe sustainable development as such, in which economic, environmental and social goals are balanced and integrated, and the rate of economic growth does not exceed the rate of reproduction of natural resources, with improvement of quality of life being considered the main indicator of this development
4	The fourth approach is adhered to by such known economists as J. Mil, J. Schumpeter, R. Harrod, F. Kotler, D. Morris and others. Among scientists the concept of sustainable development of industrial companies is connected with the concept of growth. A. Voronov and N. Shandova consider that "... the concept of stability is based on the maximum value of the enterprise's economy growth with minimal deviation of enterprise economic system from the equilibrium state". In this approach there is an identification of the concept of "development" with the concepts of "growth", "increment", which involve only an increase in the quantitative rather than qualitative characteristics of the socio-economic system

According to the author, the analysis of the issue of the stability of the sewerage utility operating company showed that research in this field of knowledge is constantly conducted, but the attention of scientists is mainly focused on its financial aspects, but production parameters cannot be neglected in the functioning of a complex production system. Although stability is a generalizing complex category, which cannot be limited to the reflection of any one aspect of the enterprise. Having considered the existing approaches to considering the concept of "stability" in more detail and let us analyze this term comprehensively [15, 69, 70, 115, 189].

It should be noted that authors in the literature note the relativity of the concept of "stability". Specifically, N. V. Osokina writes: "... On the one hand, there is no and impossible to create the general theory, capable without a residue and inconsistently to cover properties of all concrete models of stability at all levels of matter, including social matter — economy. On the other hand, it is impossible to impose a general abstract natural-scientific scheme on the economic sphere, even if such a scheme could be found, without losing the specific characteristics of economic stability. The application of this or that general scientific approach to the analysis of a particular type of systems should be further argued" [15, 69, 70, 115, 189].

A similar opinion is expressed by G. P. Krasnoperov and G. S. Rosenberg: "Despite the seeming obviousness of the concept of stability, to characterize it more clearly and unambiguously seems to be a very difficult task". Moreover, the authors believe that the concept of "stability" has such a broad meaning that there is absolutely no need for its unambiguous definition, and, from the point of view of scientific analysis, it is not a universal concept that is most appropriate, but a definition of stability in relation to this or that field of knowledge. According to scientists, it makes little sense to try to provide any kind of exhaustive definition of this rather content-rich concept, which will inevitably lead to a limited scope of application. In this case, it is preferable to use a number of fragmentary definitions concerning some individual aspects of this concept. Indeed, the category of sustainability is complex and multifaceted [70–73]. Each science puts into this concept its own meaning and value, based on the goals and objectives of the study. Specififcally, today it is possible to distinguish a number of approaches, such as mathematical, biological, economic, etc., differently defining the essence of this category.

Specifically, the famous Russian mathematician A. M. Lyapunov argued that in order to check the stability of the equilibrium state, we should give the system some small deviation " ... then, when it returns to the former or close to it state, we can talk about the stability of the system, otherwise about a violation". The followers of A. M. Lyapunov were famous scientists, mathematicians such as A. A. Andronov, L. S. Pontryagina, A. N. Kolmogorov, etc. In his turn, A. Poincaré defined stability of a system as follows: "A system is first in an equilibrium state, is removed from this state and is given to itself. If the system tends to return to the initial state, approaching it more and more, then the equilibrium is considered stable. This property can also be transferred to a system, then the system is said to be stable" [70–73].

J. Lagrange believed that a system is steady if its parameters do not exceed a certain set range of values [192].

In technical and mechanical systems, stability is also interpreted differently. For example, the stability of an automatic control system (ACS) is defined as the ability to function normally and to resist various unavoidable perturbations (actions). The state of the ACS is called steady if the deviation from it remains as small as possible under any sufficiently small changes in the input signals. In construction, the stability of erected buildings and structures and others is defined as their ability to resist the forces tending to deviate them from a given state of static equilibrium [15, 69, 70, 115, 189]. The stability of transport vehicles is the ability of transport vehicles to resist external forces tending to deflect them from their intended trajectory of movement in space.

Consequently, one can say that in mathematics, engineering and mechanics, stability is regarded as a certain property of a system that allows it to be returned to its initial state of static equilibrium after a perturbing force has been applied to it [15, 69, 70, 115, 189]. This approach overlooks such an important aspect of the stability problem as the achievement of equilibrium of the system in the course of its motion, or the process of achieving dynamic equilibrium. In this case, we do not mean movement of the system in space, but movement in the context of qualitative development.

In turn, studying the properties of adaptability and stability of biological systems, W. R. Ashby in his famous work "Introduction to Cybernetics" wrote: "Each species of organisms has a number of variables that are closely related to survival and are in close dynamic relationship with each other, so that significant changes in one of them lead sooner or later to a significant change in the others. In living organisms, the brain "… is a specialized adaptation for the survival of the organism, ensuring that essential variables are found within specified limits" [15, 69, 70, 115, 189].

The ability of living systems to maintain a state of moving equilibrium is an manifestation of the system stability. This concept means an admissible measure of deviation of given properties of a system from the norm, caused by some degree of perturbing external influences [15, 69, 70, 115, 189]. As E. A. Lyaskovskaya writes: "Biological systems … are almost stationary systems. Their functioning is characterized by constant average changes in parameters and the rate of movement of resources. If under the influence of external factors there is a deviation from the average values, then a stable system can resist them and return them to their initial level."

Thus, from the point of view of the biological approach, stability is a property of the system, by which the system can be in a state of some dynamic equilibrium, thus ensuring the finding of deviations of the system parameters within acceptable limits. Here, in contrast to the mathematical approach, the emphasis is on the dynamic component of the stability of the system according to given parameters. The limitation of the biological approach consists in the fact that deviations from the steady state are considered here in limited natural ranges. Going beyond these limits means the disruption of the system [15, 69, 70, 115, 189].

The concept of stability has also spread in the economic sphere. As in other fields, there is no unambiguous interpretation of this category. At the same time, as is often the case in scientific research, the emphasis is placed on some aspect of the problem when studying these or those questions. One of the more common approaches in economics is the consideration of system stability in inseparable connection with its ability to do its target function under conditions of external and internal actions. Specifically, Ye. P. Golubkov writes: "a system can be stable and unstable [15, 69, 70, 115, 189]. The stability of a production system is the corresponding state that characterizes the constancy of its initial variables. Unstable means that the initial variables of the system do not perform their function. In a changing environment or under the influence of various "perturbations" that reach the stability threshold, the system may cease to exist"[72].

This is also the opinion of V. S. Efremov. He writes: "The internal order maintained by an organization becomes impractical when its functional utility is lost [71]. But the functional utility of what an organization does is determined not by itself, but by its external environment. Moreover, assessments of functional utility are subject to the same dynamics as the very external organizational environment in which they arise, therefore, to preserve itself, an organization must either constantly adjust to changes in its environment, or actively influence it to justify and validate. perceptions of its functional utility, or implement a combination of both" [70–73].

Other authors, when defining the essence of stability of socio-economic system, focus their attention on the description of the mechanism by which stability is achieved. A. G. Danish defines stability as a state of dynamic equilibrium in time, in which the disturbing impact of the environment or higher level system is absorbed by the mechanism of self-regulation of the system, and, ultimately, allows to keep significant qualitative characteristics of the system within specified limits [15, 69, 70, 115, 189]. The stronger the perturbing impulse to influence, which is capable of smoothing the self-regulation mechanism, the higher the level of system stability [198]. I. V. Bryantseva, considering an enterprise as a complex socio-economic system notes: "… stability is a state of an enterprise in which the socio-economic parameters that characterize it preserve equilibrium and are within specified limits under the influence of internal and external environment … Dynamic equilibrium of the internal environment is achieved through the mobilization of internal self-organization systems as a response to adverse external influences" [198].

Therefore, based on the definitions of stability formulated by A. G. Danish and I. V. Bryantseva, one can state that the limits of change determine the quality of the system, occurring within some limits mean that the system retains one quality. Other limits of change indicate other qualities of the system [15, 69, 70, 115, 189]. Thus, one can say that the authors associate sustainability with the functional usefulness of the system, since qualitative changes always affect the functions of the system.

The category "stability of development" is closely connected with the concept of "sustainability". As defined by B. L. Kuchin, the stability of development is the preservation of the integrity of the system over many cycles of functioning, that is, the preservation of given parameters and improving them with the account of external influences and internal changes to achieve the goals [70]. The stability of development means that without violating its integrity, the system moves to a new equilibrium degree of functioning, characterized by better qualitative and quantitative characteristics. Thus, the system development process is a sequence of cycles characterized by a stable system structure and evolutionary changes within the cycle and a jump-like transition of the system state at the end of the cycle to a new qualitative level: unstable old structure and creation of a new stable one, i.e. transition to a new equilibrium state [70].

Development in this case is irreversible, that is, the transition from a new structure to the disrupted one is impossible in principle [69].

At present, in many scientific publications it is fairly noted that socio-economic systems of any complexity are characterized by two aspects of their existence, these are operation and development. At the same time, it is often not possible to draw a clear boundary between the two identified aspects in the process of system life [15, 69, 70, 115, 189]. As D. S. Lvov noted, the development of any economic system is the interaction of opposing sides and trends arising from the essential characteristics of opposites. Each economic movement and each moment of the present can be seen as the result of a clash between the past and the future. This conflict, occurring at the level of economic subjects, represents the most powerful pledge and source of continuous progressive development [70–73]. It, occurring on the scale of society as a whole, encapsulates the cause of social conflict, the eradication of the source of which is neither desirable nor possible. The competitive environment reproduced on the basis of supply and demand constantly destroys the established equilibrium, undermining the economic stability of some subjects, while reinforcing the stability and development of others [70].

As is known, complex systems, which include sewerage utility industrial operating companies, have a certain internal structure, which is described by certain interrelations and interdependencies of the parts of its components [15, 69, 70, 115, 189]. The optimality of the internal structure of this complex system for each period of time is assessed by the efficiency of the system's operation, i.e. the ability to achieve the set goals. However, over time, under the influence of external and internal factors, such an internal structure of the system ceases to be optimal. There is a need for a qualitative transformation of the system's structure to fulfill its target function. One can say that the functioning of the system is its staying in a certain equilibrium state. In turn, the development of the system is a violation of the equilibrium, the disruption of many functioning processes, perhaps even a decrease in the efficiency of the system, in order to create more stable conditions for the effective operation of the system in its near future (Fig. 2.2).

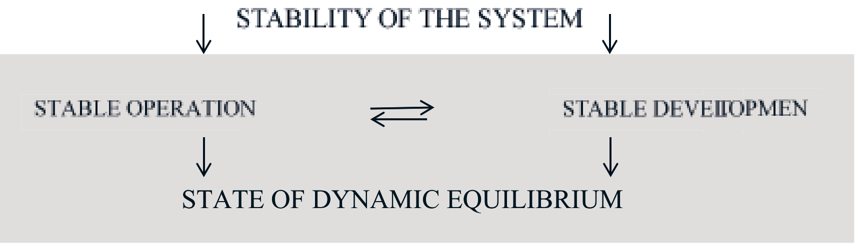


Figure 2.2. The stability of a system

In order to specify the content of the concept of stability ustainability, one should determine which factors affect it and determine the evaluation indicators of these factors. The system of the parameters of the production stability depending on the affecting factors can be presented in the form of correspondence tables (Table 2.4). Proposed factors and parameters of their measurement allow us to present the content of stability of a sewerage utility operating company (from the production point of view) in more detail. Summarizing the above, the stable operation of a sewerage utility operating company can be defined as a state of the system, in which the operation and development of the system according to the parameters that ensure the achievement of objectives set at each point in time by changing its internal structure according to the requirements of external and internal environment factors of its functioning.

Table 2.4 — Factors affecting the production stability of a sewerage utility operating company

Item No.	Factors	Parameters
1	Availability of production capacity reserves	Production capacity utilization factor of balance ratio
2	Organizational and technical level of production	Share of fundamentally new and advanced equipment Working equipment variability factor Size of progressive technology application on different types of work Fund provision, mechanical provision and energy provision for labor Level of specialization, cooperation and production, technological concentration, combination Rhythm of production Size of application of progressive forms of production and labor organization Employee qualification level Fund provision for managerial labor Degree of automation of management labor Efficiency of expenditures for management Degree of controllability
3	Availability of necessary resources to the work schedule and their status	Compliance of the size of actually supplied resources with the necessary need Compliance of the stock value with the normative value at the beginning of the planned period Level of completeness of supply of material and technical resources Quality level of incoming materials Share of advanced materials Share of own equipment in the cost of fixed assets Degree of suitability, rehabilitation, disposal and wear and tear Average secondary general education level Average qualification level of workers Average work experience in the specialty Personnel retraining intervals Personnel turnover rate Innovativeness of technology
4	Efficiency of using available resources	Labor productivity growth Incremental growth in the amount of work due to increased labor productivity Return on fixed assets The relationship between the growth rate of the capital-labor ratio and the labor productivity The level of intensive and extensive loading of machinery

The above stated definition of stability is general in nature and needs to be made more specific. A sewerage utility operating company comprises a multitude of groups of subsystems, including the sewerage networks and facilities. It is obvious that the stability of each subsystem while maintaining the features denoted by the author in the definition, will be of a specific nature. Therefore, we deem it necessary to consider the stability in terms of the object of the dissertation research, the sewerage networks and facilities, to conclusively define the nature of this complicated production category.

2.3. The System of Indices of the stable operation of the Sewerage Networks and Facilities

In the context of the present-day economic development of Ukraine sewerage utility operating companies are elements of the stability of the economic system of the state, the main function of which is to ensure the development of the public sector. To develop in today's conditions, companies should improve their condition, that is, increase their stability. To do this, it is necessary to effectively conduct production and economic activities, to improve the ratio of costs and performance results, to be solvent, to respond promptly to the configuration of the external environment [70–73, 75]. So, if it comes to the sewerage networks and facilities as a component of the system of the sewerage utility operating company, ensuring its stable operation requires the creation of a scientifically sound system of stability indices.

The summarizing index of the stability of the production system should qualitatively and quantitatively describe the degree of compliance of actual performance indices in general with its standard value [15, 69, 70, 115, 189]. The actual performance indices of the operation are summarized in the profitability of operation of the sewerage networks and facilities, so mathematically this index can be expressed as a ratio of the actual level of operational efficiency to the planned (standard) level:

$$У_{ст}=\frac{E_{ф}}{E_{пл}}$$

where:

$У_{ст}$ — is the summarizing index of the stability of a sewerage utility operating company;

$E_{ф}$, $E_{пл}$ — is the performance efficiency, the profitability of of a sewerage utility operating company (actual and planned).

Given that the stability is a relative category, it can be determined in comparison with any domestic and foreign counterparts. In this case, compare the value of the required indices of profitability of this company and its analogue. Of the stable operation of the sewerage networks and facilities a system approach should be used, which will be aimed at system analysis, modeling, design, diagnostics, assessment, decision making (Table 2.5).

The use of the index of profitability as a basis for calculating sustainability is explained by the fact that it is sufficiently objective and fully describes the quality (efficiency) of production and quality of consumption (the level of welfare of employees of the company, the potential development of production, socio-economic opportunities of society) and reflects the economic consequences owing to the production and economic and financial activities of the company and sociopolitical and other actions of governmental bodies ((legislative and executive authorities). This index is quite sensitive to changes in all external and internal factors (scientific and technological progress, political and economic changes taking place in society, suppliers, consumers, competitors, internal environment).

An important link in the process of managing the stability of the sewerage utility operating company is to determine the minimum, actually achieved and standard (maximum possible) levels and the development of growth strategy for the future [15, 69, 70, 115, 189]. The minimum level of stability corresponds to the break-even operation of the company, when all current production and economic costs are recouped and the simple reproduction of fixed assets is provided.

For a comprehensive analysis of the process of achieving the necessary level of stability of the sewerage utility operating company, the characteristic of the summarizing index is proposed to be supplemented with the system of individual indices, the main purpose of which is to assess the stability of each vector of development of the economic entity (Fig. 2.3).

Since the sewerage networks and facilities are an integral part of the sewerage utility company, its stability indices directly affect the summarizing index in accordance with Fig. 2.3.

Therefore, the main indices of the effectiveness of the operation of the sewerage networks and facilities include the following: technical condition of sewerage networks and facilities; accident rate; dynamics of replacement of worn-out areas; coverage of the cost of wastewater disposal; impact on the environment.

Table 2.5 — A system approach to the stable operation of the sewerage networks and facilities

Direction	Goal	Means of activity	Content of activity
1. System cognition	Obtaining information	Operational experience, methods of cognition	Research of technical condition of sewerage networks and facilities, monitoring
2. System analysis	Understanding problems, identifying the weaknesses of the operation	Technical information (state of networks, material, etc.), methods of its analysis	Consideration of the problem using methods of analysis
3. System modeling	Creating a model of the system of the operation of the sewerage networks and facilities	Modeling methods	Construction of a formal or full-scale model of the complex
4. System design	Creating a stable system	Design methods	Designing a stable system
5. System diagnostics	Analysis of functioning, diagnostics of the complex	Diagnostic methods	Elucidation of deviations from the standard in the structure and functions of the complex
6. System assessment	Performance assessment	Theory and methods of assessment	Obtaining an assessment of the operation of the complex
7. System decision-making	Stabilization of activity	Organizational and technological solutions	Development of organizational and technological solutions to ensure the stable operation

For a comprehensive analysis of the process of achieving the necessary level of stability of the sewerage utility operating company, the characteristic of the summarizing index is proposed to be supplemented with the system of individual indices, the main purpose of which is to assess the stability of each vector of development of the economic entity (Fig. 2.3).

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Therefore, the main indices of the effectiveness of the operation of the sewerage networks and facilities include the following: technical condition of sewerage networks and facilities; accident rate; dynamics of replacement of worn-out areas; coverage of the cost of wastewater disposal; impact on the environment.

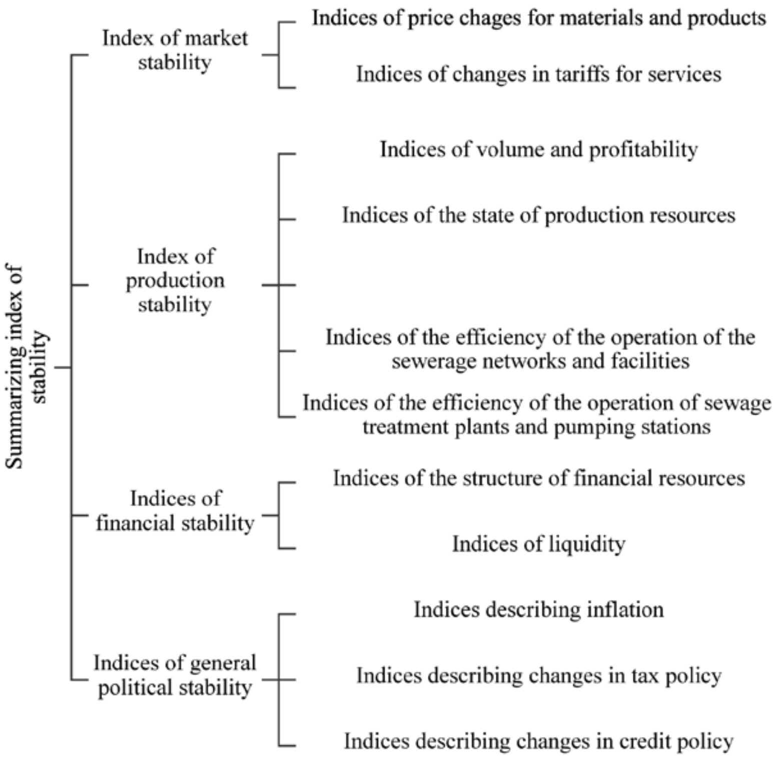


Figure 2.3. The summarizing index of the stability of a sewerage utility operating company

Conclusions to Chapter 2:

1. The modern lines of research by domestic and foreign scientists in the field of a system approach to production companies were reviewed.
2. The category of "sewerage utility operating company" as a complex system was theoretically justified.
3. A summarizing index of the stability of the sewerage utility operating company was proposed, which is based on a system of indices of the stable operation of the sewerage networks and facilities.

CHAPTER 3

INVESTIGATING THE CAUSES AND CONSEQUENCES OF ACCIDENTS OCCURRING IN THE SEWERAGE NETWORKS AND FACILITIES

3.1. Investigating the Main Causes of the Deterioration of the Sewerage Networks and Facilities That Provoke Accidents

When constructing buildings for various purposes, including the sewerage networks and facilities, the importance class of an object must be determined, which shows the degree of consequences in the event of its failure. The term of failure means the corresponding state of the object, for which the object cannot be used for its intended purpose [205].

According to regulatory documents [205–218], the class of consequences of a construction object is determined independently by individual characteristics of possible consequences of failure of the object: danger to health and life of people on the site, the amount of possible economic damage, etc. Determining the class of consequences is performed for each linear object of engineering and transport infrastructure separately [205]. According to provisions, the importance class of the construction object is set according to the highest index of the category of consequences based on the calculation data.

Sewer tunnels and facilities have are of Class CC3 of consequences, because the failure of their operation has a national level. The characteristics specified in the regulatory document are general and obligatory for objects and do not depend on their functional purpose [205]. This fact indicates that for the construction of sewerage utility facilities, determining the consequences of failure requires the use of not only the characteristics specified in the standard, but also additional definitions and rankings.

Comprehensive studies of the main causes of the disruption of the stable operation of the sewerage networks and facilities indicate that the main cause of their collapse are corrosion processes [125–127, 155–156], the presence of holes, cracks, fractures in water distribution networks. Corrosion is due to the thermodynamic instability of structural materials to the effects of substances in contact with them. In addition, trouble-free operation of the sewerage networks and facilities is often complicated by defects that occurred during construction and non-compliance with technological regulations for the use of the public utility sewerage, which leads to accidents, complete or partial shutdown of sewage conveyance and its penetration into the ground or groundwater [258].

The authors of the research investigated the main causes of the deterioration of the sewerage networks and facilities that provoke accidents, and classify them into the following groups: production factors; factors of durability of materials of linear portions of a network; organizational and technological factors; operational factors; factors of the external operating environment [41, 43, 46, 56, 60].

The production factors of the deterioration of the sewerage networks and facilities are primarily due to the process of production of pipes and fittings such as.

- Variations in the thickness of the wall due to the displacement of the cast core, shrink shells of various types and sizes.
- Typical defects arising from the manufacture of pipes made of polymeric materials.
- Deterioration of corrosion resistance and mechanical properties of pipes due to the use of low quality material.
- Insufficient corrosion protection.
- Unadequate pipe joint designs.

During the operation of the sewerage networks and facilities, the process of technical aging of materials and structures leads to their deterioration; therefore, the factors of durability of materials of the linear portion of the network are as follows.

- Corrosion of pipe material and joints due to corrosive media (Figs. 3.1, 3.2).
- Fatigue and fragility of artificial materials.
- Weakening of the stabilizing force of rubber seals.
- Decay of organic materials.

When laying and installing the sewerage networks and facilities, the technological process of construction may be not observed, which in the course of operation leads to a decrease in its operational life. Therefore, the main organizational and technological factors that influence the process of deterioration of the sewerage networks and facilities are identified as follows.

- General violations of technological regulations for pipe installation.
- Implementation of butt joints of pipes with technology breaches.
- Errors during pipe assembly and transportation.
- Insufficient corrosion protection of the pipeline inside and outside.
- Errors in pipe laying and grounding.

Figure 3.1. The condition of Industrialnyi area sewer tunnel in Kharkiv

Figure 3.2. Corrosion of the walls of the 2,000 mm diameter sewer tunnel on Matrosova street in Kharkiv

During the operation of the sewerage networks and facilities their performance is influenced by their operating conditions, both from the standpoint of the centralized wastewater disposal system (operating factors) and from the standpoint of operating conditions [179, 309].Therefore, the operational factors are as follows.

- Service life of the pipeline.
- Fluid pressure drops in the pipeline.
- Corrosion of pipe material and joints due to the effects of microorganisms.
- Corrosion of pipe material and joints due to the effects of wandering currents.
- Insufficient prevention of pressure drop, for example, lack of compensating units.
- Insufficient ventilation and/or too rapid filling, for example, restoration after preventive or repair work.
- Poor water preparation for pipeline materials, for example, lack of equilibrium in carbon lime content (increased corrosion of metal or dam water with low carbon content being corrosive for cement).
- Too high flow rate (loss of corrosion of the material, cavitation of the shape, deformation of the pipe surface).
- Damages due to accidents in water supply networks, at pumping stations.

The factors of the external operating environment include.

- Swelling and shrinkage of soil due to natural conditions.
- Increased transport load.
- Damage due to emergency situations on adjacent networks.
- Appearance of long sedimentary seams on the slopes of the mountains, in the areas of slopes, on the banks of rivers with a strong flow of groundwater and in places with frequent changes in the level of groundwater.

The impact of each of the above factors, to one extent or another, may not lead to the complete deterioration of the sewer tunnel within the given time frame [179, 309]. However, the combined impact of several factors in each group results in irreversible consequences for both the operating company and the community (Table 3.1).

Table 3.1 — Factors affecting the stable operation of the sewerage networks and facilities

Item No.	Group of factors	Affecting factors
1	2	3
1	Production factors (during pipe manufacturing)	Typical defects of casting on metal pipes, inhomogeneity of material. wall thickness variations due to the displacement of the cast nugget, shrinkage holes of various types and sizes. Deterioration in corrosion resistance and mechanical performance of pipes due to the use of low-quality material. Insufficient corrosion protection, for example in general production.Unsuitable pipe joint designs
2	Organizational and technological factors (during pipeline laying out and installation)	General violations of the standard operating procedures for pipe installation; Pipe butt joints made with procedural violations (detachable and non-detachable). Insufficient protection of the inside and outside of the pipeline from corrosion. Errors during pipe laying out and grounding. Errors during pipe storage and transportation
3	Factors of the durability of materials used for the line sections of a network (the technical ageing of materials and structure)	Corrosion of pipe and joint materials due to the corrosive environment. Fatigue and brittleness of artificial materials. Degradation of organic materials, such as jute reinforcement in bituminous shells and sealing rope in sealing joints. Decrease in the stabilizing force of rubber seals
4	Factors of the external operational environment	Soil swelling and shrinkage due to natural conditions. Permanent settlement joints appeared on mountain slopes, in the areas of inclinations, on the banks of rivers with a strong flow of groundwater and in places with frequent changes in the groundwater level. Increased transport loads
5	Operational factors	Service life of the pipeline. Fluid pressure drops in the pipeline. Corrosion of pipe and joint materials due to the action of microorganisms. Corrosion of pipe and joint materials due to the action of wandering currents. Insufficient prevention against pressure drop, for example, lack of compensating devices. Insufficient ventilation and /or too rapid filling, for example, recovery after preventive or repair work. Poor water preparation for pipeline materials, such as lack of equilibrium in carbon lime content (increased corrosion of metal or dam water being corrosive to cement due to low carbon content). Flow velocity being too high (loss of corrosion protection by materials, cavitation of the form, deformation of the pipe surface). Damage due to accidents in water supply networks at pumping stations

Table 3.1 (continued)

3.2. Investigating the Corrosion Process as the Main Factor of the Deterioration of the Sewerage Networks and Facilities

Modern Lines of Researchs of the Corrosion Process in a Sewer Environment

The experience of scientific research in recent years has shown the urgency of improving the operational life of the sewerage networks and facilities, primarily by improving their performance [90, 104]. According to the outcomes of scientific works [274–278], sulfur corrosion affecting the sewer and tunnel structures occurs in the part of the vault on the inner surface of the lining (Figs. 3.3, 3.4).

The process of biogenic corrosion was investigated according to the following scenarios.:

- Theoretical and experimental studies were conducted by immersing the samples in a corrosive environment (natural or laboratory) to further identify the characteristics of the pipeline material or protective coatings.

Figure 3.3. A 1,500 mm diameter sewer deteriorated due to corrosion on Pivdenna street in Kharkiv

Figure 3.4. A collapsed sewer at Bezlyudivski treatment facilities

- Studies of the issue of forecasting an eventual operational failure of the pipeline. For this purpose, a deterministic method of life factor is ggenerally used, the basis of which is the assessment of factors and minimization of the impact on their operational reliability [90].

Based on the comparison of modern scientific research work, the areas of research can be grouped as follows.

- Theoretical research into microbiologically influenced corrosion (Table 3.2).
- Experimental research into the corrosion process (Table 3.3).
- Research into methods for preventing microbiologically influenced corrosion (Table 3.4).
- Experimental research into corrosion-resistant materials (Table 3.5).
- Methods of forecasting corrosion processes, extending the service life of pipelines (Table 3.6).

Table 3.2 — Theoretical Research into Microbiologically Influenced Corrosion

Item No.	Researcher (Group of researchers)	Country, year of the research	Highlights of the research	Authors' comment
1	2	3	4	5
1	Nazemi M. [286]	Australia, 2016	Microbiologically influenced corrosion on the inner surface of sewers is considered to be corrosion induced by the activity of various microorganisms, including bacteria and fungi	The research does not fully cover the process of influence of the anaerobic environment on the condition of the pipeline during long- term operation
2	Matthews D., Cox A. [281]	USA, 2015	The process of influence of anaerobic microorganisms on the technical condition of metal pipelines of water supply and sewerage is considered	The specifics of the anaerobic environment in water supply and sewerage networks have significant differences, but their generalization into a single whole is not appropriate

Table 3.2 (continued)

1	2	3	4	5
3	Mahmoodian M., Alani A. [274]	United Kingdom, 2016	The research considers sulfide corrosion in reinforced concrete sewers, which is the most common form of reducing their service life. Corrosion parameters are considered as random variables because of data scarcity and uncertainties involved in the impact of corrosion on the condition of sewer networks	The research had better use the findings of existing research into the effect of corrosion on the condition of pipelines; hence, the number of relatively unknown parameters of corrosion could be reduced
4	Mahmoodian M., Alani A. [274]	United Kingdom, 2017	The research finds that the depth of the corrosion pit is a key element for predicting the performance of cast iron pipes affected by corrosion	The research is quite extensive, but it does not show how exactly the residual life of cast iron pipelines will be predicted
5	Dong Q. and coauthors [238]	China, 2017	Attention is focused on the fact that the sulfur cycle resulting from the activity of the microbial population may in the end cause serious problems in the sewerage distribution systems. The results of the research indicated that a higher diversity of microbial species was present at locations of sewers with high concentrations of H_2S.	The research does not sufficiently cover the nature of the microbial community in the conditions of dynamic environmental factors in the actual sewerage system during its continuous operation.
6	Loto C. [270]	Republic of South Africa, 2017	The research gives an in-depth review of microbiologically influenced corrosion and investigates into the bacterial population. The review also reports on biofilms, various mechanisms for reducing the number of sulfate-reducing bacteria, methods of biodetermination of the environment, and so forth	The research does not provide the boundary relation of the content of microorganisms that affect the time of the corrosion process
7	Bill D. and coauthors [229]	Australia, 2016	The issue of the influence of microbiological and biofilm processes on corrosion is deepened. The authors proposed a study of inhibition of microbiological corrosion using Omics-methods, where you can better understand the bacterial population in terms of diversification and metabolism	Both traditional methods of biogenic corrosion research and innovative ones for
8	Routil L. and coauthors [299]	Czech Republic, 2015	The researchers have investigated into the effect of microbiologically influenced corrosion on the bearing capacity of concrete sewers during their operation. The authors have found that every year the pipelines in operation have a decrease in their bearing capacity, primarily because of the wear and tear of the reinforcing bars	The research should better consider designs of sewer shafts in a complex, separation of reinforcing cores does not reflect the general process of decrease in their bearing capacity as, first of all, concrete is exposed to biogenic corrosion

Table 3.3 — Experimental Research into Microbiologically Influenced Corrosion

Item No.	Researcher (Group of researchers)	Country, year of the research	Highlights of the research	Authors' comment
1	2	3	4	5
1	Nazemi M. [286]	Australia, 2016	Microbiologically influenced corrosion on the inner surface of sewers is considered to be corrosion induced by the activity of various microorganisms, including bacteria and fungi	The research does not fully cover the process of influence of the anaerobic environment on the condition of the pipeline during long- term operation
2	Matthews D., Cox A. [281]	USA, 2015	The process of influence of anaerobic microorganisms on the technical condition of metal pipelines of water supply and sewerage is considered	The specifics of the anaerobic environment in water supply and sewerage networks have significant differences, but their generalization into a single whole is not appropriate
3	Mahmoodian M., Li C. [277]	United Kingdom, 2016	The authors investigated the effect of temperature and acidity of sulfuric acid solution on particular specimens of reinforced concrete sewer pipes. Concrete specimens were immersed in three different solutions of sulfuric acid (pH = 0.5, pH = 1 and pH = 2) for 91 days at different temperatures (10, 20 and 30 °C). Mass loss and compressive strength of concrete specimens were tested and recorded at 7, 14, 28, 42, 56 and 91 days, providing interesting data to visualize changes occurring in specific specimens (change in properties) during the immersion time. The results showed that the total mass of the samples increases in the early stages of the corrosion process. It was also found that the total weight of the samples decreased significantly in the later stages of the testing process for the acidity of the solutions used	Experimental data have shown a high correlation between solution acidity and corrosion rate over time, but 91 days of laboratory studies are not enough to study the corrosion process in detail. The presence of samples in solutions for more than 91 days will allow you to get probable results
4	Orlova S.S. and coauthors [290]	Russia, 2016	Using statistical and field data on the growth of the depth of the corrosion cavity, a quantitative assessment of the corrosion risk of metal drainage pipelines. Analysis of the obtained dependences showed that for some time, after contact of the pipeline with wastewater, the metal will not collapse, then the corrosion process develops with some acceleration, and then becomes clearly fading	It should be noted that it would probably be appropriate to compare data from field and laboratory studies. The process of corrosion of pipes in operation depends on a number of factors and can differ significantly from the samples for the experiment
5	Huang Ch. and coauthors [254]	China, 2017	The influence of fluid composition on the corrosion rate of metal pipelines has been studied. The authors found that the concentration of sodium hydroxide 30 % or 50 % sulfuric acid to adjust the pH of water can ensure a corrosion rate of metal pipeline of at least 0.075 mm / year, which meets the safety requirements of relevant standards within the range	Prolonged laboratory tests will allow you to get probable results on the speed and nature of corrosion

Table 3.3 (continued)

1	2	3	4	5
6	Romanova A. [297]	United Kingdom, 2016	The process of corrosion of concrete and reinforced concrete sewer pipes caused by hydrogen sulfide, The main attention is paid to laboratory experiments to establish the corrosion rate of concrete by immersing the samples in a solution of sulfuric acid for up to 120 days at temperatures of 10–30 °C. The results showed that some samples at a very early stage of the corrosion process gained total mass and density with the reverse process over time. In general, corrosion rates of 5-25 mm / year were observed in the laboratory.	In the study, it would be advisable to immerse the samples in different concentrations of sulfuric acid, which would allow for comparison and construction of relevant dependencies.
7	Hans I. [252]	Turkey, 2015	The author notes that many studies have been conducted on different types of corrosion of steel bars. However, only some works deal with to the effects of corrosion due to the action of sulfuric acid on the wear of the fittings. Studies have been conducted to study the corrosion behavior of unprotected carbon reinforced steel under the action of different concentrations of H_2SO_4 solutions. Fittings in sizes Ø12, Ø14, Ø16 and bent at angles of 0°, 45°, 90°.	It should be noted that steel rods and concrete work together to ensure the bearing capacity of collectors, therefore it is expedient to consider this question not separately from each other.

Table 3.4 — Research into methods for preventing microbiologically influenced corrosion

Item No.	**Researcher (Group of researchers)**	**Country, year of the research**	**Highlights of the research**	**Authors' comment**
1	**2**	**3**	**4**	**5**
1	Nazemi M. [286]	Australia, 2016	As the main method of controlling MK, special attention is paid to polymer coatings, such as epoxy solutions, the effectiveness of which depends on understanding how the properties of the coating affect their ability to resist the spread of corrosion. The study also highlights the interaction of anti-corrosion coating and organic and inorganic acids found in the sewer environment.	Modern sewage pipelines are a complex set of interconnected structures in which various physical, chemical and biological processes take place. The operation of such processes is not controlled and is accompanied by significant costs associated, in particular, with a decrease in the operational reliability of sewer collectors. Almost all modern studies of methods to increase the service life of sewerage networks, which are destroyed by microbiological corrosion, are associated with the use of technologies for the use of polymeric materials. Multicomponent modern materials have high-quality anti-corrosion properties damage to structures.
2	Moskvicheva E. with co-authors [284]	Russia, 2016	The problems of steel drainage pipelines that arise as a result of corrosion and biological growth are analyzed. The authors present recommendations for the prevention and protection against biogenic corrosion of existing and drainage pipelines under construction.	

Table 3.4 (continued)

1	2	3	4	5
3	Noah T. [288]	Australia, 2017	The paper considers the biogenic impact on the technical condition of sewers. Recently, to prevent and control damage by biogenic corrosion of concrete structures in corrosive environments, nanomaterials with new functionalities, such as self-protection and anti-corrosion ability, have been successfully developed. The author presents an overview of both existing control measures to prevent biocorrosion and advanced nano-approaches to protect specific structures from biogenic wear	

Table 3.5 — Experimental research into corrosion-resistant materials

Item No.	**Researcher (Group of researchers)**	**Country, year of the research**	**Highlights of the research**	**Authors' comment**
1	**2**	**3**	**4**	**5**
1	Matthews D., Cox A. [280]	USA, 2015	The authors present polymer nanocoatings for corrosion control of iron pipelines	The compositions of epoxy coatings proposed by the authors in the study of microbiological corrosion of metal pipes in the laboratory demonstrated their high quality indicators. However, it would be appropriate to conduct a detailed analysis and testing of samples at different concentrations of H_2SO_4
2	Tambe S. and co-authors [313]	India, 2016	The microbiological phenomena of corrosion of sewage networks in the laboratory are simulated and the characteristics of epoxy coatings with and without biocides are investigated by extraction of their culture of sulfate reducing bacteria under anaerobic state	

Table 3.5 (continued)

1	2	3	4	5
3	Royem N. and co-authors [296]	Brazil, 2016	The study is concerned with the study of the use of polymer matrix composites for the repair and strengthening of damaged pipeline structures. On the basis of experimental researches efficiency of a new composite material for restoration of an internal wall of pipelines is revealed	The authors experimentally studied composite materials for the protection of concrete and reinforced concrete sewers from biogenic corrosion. Tests of samples for time (more than 120 days) were not performed, but given the complexity of populations of microorganisms, it would be advisable to conduct a study lasting more than 120 days
4	Pozoki M. and co-authors [291]	Iran, 2016	The evaluation of polyurethane and polyvinyl chloride in the lining of concrete sewer pipes to prevent biological corrosion is presented. Experimental results showed that after three months, compared with PVC, polyurethane showed better strength and resistance in acidic aggressive environments	
5	Luo K. and co-authors [272-273]	China, 2016	The research deals with the description of tubular composite raw materials and comparison of methods of formation and evaluation of their productivity, first of all from the standpoint of durability and corrosion resistance	
6	Kolisvi M. [264]	South Africa, 2016	The scientist's research deals with the study of the rate of biogenic concrete corrosion, which depends, in particular, on the chemical composition of binders (cement, additional cementitious materials and microstructural characteristics of concrete mixtures used in the manufacture of sewer pipes)	

Table 3.6 — Methods of forecasting corrosion processes, extending the service life of pipelines

Item No.	Researcher (Group of researchers)	Country, year of the research	Highlights of the research	Author's comment
1	2	3	4	5
1	Matthews D., Cox A. [280]	USA, 2015	The authors present polymer nanocoatings for corrosion control of iron pipelines	The compositions of epoxy coatings proposed by the authors in the study of microbiological corrosion of metal pipes in the laboratory demonstrated their high quality indicators. However, it would be appropriate to conduct a detailed analysis and testing
2	Mahmoodian M., Alani A. [376]	Great Britain, 2016	A reliability-based methodology for assessing the performance of pipes under the influence of biogenic corrosion is presented. The depth of the corrosion lens is considered a critical parameter that causes the failure of the sewer collector when it exceeds the wall thickness of the pipe	The model developed by the authors to determine the depth of corrosion of cast iron pipes allows to quantify the probability of leaving the operational distribution network, but special attention is not paid to butt joints of pipes, which may not accurately predict its exit from working condition
3	Mahmoodian M., Alani A. [275]	United Kingdom, 2017	The study introduced a time-dependent nonlinear state model for structural analysis of corrosion-resistant steel pipelines reinforced by external forces. Following the concept of the limit state, the simultaneous effect of external loading and corrosion of the material is considered by the authors in the failure modes. To account for uncertainties related to design parameters and the environment, the Monte Carlo modeling technique using MATLAB was used	The authors used a model to model the loss of pipe wall thickness during the period of operation. However, in terms of predicting the exit of the pipeline from working order, the loss of wall thickness of the pipe is not the main indicator, it is necessary to take into account the factors that affect the reliability of the set
4	Orlova S. S. with co-authors [290]	Russia, 2016	Using differential geometry, an approach to definition of reliability of operation of sewer collectors is developed. Graphic differentiation allowed to find quantitative values of the speed of the corrosion process, to identify the nature of its change over time; determine the relationship between the depth of the corrosion cavity and the rate of formation of this cavity; establish that the corrosion process can be described by a differential equation	The presented approach is meaningful, and for further implementation in production and use in practice requires certain qualifications
5	Anbari M. and co-authors [224]	Iran, 2017	A probabilistic model of risk assessment of the drainage network is presented, which included both structural and hydraulic failures, primarily due to their damage by microbiological corrosion. This model is based on the approach to calculate the probability of failure and the weighted average method for calculating the consequences of failure values using Bayesian networks. A fuzzy inference (FIS) approach has been used to address the uncertainties and consequences of failure values	The system of fuzzy conclusions requires a high knowledge base for their formation. To assess the risk of failure of the network, special attention should be paid to factors that affect the performance of a particular section of the pipeline

Table 3.6 (continued)

1	2	3	4	5
6	Alani A. and co-authors [274]	United Kingdom, 2016	Three probabilistic methods of reliability analysis have been developed, including: time model, including probability theory, gammaray wear model and Monte Carlo modeling methodology	The temporal model of reliability assessment should be based on experimental research, but this is not covered in the paper
7	Stanyk N. and co-authors [308]	The Netherlands, 2017	The authors present an improved prototype of the technology for assessing the impact of biogenic corrosion and technical condition of the pipeline with a 3D image of the pipe	The 3D image of the pipe in operation gives a visual idea of its operation in the environment under the impact of factors
8	Elmesri M. and co-authors [240]	Canada, 2017	A model of wear of sewers based on defects (primarily due to corrosion) for sewage pipelines using Bayesian belief network models (BBN) is presented, which is used to develop a static model using event probability and conditional probabilities from observations of the existing sewer network. Temporal measurements are entered into the developed model, using logistic regression as temporal connections, necessary to build a dynamic Bayesian beliefs network	Implementation and testing in practice of the proposed model and the accuracy of its work depends on the actual data regarding the pipeline in operation. Therefore, the completeness of the data will allow predicting failure
9	Ian N. and co-authors [259]	France, 2015	The work deals with modeling the wear and destruction of concrete under the influence of biogenic acid. A reactive transport model for simulating all bioabsorption processes is proposed concrete in contact with H_2S and sulfur bacteria	The authors describe this process in three stages: neutralization of the concrete surface, which provides a suitable environment for the growth of oxidizing sulfur bacteria, the formation of sulfuric acid (H_2SO_4) and chemical reactions between the products of H_2SO_4 and hydration of cement

Based on the review of latest research, approaches, and practices dealing with the investigation into corrosion processes in the sewerage networks and facilities, and following the results of their grouping according to the area of research, the authors proposed a method of investigating microbiologically influenced corrosion in the sewerage networks and facilities, and basic techniques to prevent it [90].

The rationale for choosing the method is justified by the fact that the logical structure of conducting research should be based on theoretical, experimental (field and laboratory) research into the process of biogenic corrosion. Based on the obtained insight into the complex process of biogenic corrosion, modern methods of combating it (field and laboratory tests of corrosion-resistant materials, compounds, etc.) should be diagnosed. On the basis of the data obtained, a rational method is chosen to protect the pipeline in operation against biogenic corrosion.

Investigating the Corrosion Resistance of Materials Used to Restore the Stable Operation of the Sewerage Networks and Facilities.

Assessing the Corrosion Resistance of Modified Concretes in Sulfuric Acid Solution

The sewerage networks and facilities, due to the action of deterioration factors, primarily the effects of sulfuric acid of biogenic origin, are currently in disrepair or in dilapidated state [25, 26]. Restoring their operational characteristics is an important area of research. Concretes based on cements used in rehabilitation work allow addressing the issue with technical and economical efficiency. Improving the physical and chemical properties of concrete is a modern area of research for researchers in Ukraine and abroad [27–33]. The introduction of chemical admixtures is aimed at reducing the permeability of concrete, which according to DSTU Б В.2.6-145:2010 [34] is one of the main ways to reduce the corrosivity of the environment towards concrete. Using active and pozzolanic mineral admixtures according to [27, 32, 33] allows obtaining hydrates more resistant to sulfuric acid. As a result of many years of laboratory and field tests, the author [31] also concluded that admixtures in highly corrosive environments cannot provide the necessary durability of concrete without the use of secondary protection.

The corrosion resistance of modified concretes in sulfuric acid solution was assessed by exposing the specimens to the concrete corrosive environment for a period of 180 days [27–33]. The materials used to produce Set 8 of 16 concrete mixes are given in Table 3.7. The compositions were prepared from two types of cement, CEM II / A-S 32.5 and CEM III / A 32.5, granite crushed stone 5–10 mm, fine quartz sand, tap water and highly effective modifying additives, which are usually used to reduce the porosity and increase the corrosion resistance of concretes [31].

The materials used were as follows: a polycarboxylate-based superplasticizer to produce ready-mixed concrete (A1); a mineral pozzolanic admixture such as highly dispersed microsilica obtained from the waste from the local ferroalloy plant (A2); a colmatant modifying concrete microstructure such as Portland cement and various active, protected chemicals. These active chemicals react with moisture in fresh concrete and with cement hydration by-products to set off a catalytic reaction that produces insoluble crystalline formations in the pores and capillaries of the concrete (A3); as water repellent and waterproofing admixture, an aqueous solution of potassium methyl siliconate (A4) is used. The optimum concentrations of admixtures were chosen with reference to their effect on concrete hardening and their compatibility with cements [36]. The component consumptions are given with regard to the actual density of concrete mixes. Sets I to VII were produced from high-slump mixes and Set VIII from a no-slump mix. All sets except Set VII had an approximate binder consumption of 400 kg/m^3, and Set VII had a consumption of 600 kg/m^3 of concrete [31].

According to DSTU Б В.2.7-213:2009 [37] and DSTU Б В.2.6-181 : 2011 [38], the acid concentration under which the test is performed is not regulated and should be chosen depending on the operating conditions of the structure. When investigating the effect of sulfuric acid on the corrosion rate of cement stone and concrete, the acid concentration is taken to be in the range of 0.01 to 10 % [39–40]. On the assumption that the concentration of sulfuric acid on the concrete surfaces of sewers may reach several percent, for conducting research, its value was chosen according to ASTM C267-01 [40] and was equal to 5 %. Cube and beam specimens measuring 10 × 10 × 10 cm and 16 × 4 × 4 cm respectively were made according to standard methods and exposed for 28 days under normal conditions, after which some specimens were picked up to determine the compressive strength, bending tension, and water absorption of concrete by weight (Table 3.7).

Table 3.7 — Concrete mix proportions in the specimens

Set	Mixes	Cement		Coarse aggregate, kg/m^3	Fine aggregate, kg/m^3	Water, kg/m^3	W/C	Shrinkage, cm	Value	
		Type	kg/m^3						Admixture	kg/m^3
I	1	CEM II	397	1041	744	247	0.62	20	-	-
	2	CEM III	391	1026	733	245	0.63	20	-	-
II	3	CEM II	397	1043	745	205	0.52	19	A1	6
	4	CEM III	397	1043	745	199	0.5	26	A1	6
III	5	CEM II	403	1057	755	192	0.48	25	A1	8.1
	6	CEM III	404	1061	758	184	0.46	26	A1	8.1
IV	7	CEM II	366	1044	746	175	0.48 (0.44)	21	A1	8
									A2	31.8
	8	CEM III	364	1037	741	168	0.46 (0.42)	22	A1	7.9
									A2	31.6
V	9	CEM II	368	1050	750	178	0.48 (0.44)	23	A1	8
									A2	32
									A3	4
	10	CEM III	363	1037	741	171	0.47 (0.43)	22	A1	7.9
									A2	31.6
									A3	4
VI	11	CEM II	360	1028	734	174	0.48 (0.44)	24	A1	7.8
									A2	31.3
									A3	3.9
									A4	0.8
	12	CEM III	359	1024	731	168	0.47 (0.43)	23	A1	7.8
									A2	31.2
									A3	3.9
									A4	0.8
VII	13	CEM II	558	1062	587	167	0.3 (0.28)	26	A1	12.1
									A2	48.5
									A3	6.1
	14	CEM III	557	1059	585	163	0.29 (0.27)	27	A1	12.1
									A2	48.4
									A3	6.1

Other specimens were immersed in a reservoir filled with a 5% solution of sulfuric acid (Fig. 3.5, a) and soaked for 28, 56 and 180 days. The concentration of the acid solution was controlled by its density. In case of a decrease in the density, the required amount of acid was added to reach the initial value of the density of the solution. In each specified period of time, two specimens were taken from the solution, and the corroded layer of concrete was removed using a brush (Fig. 3.5, b). Next, the specimens were weighed, photographed before being tested, and then tested for strength and pH. To determine the pH, after destroying the specimens concrete samples were taken from the surface and the inside (at least 1 cm from the edge of the specimen), and the pH of the aqueous extract was found using the pH indicator.

a b

Figure 3.5. Specimens after being soaked in the sulfuric acid solution
(a): Soaking in the acid solution;
(b): After removing the corroded layer

The water absorption of concrete specimens by mass (W_m) after 28 days is given in Table 3.8. Modifying admixtures allowed reducing the water absorption by 2 to 2.5 times. The maximum effect of reducing the water absorption was achieved through the introduction of superplasticizer admixtures, which allowed reducing the water consumption and the water-binder ratio. All other admixtures did not have a significant effect on the water absorption of concrete (W/B). A more significant decrease in the water absorption was observed in concrete made with CEM III/A 32.5.

Table 3.8 — Water absorption of concrete

Mix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Wm, %	8.1	8.4	7.2	6.9	5.8	5.8	6	5.5	5.6	5.2	5.7	4.8	3.9	3.4	4	3.4

All the specimens irrespective of the type of cement, composition, strength and water absorption show a complete deterioration of the upper mortar layer of concrete after 28 days. The loss in the mass of the cube and beam specimens ranged from 3.6 to 6.6 % and 9.2 to 16.3 % respectively; 7.2 to 12.6 % and 16.8 to 32.8 % respectively after 56 days, and 11.8 to 22.5 % and 21.7 to 50.3 % respectively after 180 days. The specimens reduced in overall size by 5 to 10 mm after 180 days, which corresponds to a corrosion rate of 5 to 10 mm / year. The loss in the mass was 2 to 2.5 times greater for the beam specimens than for the cube specimens, which is due to a 1.9-fold increase in the coefficient of the exposed surface area. Therefore, beam specimens are more appropriate to rapidly assess the corrosion resistance of concrete. It should be noted that apart from the size of the specimens, the obtained results can be significantly affected by the exposure conditions. For instance, with a continuous circulation of the acid solution, an increase in the corrosion rate is observed [41].

The type of cement did not significantly affect the loss in the mass of the specimens, that is, an increased addition of slag does not improve the resistance of concrete in these conditions. Neither a 1.5 to 3-fold increase in the strength of the specimens (Table 3.9) nor a decrease in the water absorption did not allow improving the resistance of concrete. On the contrary, the sets of the specimens containing admixtures could show a slightly greater loss in the mass. The exception was Set VII having high cement content, a compressive strength of 76.7 to 82.5 MPa and a W/B ratio of 0.27 to 0.28. Set VII was losing less mass than Set I after 56 days of soaking, and particularly after 180 days of soaking. However, there is no clear indication that a decrease in the permeability of concrete and a reduction in W/B to 0.27 could improve the resistance of concrete because no such effect was observed with Set VIII. According to research [33, 41], a reduction in W/B leads to a decrease in the corrosion resistance.

Table 3.9 — Loss of mass of concrete samples after soaking in a 5 % solution of sulfuric acid

Sets	**Mixes**	**Mass loss, %**					
		Cube			**Beam**		
		28 days	**56 days**	**180 days**	**28 days**	**56 days**	**180 days**
I	1	3.6	9.0	15.8	10.4	21.9	41.7
	2	3.6	8.6	17.6	9.2	23.8	41.7
II	3	5.0	12.2	20.2	11.3	28.8	42.2
	4	5.0	10.8	20.9	13.2	20.5	43.3
III	5	5.6	12.3	19.0	10.5	28.6	38.8
	6	5.7	9.1	17.6	15.0	26.8	40.6
IV	7	6.3	11.6	21.0	12.0	28.2	43.8
	8	6.6	11.7	21.5	16.3	31.2	48.1
V	9	6.0	12.1	20.9	12.9	29.0	41.9
	10	6.1	11.4	21.0	14.5	32.8	48.9
VI	11	6.3	10.8	21.5	13.5	28.8	44.0
	12	6.7	12.6	22.5	15.8	30.0	50.3
VII	13	4.5	8.5	12.0	10.2	16.8	21.7
	14	4.3	7.2	11.8	12.9	19.3	23.8
VIII	15	5.7	10.0	20.6	12.6	25.1	43.0
	16	5.1	9.2	21.2	13.5	31.5	46.6

In research [33] there was an increase in the weight loss of the samples with a decrease in W/B from 0.45 to 0.25, and in research [41] a change in W/B from 0.65 to 0.35 led to an increase in the thickness of the deterioration of concrete. This is due to the fact that concrete with a high ratio of cement in water has a higher ability to absorb the reaction of expansion of gypsum production than one that has a low coefficient of water-cement. Comparison of Sets III–VI, which had approximately equal W/B (0.43–0.48), allows us to state that the introduction of microsilica additives, colmatant and hydrophobic admixtures in the selected concentrations is completely ineffective. Thus, the statement of the authors [27] is confirmed, that the effectiveness of mineral supplements needs to be tested in each case. In general, we can conclude that the corrosion rate of concrete is very significant for all sets of samples, because according to the requirements of DSTU Б В.2.7-213:2009 the loss of mass of chemically resistant concrete after one year should not exceed only 1%.

Table 3.10 — Change in the strength of concrete specimens after soaking in a 5 % solution of sulfuric acid

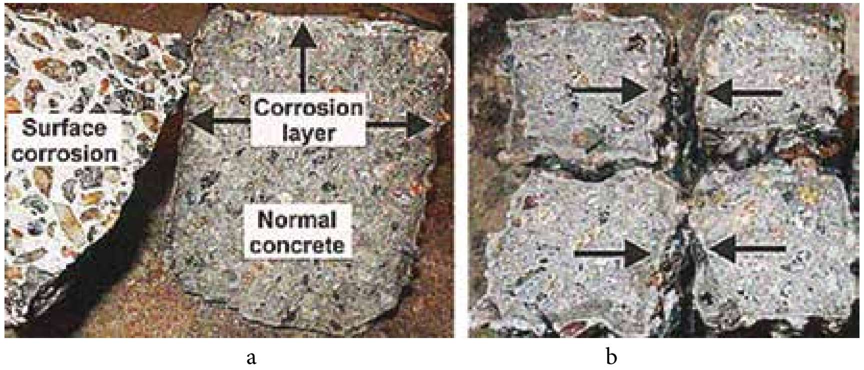
Sets	**Mixes**	**Pinitial strength, MPa**		**Loss of strength, %**			
		28 days	**56 days**	**28 days**		**56 days**	
				Compressive strength	**Flexural strength**	**Compressive strength**	**Flexural strength**
I	1	26.4	4.6	19.2	-18.8	38.6	14.9
	2	26.1	5.0	22.6	26.4	43.3	34.5
II	3	38.2	7.0	35.2	19.3	52.3	31.5
	4	39.5	5.7	36.9	6.8	58.3	26.4
III	5	44.1	7.5	36.5	3.1	53.8	50.3
	6	50.0	7.0	37.7	-1	48.7	40.4
IV	7	44.7	7.3	34.5	12.4	53.2	45.1
	8	46.5	6.3	46.1	19.9	60.1	38.2
V	9	48.9	8.4	33.6	10.2	55.1	46
	10	48.2	7.5	35.4	7.7	53.4	43.4
VI	11	45.9	7.8	31.3	26.3	56.4	40.2
	12	51.8	8.6	37.2	31.6	62.7	46.3
VII	13	76.7	8.2	37.9	-39.4	57.2	10
	14	82.5	8.7	35.8	14.5	48.2	9.4
VIII	15	64.6	9.0	36.6	62	49.0	60.9
		62.5	8.7	32.7	32.7	43.6	55.7

The loss of strength of concrete specimens due to corrosion was more significant than the loss of mass. The compressive strength of the cube specimens decreased by 19–46 % after 28 days and 39–63 % after 56 days of soaking. The flexural strength changed differently: in Specimens 1, 6, 13 there was an increase in strength to 39 %, and in other specimens there was a decrease in strength to 62 % in 28 days. At 56 days, there was a decrease in compressive strength by 39–63 % and flexural strength by 9–61 %. The correlation between the change in compressive strength and bending was not observed, the results were random. For example, Specimen 13 had a decrease in compressive strength by 38 % and an increase in bending strength by 39 % (Table 3.10).

In view of this, in 180 days the strength of concrete was not determined. This nature of the change in the strength of concrete, in our opinion, is associated with uneven load transfer to the surface of the specimens with exposed coarse aggregate. The body of the concrete itself has not undergone visual changes (Fig. 16), so all concrete of the specimens could not reduce the strength so much. The absence of corrosion of the internal concrete of the specimens confirms the pH value of the water extract, which was equal to 3-5 on the surface, and 12 inside for all specimens.

According to [39, 41] there are three distinct layers of concrete, the first, a loose surface layer of corroded concrete, which has no strength, the second, a thin (several mm) layer of concrete, which has some strength, and the third, inner concrete in which there is no deep or selective deterioration. To more accurately determine the strength of concrete in the study [33], the surface was leveled with cement-sand mortar 1 : 3. This allowed obtaining clearer dependences of the loss of strength of concrete over time, the value of which for 180 days for different compositions of concrete was from 20 to 45 %. But, in our opinion, this method of specimen preparation should not be considered the most effective. To obtain accurate results, it is necessary to completely remove the second layer of concrete and prepare the surface of the specimens for testing according to standard requirements. An alternative method of analysis of changes in the strength of concrete can be splitting cubes to determine the tensile strength (Fig. 3.6). In this case, the effect of the surface of the specimens should not be significant.

The obtained results show that the method of determining the weight loss is more correct than the method of determining the strength of concrete. The authors of the measurement of weight loss determined the appropriate test method to determine the strength of concrete against the attack of sulfuric acid [33]. However, when testing in a less concentrated solution (1 %), we believe that weight loss itself is not a reliable indicator for measuring the strength of concrete in acid attack, and it should be supplemented by strength tests.



a b

Figure 3.6. Concrete specimens after tensile tests: (a) cubes; (b) beams

To date, there is no single method in the world to determine the resistance of concrete to the action of sulfuric acid solutions, which significantly affects the results obtained by various researchers. The most important factors are the concentration of the acid solution, the soaking conditions and the size of the specimens. Particular attention should be paid to the method of determining the strength of concrete that has a decayed top layer. The conducted studies have shown that the selected admixtures do not significantly change the resistance of concrete based on conventional cements to the action of a solution 5 % of sulfuric acid. Improving the strength properties, reducing the W/B value to 0.3 and reducing the absorption of concrete by 2–3 times is not effective. Concrete with a W/B value of less than 0.25 and more than 0.65 needs further testing.

Investigating the Resistance of Aluminous Cement-Based Concrete to the Action of Sulfuric Acid Solution

It has long been known [42, 43] that aluminous cement-based concrete feature greater sulfate resistance than Portland cement-based concrete, as evidenced by examples of successful long-term operation of structures in sulfate media. This is due to the peculiarities of the chemical and mineralogical composition of cement stone in which there is no soluble calcium hydroxide, easily leachable, the presence of insoluble hydrate of alumina and dense formations of low-basic calcium hydroaluminates. However, when it comes to the action of sulfuric acid, aluminous cement-based concrete, like Portland cement-based concrete, loses its performance properties under long-term exposure, although it may show greater corrosion resistance.

This study was aimed at investigating the corrosion rate of aluminous cement-based concrete depending on its physical and mechanical properties, and comparing it with the corrosion rate of Portland cement-based concrete.

Four sets of concrete sppecimens based on Calight 40 (Netherlands) and Gorkal 40 (Poland) cements were made for testing. Granite crushed stone of size 5 to 20, quartz sand of FM = 1, superplasticizer polycarboxylate Sika Greate 1020 UA (SP) and microsilica (MS) were used to prepare concrete mixes. Beam specimens measuring 160 × 40 × 40 mm were made according to standard methods and exposed for 28 days under normal conditions, after which some specimens were picked up to determine the compressive strength, and water absorption of concrete by weight. Other specimens were immersed in a reservoir filled with a 5 % solution of sulfuric acid and soaked for 28 and 56 day. In each specified period of time, two specimens were taken from the solution, and the corroded layer of concrete was removed using a brush (Fig. 3.7), after that they were weighed. Due to the unevenness of the corroded surface, the strength of the specimens was not determined. The concrete compositions, their properties and the results of keeping the specimens in the solution of sulfuric acid are given in Table 3.11.

Table 3.11 clearly shows that the mass loss of the specimens significantly depended on the W/C ratio. With increasing W/C from 0.3 to 1.3 the mass loss increased from 5.6 — 10 % to 38.5 — 40.3 % after 28 days of soaking and from 9.4 — 12.6 % to 54.1 — 60 % after 56 days. The mass loss for all specimens was lower in Calight 40-based specimens; however, it was only 1 to 6 %.

The results of previous studies of Portland cement-based concrete [44] showed that modifying concrete with admixtures and reducing the W/C ratio from 0.65 to 0.27 does not increase the resistance of concrete to sulfuric acid solution. The mass loss was 28.2 % in 28 days and 20.5 — 31.5 % in 56 days, and no relationship was found between mass loss and concrete properties. A decrease in W/C could lead to an increase in mass loss.

From the obtained results it can be concluded that aluminous cement-based concretes, and Portland cement-based concretes, are not resistant to sulfuric acid corrosion, whichever the W/C ratio. However, its value for aluminous cement plays a significant role, and at low values aluminous concrete is more resistant to sulfuric acid than Portland cement-based concrete. The obtained results are in agreement with the conclusion in the study [45] that there is no significant difference in the resistance of Portland cement, pozzolanic Portland cement and aluminous cement under the action of concentrated sulfuric acid solutions, whatever the cement type and clinker mineral composition.

Table 3.11 — Specimen features

Sets	Mixes	Cement		Crushed stone, kg/m^3	Sand, kg/m^3	Water, kg/m^3	Admixtures		W/C	ST, cm (W, s)	Wm, %	Compressive strength, kgf/cm^2	Mass loss, %	
		Type	kg/m^3				SP, %	MS, %					28 days	56 days
I	1	Caligt	400	1050	750	225	-	-	0.56	21	6.8	635	14.3	19.1
	2	Gorkal	400	1050	750	239	-	-	0.59	20	6.6	580	16.6	23
II	3	Caligt	400	1050	750	168	1.5	-	0.42	20	5.3	780	11	17.5
	4	Gorkal	400	1050	750	177	1.5	-	0.44	24	4.5	760	14.2	18.5
III	5	Caligt	200	1100	850	249	-	-	1.25	17	8.7	125	38.5	54.1
	6	Gorkal	200	1100	850	259	-	-	1.3	20	9.2	160	40.3	60
IV	7	Caligt	400	1400	500	120	1.5	12.5	0.3	60 (s)	3.4	920	5.6	9.4
	8	Gorkal	400	1400	500	120	1.5	12.5	0.3	60 (s)	2.9	800	10	12.6

a

b

Figure 3.7. Specimens after being soaked in a 5 % solution of sulfuric acid: (a) before cleaning; (b) after cleaning corrosion products

Investigating the Effectiveness of Protection of the Concrete Surface Using Epoxy Coating From the Action of Sulfuric Acid Corrosion

According to the analysis of the occurrence of accidents in sewerage networks, sewer tunnels, sewers, and inspection shaft structures fail before the standard service life. A study of the operational life of sewerage distribution networks shows that up to 80–90 % of accidents are caused by corrosion processes. Chemical reactions occurring in the free space of the sewer network, form a corrosive environment towards its structures [46–48]. Restoringn the operational characteristics of sewers to extend accident-free service life is a costly and challenging task. Modern cement concrete, which is used for repair work, allows solving it with different technical and economic efficiency. However, it should be understood that acid corrosion is inevitable for them, because cement-based concrete is alkaline in nature and is destroyed by acidic environment.

One of the ways to protect concrete from acid corrosion, including in sewers, there is the application of corrosion-resisstan coatings based on epoxy resins [46]. However, despite the fact that the coatings themselves are resistant to sulfuric acid, their use in the protection of concrete is often ineffective. For example, R. Biletsky and G. Schremmer [48] describe a case of damage to a 4-kilometer section of a sewer in Hamburg two years after commissioning. They occurred on the inner epoxy-insulated surface of Classes C30–C40 concrete, which led to swelling of the coating and subsequent destruction of concrete. N. K. Rosenthal [48] repeatedly observed the same damage to coatings on concrete specimens tested in hydrogen sulfide reservoirs. Their destruction is associated with diffusion processes, osmosis and penetration of hydrogen sulfide or acid under the coating. These mass transfer and corrosion processes largely depend on the properties of concrete and the amount of adhesion of the coating to the substrate. In our opinion, it is appropriate to find effective epoxy coatings in combination with a single concrete-epoxy coating system.

Laboratory studies were conducted in two stages. At the first stage, the stability of concrete in a 5 % solution of sulfuric acid was studied [46–48]. 8 sets of specimens were made in two compositions based on different cements (Portland cement and Portland slag cement), which differed in the content of chemical (superplasticizer, water repellent, colmatant admixture) and mineral (microsilica) admixtures and had different physical and mechanical properties (strength from 25 to 80 MPa, water absorption from 3 to 8 %, water resistance W4–W12 and above) [27–33]. As a result of soaking for 28 days of beams measuring 40 × 40 × 160 mm in a solution of sulfuric acid, all specimens underwent significant surface damage, the mass loss exceeded 10 %, and the strength loss exceeded 20 %. This allowed us to conclude about the low resistance of conventional concretes to the action of sulfuric acid, whatever the type and content of modifying admixtures.

At the second stage, to evaluate the effectiveness of the concrete-epoxy coating system epoxy two-component coating Penetron PenePoxy 2K resistant to sulfuric acid was applied in one layer on the Specimens (No. 2, 4, 6, 8, 10, 12, 14, 16). The thickness of the coating was 1–2 mm. The acid resistance of the coating was tested by immersion for 1 year of beams made of epoxy coating in an acid solution. As a result of the examination of the specimens, no signs of corrosion were found, their mass increased by 1 %, and the tensile and compressive strength did not change.

The joint behavior of the coating and concrete was evaluated by visual inspection of the specimens after exposure to a 5 % solution of sulfuric acid for 60 and 120 days. After 60 days of soaking, all specimens, except specimen No. 10, had minor damage to the epoxy coating (Fig. 3.8).

They were local in nature and formed in places of penetration of sulfuric acid under the coating (Fig. 3.9). After 120 days, the areas of the destroyed coating began to grow significantly (Fig. 3.10). The largest fractures were in specimen No. 14, which had the lowest W/C value (0.27) and the highest binder consumption (600 kg/m^3). Specimen No. 10 had no destruction of the coating for the entire study period [27–33]. Based on the similarity of the composition 10 of 8 and 12, it was concluded that the mechanism of destruction of the coating is largely due to the presence on its surface of local microdefects through which acid penetrates with subsequent expansion of concrete and swelling of the coating. It should be noted that the increase in

Figure 3.8. Specimens with epoxy coating after 60 days of exposure to acid

water resistance of concrete did not lead to a slowdown in the corrosion rate of the concrete-epoxy coating system [27–33]. This allowed us to state that for such systems the use of modified concrete with low water absorption and high water resistance grade is inefficient and can lead to the opposite effect

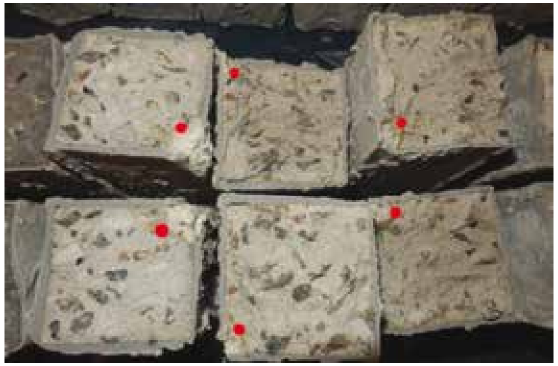


Figure 3.9. Pitting corrosion of epoxy coated concrete

Figure 3.10. Specimens with epoxy coating after 120 days of exposure to acid

with more accelerated destruction of the coating and concrete. To confirm the results of laboratory tests, field studies were conducted with the immersion of concrete samples into the sewer and their soaking for 140 days in the summer [27–33]. In order to speed up research, a sewer shaft was selected in which the concentration of H_2S exceeded 30–50 times its maximum allowable concentration.

After being exposed, all specimens suffered significant deterioration, however, it did not occur on their entire surface. Where the specimens were dry, no corrosion processes were observed [27–33]. These results are due to the significant complexity of research in dilapidated sewer shafts , which are opened twice a year, and to control the progress of research is not possible. In this regard, a quantitative analysis to measure changes in mass and strength was inappropriate. The results were analyzed visually, including by checking variations in the cross section of the specimens in some places [27–33]. They confirmed the previously obtained data on the lack of significant efficiency from increasing the strength and water resistance of concrete. The cross section of all specimens in some places in such a short period of time decreased by 10–15 mm. Coating the specimens significantly protected them from corrosion, but, as in a 5 % solution of acid, there was a local destruction of the coating (Fig. 3.11).

The obtained results allow us to conclude that the studied concrete-epoxy coating system has a much longer service life in a corrosive acidic environment than concrete. For its effective work, first of all, there should be no defects on the surface of the coating, through which the corrosive environ-

Figure 3.11. Uncoated and coated specimens after being exposed in the sewer for 140 days

ment penetrates the concrete surface [89, 147, 221]. They can be reduced by thouroughly coating in several layers. However, this will significantly increase the cost of corrosion protection of concrete. In addition, during the operation of sewer networks, their deformations are inevitable, which may be accompanied by the formation of cracks on the surface of the coatings. Modifiying concrete by admixtures and improving its physical and mechanical properties do not allow for an increase in the stability of the system, and can worsen it. It is appropriate to periodically monitor the condition of coatings to identify and eliminate local areas of corrosion.

3.3. Investigating the Consequences of Accidents Occurring in the Sewerage Networks and Facilities

After analyzing the decrease in the operational life of the sewerage networks and facilities, the main groups of consequences caused by accidents have been classified, in particular the following groups have been identified: ecological; economic; technical; social; innovative [309]. The ecological group of consequences includes the effects on the atmosphere, lithosphere, and hydrosphere (Table 3.12). The economic group of consequences covers the macroenvironment and the microenvironment of the operating company (Table 3.13).

Table 3.12 — Ecological group of consequences of an accident occurred in a sewer tunnel

Item No.	Sphere of impact	Nature of impact	Consequences
1	2	3	4
1	Atmosphere	Release of hydrogen sulfide, mercaptan, sulfur dioxide, carbon dioxide, methane and the like	Intense man-caused environmental load, which is a source of significant environmental hazards for urban areas, especially if the exceedance of maximum allowable concentrations for substances of the second class of danger is recorded
2	Hydrosphere	Penetration into groundwater	Changing the chemical composition of water and the appearance of other undesirable components that threaten environmental safety
		Penetration into surface water of sources	Dangerous increase of concentrations of substances and pollution of the main sources of water supply
3	Lithosphere	Flooding of territories and disturbance of water exchange	Increase in the level of groundwater and their corrosivity as a result of feces water contamination causes the activation of karst processes, which leads to the formation of karst holes, which threatens facilities, the deterioration of the body of foundations, corrosion of reinforcement and concrete; deterioration of soil mechanical properties (shear resistance decreases)
		Soil degradation	Deterioration of soil beneficial properties and fertility
		Suppression of plant complex	Reduced seed germination, slow growth of plants, abnormal development of root systems, chlorosis, withering, plant death
		Contamination of the topsoil with heavy metals	Toxic, even in minimal amounts, heavy metals are not susceptible to decomposition processes, but are only able to be redistributed between natural environments; therefore, they are concentrated in living organisms, causing different pathologies

The technical group of consequences of an accident occurred in the sewerage networks and facilities includes the following: disruption of the stable operation of the wastewater disposal system; stoppage of continuous operation of the wastewater disposal process; search for alternative wastewater disposal solutions; additional load on redundant lines and pumping equipment [309].

A significant impact on the population is due to the inconveniences caused by the disruption in the operation of the centralized wastewater disposal system. The social group of consequences of an accident occurred in the sewerage networks and facilities includes as follows: deterioration of a state of health of people as a result of influence of poisonous gases in air; disruption of the life support system due to the interruption of the centralized water supply and wastewater disposal systems; inconvenience due to the temporary wastewater disposal process; high probability of the occurrence of foci of infectious diseases; danger to the population due to collapsed ground and damage to the road surface; disruption of the normal functioning of the city transport system; aesthetic inconvenience for the population [179, 309].

However, the occurrence of an accident in the sewerage networks and facilities induces an innovative group of consequences, which involves searching for innovative solutions to minimize losses. The innovative group includes: development of alternative solutions for centralized wastewater disposal; development of innovative organizational and technological solutions for rehabilitation of distribution networks; modernization of damaged sections of sewer tunnels; use of modern materials with anticorrosive properties; conducting research into the stable operation of the wastewater disposal system; implementation of a system for monitoring the stable operation of sewer tunnels [179, 309].

Table 3.13 — Economic group of consequences of an accident occurred in a sewer tunnel

Item No.	Sphere of impact	Nature of impact	Consequences
1	2	3	4
1	Macroenvironment of the operating company	The need to allocate additional funds from the budget for carrying out work	Destabilization of the financial environment of the local budget
2	Microenvironment of the operating company	The need to eliminate the emergency.	Allocation of funds for temporary stoppage of wastewater disposal, local elimination of consequences of an emergency
		The need for temporary provision of uninterrupted operation of the wastewater disposal distribution system	Allocation of funds for the installation of a wastewater bypass line, pumping equipment, etc.
		The need to overhaul a worn-out sewer tunnel or build a new one	Allocation of funds for the development and approval of the complete set of design, budget and as-built documentation; carrying out construction works for the rehabilitation of an existing or construction of a new sewer tunnel

Based on research into operational practices and statistics on the occurrence of accidents, the authors have identified six criteria by which one can assess the consequences of an accident occurred in the sewerage networks and facilities (C1 to C6). Using the method of expert evaluation by experts in the field of sewer utilities, the criteria are ranked in the order of increasing or decreasing level of impact of the criterion on the consequences of an accident [179]. When determining the level of impact, the expert gave an assessment (from 1 to 6) to each of the criteria in the order that they deem to be the most rational, particularly: when assigning a score of 1, the criterion receives the highest level of significance, and a score of 6 means the lowest one. Therefore, the order scale resulting from the ranking should meet the condition of equality of the number of ranks "6" to the number of the ranking factors "*n*" [179]. The obtained expert data are summarized in the table of ranks (Table 3.14).

Table 3.14 — Findings of the survey of experts in the field of sewer utilities

Item No.	Criterion	Expert						Score
		1	2	3	4	5	6	
C1	Technical characteristics of the damaged section	5	5	6	6	6	5	33
C2	Impact aureole of the sewer tunnel on the environment	4	3	3	3	3	4	20
C3	Population coverage	2	1	2	2	1	1	9
C4	Extent of damage or deterioration and maintenance of temporary (or permanent) wastewater disposal system	3	4	4	4	4	3	22
C5	Cost of complete elimination of consequences	1	2	1	1	2	2	9
C6	Organizational and technological measures of restoration of the stable operation of the sewer tunnel	6	6	5	5	5	6	33
Total:		21	21	21	21	21	21	-

The diagram of the total ranks of the investigated criteria for the consequences of an accident occurred according to the results of expert evaluation is shown in Fig. 3.12. The criteria for population coverage and cost of complete elimination of consequences of an accident are the most important parameters in assessing the consequences of an accident in sewer tunnels [179, 309]. The technical and technological criteria (C1, C6) have less impact on the consequences, but they are directly affected by the cost of elimination of an accident on the whole. According to the performed research, the authors proposed a scale of ranks of consequences of an accident occurred in a sewer tunnel and an appropriate system for determining the rank. With reference to the criteria of C1 to C6 the range of their values has been determined, according to which an assessment is given following the accident, particularly.

- — Technical characteristics of a damaged section of the sewer tunnel (diameters of the tunnel are of 1500 to 2000 mm, 2000 to 2500 mm, and more than 2500 mm; depths are up to 5 m, 5 to 12 m, and more than 12 m; damage areas are up to 5 m, 5 to 12 m, and more than 12 m).
- — Impact aureole on the environment.
- — Population coverage (up to 5 thousand people, 5 to 15 thousand people, and more than 15 thousand people).
- — Extent of cost for eliminating the damage or deterioration and ensuring the functioning of a temporary (or permanent) wastewater disposal system.
- — Cost of complete elimination of consequences.

An accident is understood to be an accident in a facility or network that has emerged or may emerge according to the results of the survey for reliability and stability of operation [89, 147, 221].

Table 3.15 shows the procedure for determining the rank of the consequences of an accident occurred in the sewerage networks and facilities and describes the procedure for determining the rank of the consequences of the occurrence of an accident in the sewerage networks and facilities for each individual accident that occurred in a sewer tunnel and facility. It should be noted that subject to different rank values according to the definition criteria, the mean value is calculated and a higher value is selecte [179, 309].

In order to determine the necessary rank of the consequences of an accident occurred in the sewerage networks and facilities, one should have the result of a comprehensive study of each individual section or facility.

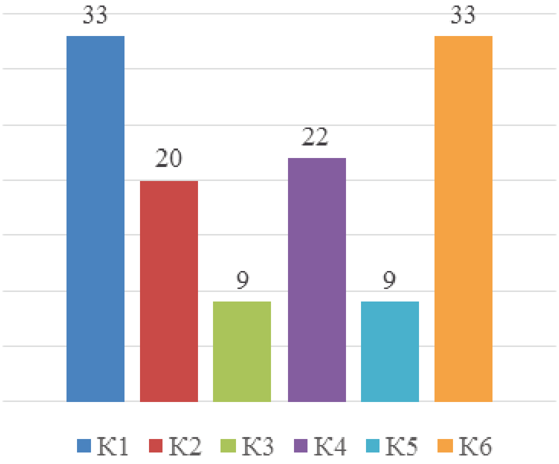


Figure 3.12. Diagram of the summed ranks of the investigated criteria for the consequences of the accident in the sewerage networks and facilities according to the expert evaluation findings

Table 3.15 — Determining the rank of the consequences of an accident occurred in the sewerage networks and facilities

Item No.	Criterion	Parameter value according to the rank of consequences		
		I	II	III
1	2	3	4	5
1	Technical characteristics of the damaged section (C1)*			
	diameter of the tunnel, mm	1500 to 2000	2000 to 2500	over 2500
	depth, m	up to 5	5 to 12	over 12
	damage area, rm	up to 5	5 to 15	over 15
2	Impact aureole of the sewer tunnel on the environment (C2)	up to 50 m, no pollution of water resources	50 to 150 m, no pollution of water resources	over 150 m, there is pollution of water resources
3	Population coverage (C3), thous. people	up to 5	5 to 25	over 25

Table 3.15 (continued)

1	2	3	4	5
4	Extent of damage or deterioration and maintenance of temporary (or permanent) wastewater disposal system (C4)	Switching over to the redundant wastewater disposal line	Arranging a temporary wastewater disposal system by means of pumps and temporary ground wastewater disposal lines	Inability to arrange a temporary wastewater disposal system and shutdown of water supply
5	Cost of complete elimination of consequences (C5), thous. of c.u.	up to 500	500 to 1000	over 1000
6	Organizational and technological measures of restoration of the stable operation of the sewerage networks and facilities (C6)	Typical measures to restore the operation	Organizational and technological measures of increased complexity	Innovative measures for the complete reconstruction

* When determining the criterion rank under different values, the highest value is taken

Conventionally, after the diagnostics of the functioning of the selected section of the sewer tunnel, the following parameters are obtained.

- the diameter of the tunnel is 2000 mm; the tunnel is laid at a depth of 7 meters;
- the length of the technically worn-out section is 8 running meters (rm);
- at a distance of 150 rm it does not have any surface water resources; the protection zone of operation does not exceed 150 rm;
- the area of influence of the sewer tunnel covers more than 50 thousand inhabitants of the city;
- due to the dense development of the city, provided the tunnel is damaged, it is almost impossible to arrange a temporary wastewater disposal solution;
- in case of damage to the sewer tunnel, non-conventional repair methods should be used as a result of the lack of possibility of cessation of wastewater runoff, dense development and structural characteristics [309].

Therefore, according to Table 3.15, rank II of consequences is chosen based on two criteria; rank III of consequences is chosen bades on three criteria.

In this case, subject to different rank values according to the definition criteria, the mean value is calculated and a higher value is selected.

Figure 3.13 shows a graphical representation of the methodology for determining the rank of the consequences of the occurrence of an accident.

An important issue for operating companies is to evaluate the probable consequences of an accident occurring in the sewerage networks and facilities, or when planning measures to be taken upon the occurrence of an accident. When planning major and scheduled repair and selecting priority sections for rehabilitation work, it is important to justify the cost of repair. The technique proposed by the authors is a significant tool in the system of monitoring the stable operation of the sewerage networks and facilities [309]. Based on certain definite consequences, it is possible to build a program of reconstruction of the sewerage networks and facilities for the future.

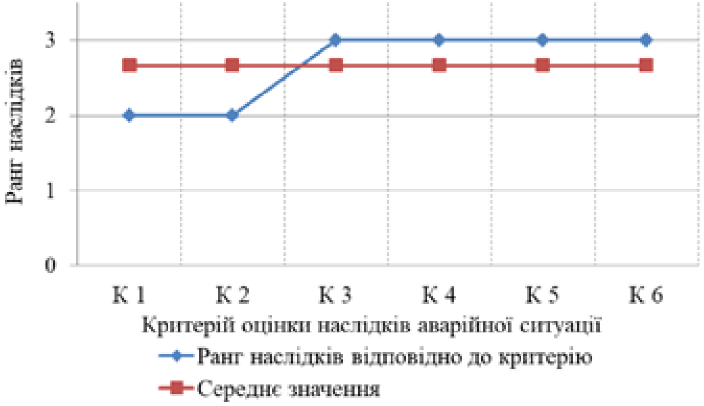


Figure 3.13. Determining the rank of the consequences of the occurrence of an accident in the sewerage networks and facilities

3.4. Analysis of Possible Emergencies That May Occur Due to the Operation of the Sewerage Networks and Facilities

Since the objects to be rehabilitated are parts of the city system of the sewerage networks and facilities that are in poor condition (sometimes in disrepair), the rehabilitation of the preselected areas will not ensure safe operation of all sewerage utilities [89, 147, 221]. During the operation of the sewerage networks and facilities the following hazardous production factors can arise.

- A threat of soil subsidence with damage to buildings (tram tracks) in the collapse of the vault of the tunnel or sewer.
- A threat of wastewater outflows in the amount of 0.450 m^3/s from sewer shafts in case of the emergency clogging of the sewer cross-section.
- Development of an emergency situation, under adverse conditions, at the local level.

The choice of emergency (EM) codes, the occurrence of which is possible at an economic entity, is given in Table 3.16 according to the classification of emergencies (EM) given in compliance with the methodology for identifying potentially dangerous objects.

Analysis of the indicators for the signs of emergencies and determination of their threshold values using the Classification signs of emergencies, approved by Order No. 119 from April 22, 2003 of the Ministry of Emergency Situations of Ukraine and registered with the Ministry of Justice of Ukraine (Table 3.17) [89, 147, 221].

Table 3.16 — Potential hazard identification

EM Code	Description
10170	Accidents in pipelines
10181	Accidents in urban electric transport
10600	Unexpected collapse of buildings and structures
10810	Accidents in sewer systems followed by dumping and discharge of pollutants
20600	Human infectious disease
21000	Mass death of fish

Table 3.17 — Classification signs of emergencies

Item No.	Description of the sign (Short description of the situation, incident, event, accident)	Unit of measurement of the indicator for the sign	Threshold value of the indicator for the sign
1.37	Maximum one-time concentration one or several normalized substances in water (except for drinking water) in concentrations that exceed the MPC by 100 or more times	Fact	1
1.69	Dumping untreated or not enough treated wastewater within the territory of a settlement or in water bodies in the amount of more than 100 cubic meters per hour, total amount of dumping	Cub m	More than 400
2.31	Diseases of dangerous infectious diseases: dysentery and other acute intestinal infectious diseases of specified and unspecified etiology, salmonellosis, viral hepatitis A	Human	3 people and more people: in organized teams (5 people and more: in population) for 3 days
2.38	The case of mass death of aquatic biological resources (fish, mollusks, aquatic vegetation and other aquatic organisms) on the water surface area of more than 1 sq. km	Fact	1
3.1	Death or injury to people due to dangerous events	Human	from 3 to 10 victims

Table 3.18 — Sources of hazard that can cause emergencies

Description of the source of hazard	Analogue of the source of hazard
A section of a gravity sewer tunnel, sewer and facility	**To Appendix 4 :** a linear section of the main pipeline
	To Appendix 3: ecological, bacteriological, hydrodynamic hazard

Identification by the results of the analysis of the sources of hazard, which under certain conditions (accidents, violations of the mode of operation, the occurrence of natural hazards, etc.) can cause emergencies with exceeding the threshold values of the indicators for the signs of emergency (Table 3.18) [89, 147, 221].

Assessment on the basis of the obtained data of the emergency distribution zone, which can initiate each of the identified sources of hazard, assessment of the possible consequences of the emergency for each of the sources of hazard (number of dead, injured, those who have disrupted living conditions, material damage) and the establishment of the maximum possible levels of emergency for each of the sources of hazard in accordance with Appendix 4 to Methodology (Table 3.19) [89, 147, 205, 221]. The determination of the compliance of the object with the current regulatory legal acts is given in Table 3.20.

The maximum level of possible emergency is defined as local. In view of the fact that the specified objects in the city of Kharkiv are subject to Resolution No. 1107 dated October 25, 2011 of the Cabinet of Ministers of Ukraine and Order No. 98 dated February 23, 2006 of the Ministry of Emergency Situations, the sewerage networks and facilities near the KhTZ plant and on Grekivska street are recognized as potentially dangerous objects [89, 147, 221].

The reliability coefficient in terms of importance (importance coefficient) γn is determined for the class of consequences of the Class CC2 object and the type of design situation according to Table 5 of DBN V.1.2-14-2018 (Table 3.21) [89, 147, 221]

Barriers to safety and prevention of construction accidents are compliance with the technical regulations for operation of the construction, and periodic inspections of the main elements of the construction [89, 147, 221]. Only personnel who have been properly instructed and have the appropriate clearance is allowed to work at the site.

To prevent risks according to DBN B.1.2-9-2008, the following measures are provided:

- The 1st group of risks: The collapse of the arch is not foreseen in the tunnel section.
- The 2nd group of risks: There is a degasser (natural ventilation) in shaft No. 4 adjacent to the object of reconstruction. The reconstructed shaft is equipped with a natural ventilation system for the period of operation and forced ventilation is provided for the period of reconstruction. During the period of operation (repair), forced and natural (maintenance of the cartridge-type dry filtration apparatus) ventilation is provided by the operating company.
- The 3rd group of risks: The object of reconstruction is located in a green zone, does not border on a highway with heavy traffic; the road has border stone; the reconstruction site is protected, fenced off, the necessary signs and equipment are provided [89, 147, 221].

Table 3.19 — Maximum possible levels of emergencies

Description of the source of hazard	**The amount of required technical and material resources of the amount of relevant local budgets**	**Territorial distribution**	**Death toll, people**	**Number of victims, people**	**Disrupted living conditions, number of people**	**Losses, thousand min, salary**	**Emergency level**
The sewerage networks and facilities	Exceeds own capacities of the potentially hazardous object	EM goes beyond the object	1 to 2	250	10 to 20	0.39 to 14.5	Object-related, local

Table 3.20 — The determination of the compliance of the object with the current regulatory legal acts

The object is (is not) subject to a regulatory legal act	**The name of the normative and legal act**
1	**2**
Is subject to	Resolution No. 808 dtd August 28, 2013 of the Cabinet of Ministers of Ukraine “On approval of the list of activities and objects that pose an increased environmental hazard”
Is not subject to	On approval of the list of enterprises of strategic importance for the economy and security of the state (Resolution No. 1734 of December 23, 2004 of the Cabinet of Ministers of Ukraine, as amended)

1	2
Is not subject to	The list of particularly dangerous enterprises, the termination of which requires the implementation of special measures to prevent damage to the lives and health of citizens, property, structures, and the surrounding natural environment, approved by the Resolution No. 339 dated May 15, 2013 of the Cabinet of Ministers of Ukraine
Is subject to	Resolution No.1214 dated August 4, 2000 of the Cabinet of Ministers of Ukraine "On approval of the list of objects and individual territories that are subject to permanent and mandatory service by state emergency and rescue services on a contractual basis"
Is subject to (Construction, repair; Annex 2 Clauses 15, 16, 19, 21, 23; Annex 3 Clause 19)	On the approval of the Order of issuance of permits for high-risk work and operation (utilization) of machines, mechanisms, equipment of increased danger (Resolution No. 1107 dated October 25, 2011 of the Cabinet of Ministers of Ukraine)
Is subject to	Ministry of Emergency Situations of Ukraine (since 2005); Order, Methodology, List No. 98 dated February 23, 2006 On approval of the Methodology for the identification of potentially dangerous objects"
Is not subject to	Resolution No. 956 dated July 11, 2002 of the Cabinet of Ministers of Ukraine "On identification and declaration of safety of objects of increased danger"

Table 3.21 — The reliability coefficient in terms of importance of the sewerage networks and facilities

Class of consequences (Importance)	Importance class of the structure	Value γn, for design situations				
		Established		Transition		Damaged
		1st group of limit states	2nd group of limit states	1st group of limit states	2nd group of limit states	1st group of limit states
CC2	A	1.10	0.975	0.975	0.950	0.950
	B	1.05		0.950		
	C	1.00		0.925		

Conclusions to Chapter 3:

1. The main causes of the destruction of the sewerage networks and facilities that provoke the occurrence of accidents were investigated and classified into the following groups: production factors; factors of durability of materials of linear portions of a network; organizational and technological factors; operational factors; factors of the external operating environment;
2. The corrosion process as the main factor in the deterioration of the sewerage networks and facilities was investigated. The modern lines of research by domestic and foreign scientists f the corrosion process in the sewer environment were reviewed. Based on the comparison of research works, they were grouped in accordance with the area of research: theoretical research into microbiologically influenced corrosion, experimental research into the corrosion process, research into methods for preventing microbiologically influenced corrosion, experimental research into corrosion-resistant materials, Methods of forecasting corrosion processes, extending the service life of pipelines. A block diagram of the methodology for research of microbiologically influenced corrosion in the sewerage networks and facilities was given.
3. Laboratory tests were conducted to assess the corrosion resistance of modified concrete in a sulfuric acid solution (the results obtained show that the method for determining mass loss is more correct than the method for determining the strength of concrete); to assess the resistance of aluminous cement-based concrete to the action of a sulfuric acid solution (according to the results obtained, it can be concluded that concretes based on aluminous cement, and those based on Portland cement, are not resistant to sulfate corrosion, whatever the W/C ratio); evaluate the effectiveness of protecting the concrete surface from sulphate corrosion with an epoxy coating (the results obtained allow concluding that the studied concrete-epoxy coating system has a significantly longer service life in a corrosive acid environment than concrete);
4. The consequences of the occurrence of acciidents in the sewerage networks and facilities were investigated, and a methodology was developed for determining the rank of the consequences of the occurrence of an accident. Based on the identified consequences, it is possible to elaborate a program for the reconstruction of the sewer networks and facilities for the future as a tool for organizational and technological monitoring for their stable operation.

CHAPTER 4

METHODOLOGICAL PRINCIPLES OF MONITORING THE STABLE OPERATION OF THE SEWERAGE NETWORKS AND FACILITIES

4.1. Theoretical and Methodological Foundations of the Category of Monitoring

The term "monitoring" came from the English language, but has a Latin basis. The words such as "moneo", "monitor", "monitorius", "monitum", and "monitus" are cognate and ambiguous. One of the meanings of the word "moneo" is to "punish"; "monitor" — "supervisor"; "monitorius" — "warning"; "monitum" — "instruction"; "monitus" — message. Given this interpretation of the word "monitoring", its traditional meaning i.e., observation and analysis, automatically expands by a component such as the elimination of violations of the legislation identified in the course of its implementation and provides in its composition the stage of mandatory implementation or consideration in the further regulatory activities of the results of the legislative monitoring [25, 30, 65, 83, 96, 102–103, 107, 139, 145, 192].

The essence of monitoring is the synchronicity of the processes of observation, measurement, and development on this basis of new knowledge about the state of the object with further modeling, forecasting and making an appropriate management decision. Therefore, monitoring is functionally related to all stages of management by forming a closed-loop regulation cycle with them [25, 30, 65, 83, 96, 102–103, 107, 139, 145, 192].

It should be noted that monitoring should reflect the real state of the system in question at any current time and allow assessing and determining the main lines of its development for the long run. In this regard, the main tasks to be implemented in the course of monitoring include.

- Acquiring and processing all incoming information.
- Flexibly responding to structural shifts and on the basis thereof, updating and validating the information and regulatory framework and managerial decisions.

- Tracking the state of reforming; conducting a comparative analysis of similar systems.
- Monitoring the forecast indices and performing their verification [10].

Monitoring as a phenomenon has the following main features.

- Monitored objects are dynamic and in constant development. They depend on external impacts, which, in turn, can lead to undesirable changes in the functioning of the monitored object.
- Using the monitoring process involves the arrangement of continuous monitoring of the object. The measure of stability is determined by the characteristics of the object and resource capabilities.
- Arranging the monitoring process involves the selection of justified parameters and indices. Observation is performed by direct measurement or description of the parameters of the object.
- Monitoring results are used to forecast the development of the object.
- Every particular monitoring system is tailored to a particular consumer [83, pp. 18–23].

Monitoring may be considered as an activity consisting of five stages, which is shown in Fig. 4.1.

It should also be noted that conducting the monitoring process should comply with a number of key principles, the main of which are timeliness and compliance with the set objectives; integrity and scientificity; accuracy, consistency and detail of information, its mandatory detailed and in-depth verification; confidentiality of information sources; objectivity; predictability[4].

Theoretical approaches to the content of monitoring confirm that this is not only a process of observation, but also analysis, evaluation, and forecasting in view of the environmental impact factors. The practice of applying monitoring technology at all levels of management confirms its effectiveness and necessity, which in turn requires more detailed research and improvement of this process by developing new elements [107].

There are a great many interpretations of the concept of monitoring, which is described in a number of literature sources (Table 4.1).

Thus, based on the above.

1. Having analyzed the definition of the category of monitoring from different literary sources given in Table 4.1, one can conclude that

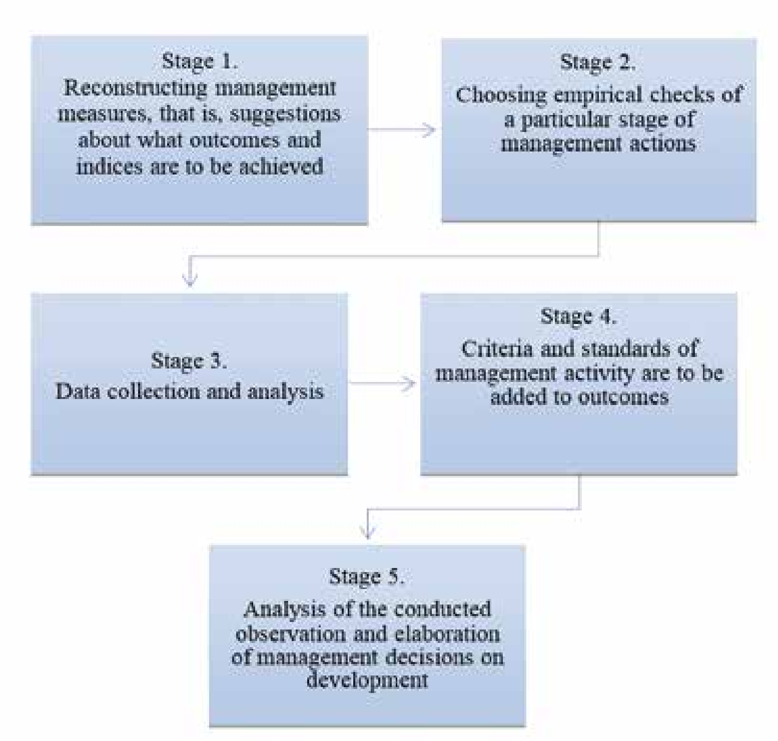


Figure 4.1. Stages of the monitoring process
Note: Developed by the author based on source [103]

there is no unified approach to the interpretation of this concept, so monitoring can be characterized as a process and as a system.

2. Considering monitoring as a process, one can mention its consistency, its focus; the function of collecting, systematizing and processing information; assessing the object to make quality management decisions, and justifying a short-term forecast for the development of the object.

3. Monitoring as a system is a set of interrelated elements: subject and object of research, purpose and research program, assessment characteristics and criteria, and a necessary methodological framework. In the meantime, monitoring is a subsystem of the management system. The elements within the monitoring system show the property of being organized, which is determined by the level of control of the links between the elements of the system and the links of the system with the external environment. The special organization of the interaction between the elements directly indicates the property of the system of being organized. The organization and efficacy of this system depends on how all elements of the system are connected and whether they are adequate to each other. The nature of the elements of the monitoring system is determined by its subject area [225].

Table 4.1 — Analysis of scientific definitions of the concept of monitoring

Author	Definition of monitoring
Goroshko A., Narchynska T., Ozymok I., Tarnay V. [65]	A process of regular collection and analysis of quantitative and qualitative data on pre-defined indicators to facilitate timely decision-making.
Olmezov V. [149]	In practical terms, a method of systematic study of reality aimed at ensuring the management of various types of timely and quality information.
Morozov A. O., Kosolapov V. L., Kolosov V. Ye. [140]	Continuous observation of any process to determine its compliance with the desired result or development trends. Systematic collection of information on the progress of work within the monitoring is a kind of scanning of events and is conducted to detect deviations from the outlined plans.
Protsenko I.I., Gudimenko K. M. [159]	A system for collecting, processing, storing and disseminating information about a system or its individual elements, aimed at providing the information support of the management of this system, which allows making judgments about its state and making it possible to predict its development.
Livak B. G. [129]	A specially arranged systematic observation of the condition of any objects.
Grigoriev G. S. [67]	Continuous observation of a process or phenomenon under appropriate conditions with regard to external and internal environmental factors.
Korobov Yu. I., Ruban Yu. B., Soldatkin V. I. [118]	Observation, assessment, prediction of the state of any phenomenon or process to prevent undesirable changes in the situation.
Yeliseyeva I. I. [86]	A system of measures to continuously monitor the condition of a particular object, to register its most important characteristics, to evaluate them, and to promptly identify the results of the effects of various processes and factors on the object.

It should also be noted that there are different types of monitoring (Table 4.2) [65]. According to the subject of the dissertation research, attention should be paid to the monitoring of environmental and technical aspects.

In the late 1960^{s}, the global community began to recognize the need for coordinated efforts to collect, store, and process environmental data. In 1972, a conference on environmental protection was held in Stockholm under the aegis of the United Nations, where the concept of environmental monitoring was defined for the first time. It was agreed that environmental monitoring should be understood as a comprehensive system of observing, assessing and forecasting changes in the environment under the impact of man-made factors. The term appeared as a supplement to the concept of monitoring the state of the environment. At present, monitoring is understood as a set of observations of certain components of the biosphere, specially organized in space and time, and a package of methods of environmental forecasting.

Environmental monitoring is an information system of observation, assessment and forecasting of changes in the state of the environment, created to highlight the man-made components of these changes against the background of natural processes [143].

Table 4.2 — Types of monitoring

Item No.	Type	Features
1	Dynamic	Data on the dynamics of a particular object, phenomenon, or indicator are taken as the basis for the examination. It is the simplest way, which can be the analogue of the experimental plan of time series. For relatively conventional systems, local monitoring or monitoring of physical objects this approach may be sufficient [65]
2	Competitive	The stimulus for analysis is the results of an identical examination of other systems. In this case, monitoring becomes similar to a plan with multiple series of tests. Several subsystems of larger systems are studied in parallel using the same tools, at the same time, which gives the basis to draw a conclusion about the magnitude of the effect in a particular subsystem. In addition, the specified approach makes it possible to estimate the magnitude of the hazard, and its criticality
3	Comparative	The basis for the expert examination is the results of an identical survey of one or two higher-level systems. This case is specific to monitoring and is not considered when planning experiments. It is that the data on the system are compared with the results obtained for a higher level system [83]

It is commonly known that the most effective method of preventing ecological disasters are methods of observing the state of the environment. The concept of monitoring continues to evolve as an alternative to traditional methods of observing the state of the environment in the context of ever-increasing man-made pressures on the biosphere [143].

As of yet, environmental monitoring is a particularly pressing issue, because according to UN statistics, about 7 million people die annually around the world from polluted air. The level of human impact on the environment depends primarily on the technical equipment of society. Only a comprehensive approach can greatly simplify the control over compliance by polluting companies with legislative provisions.

Ukraine is one of the largest countries in Europe in terms of population, area and resource potential. However, unfortunately, it is at the same time one of the most disadvantaged countries in Europe in environmental terms. The central and eastern regions of Ukraine are considered the most polluted and environmentally hazardous to the health of the population. Despite the measures taken, the environmental situation in general remains very tense, and in many regions it is even close to being critical [18].

According to the data provided by the State Statistics Service [40], emissions from stationary sources in Ukraine and Kharkiv region, although tending to decrease, still remain at a fairly high level (Table 4.3).

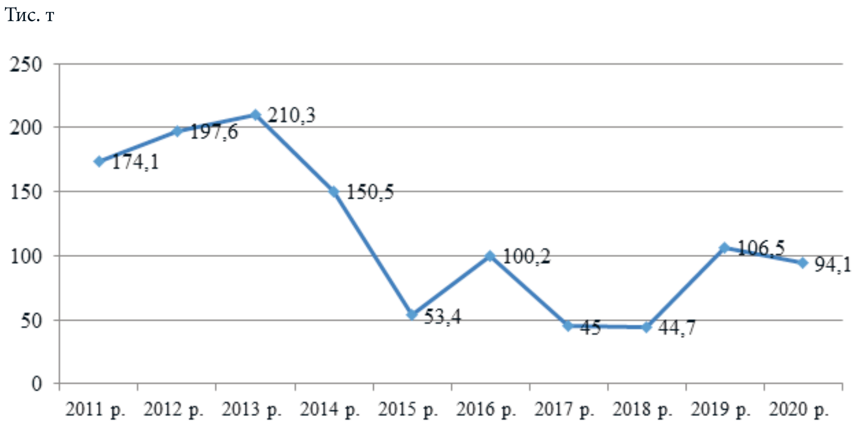


Figure 4.2. The dynamics of pollutant emissions to atmospheric air from stationary sources in Kharkiv region.
Note: Developed by the author based on source [40]

The data given in Table 4.3 indicate that Kharkiv region ranks 5th out of all Ukrainian regions and the city of Kyiv, in the overall structure of pollutant emissions from stationary sources to air with a share of more than 4 %.

Figure 4.2 shows the dynamics of the given parameters for easier perception of the data shown for Kharkiv region (Table 4.3).

From Figure 4.2, one can conclude that emissions of pollutants into the atmospheric air from stationary sources in Kharkiv region for the decade (2011-2020) show an ambiguous trend; the years of 2017 and 2018 can be noted to be the most successful, but the year of 2019 shows an increase.

The main environmental problems in Ukraine according to the Strategy of the State Environmental Policy of Ukraine for the period up to 2030 are given in Table 4.4 [19].

The above provisions of the Strategy of the State Policy illustrate the importance and significance of environmental monitoring within Ukraine.

As already mentioned, the environmental situation in Ukraine is extremely dire; to preserve and restore the objects that may be gone, one should know their location, number, tendencies to decrease or vice versa to increase in number [20].

This is what monitoring, continuous observation and record keeping of the quality of objects such as plants, animals, landscapes, and chemical, biological, and physical factors, is meant for. Monitoring does not involve environmental quality management, and proper, scientifically sound management is possible only with the functioning of this system. There are specialist monitoring centers. The largest is the World Conservation Monitoring Center, established in 1981. It includes the International Union for Conservation of Nature and the World Wildlife Fund, and the International Environment Information System (established in 1977). These organizations provide the public with objective information about the state of the environment, promote the integration of national environmental monitoring networks into an international system [221–224].

Of particular importance is the global system of biosphere reserves that conduct the so-called basic monitoring, they monitor the status and forecast natural phenomena without any man-made interventions; diagnostic monitoring, they detect trends in biosphere changes; prognostic monitoring, they by experiment investigate trends in changes in the abiotic environment and forecast biological results; and climatic monitoring. There are several levels in each group which are shown in Fig.4.3.

Table 4.3 — Pollutant emissions to atmospheric air from stationary sources by region

Ukrainian regions	**2011**	**2012**	**2013**	**2014***	**2015***	**2016***	**2017***	**2018***	**2019***	**2020***	**Share (2020)**	**Place of the region by the amount of pollution**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Ukraine	**4374.6**	**4335.3**	**4295.1**	**3350.0**	**2857.4**	**3078.1**	**2584.9**	**2508.3**	**2459.5**	**2238.6**	**100**	-
Vinnytska	87.3	101.3	149.5	124.5	134.7	119.8	155.8	97.3	99.7	78.2	3.49	6
Volynska	7.6	7.3	6.6	4.3	4.7	4.7	5.1	5.1	5.3	5.1	0.23	22
Dnipropetrovska	950.4	962.0	940.5	855.8	723.9	833.0	657.3	614.3	576.9	534.7	23.89	2
Donetska	1525.9	1514.8	1448.1	1043.0	917.6	981.4	784.8	790.2	773.5	751.0	33.55	1
Zhytomyrska	19.0	18.5	17.2	10.9	9.0	9.3	10.3	13.0	12.7	11.8	0.53	17
Zakarpatska	17.2	8.1	7.7	3.9	4.4	4.9	3.2	4.0	3.7	3.3	0.15	23
Zaporizka	229.3	207.6	245.9	206.7	193.7	167.0	180.9	174.7	173.4	155.5	6.95	3
Ivano-Frankivska	221.8	196.7	202.9	228.8	223.9	196.7	198.3	221.4	205.0	140.4	6.27	4
Kyivska	113.6	129.4	111.9	96.2	78.1	98.2	48.2	81.3	84.4	66.6	2.98	8
Kirovohradska	15.2	16.8	15.7	11.8	14.2	11.8	12.2	12.2	12.8	10.7	0.48	19
Luganska	472.0	447.6	442.0	197.8	115.2	155.5	75.1	46.7	37.4	35.5	1.59	12
Lvivska	129.4	130.7	121.4	100.2	102.4	103.1	109.1	106.7	88.9	76.0	3.39	7
Mykolayivska	25.7	25.1	20.4	15.9	15.8	13.9	14.2	13.1	12.1	11.2	0.50	18
Odeska	30.5	28.2	26.2	23.2	26.1	26.4	29.6	37.4	33.1	42.6	1.90	11
Poltavska	72.3	67.9	66.6	62.9	55.6	56.2	55.9	52.1	51.0	45.8	2.05	10

Table 4.3 (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13
Rivneska	17.1	14.9	12.0	11.6	10.2	9.1	9.6	9.1	9.9	10.1	0.45	20
Sumska	35.9	30.2	30.5	27.0	17.5	19.8	20.3	20.8	21.7	20.9	0.93	14
Ternopilska	20.4	20.9	15.9	8.2	8.5	9.0	10.6	10.2	9.4	9.5	0.42	21
Kharkivska	**174.1**	**197.6**	**210.3**	**150.5**	**53.4**	**100.2**	**45.0**	**44.7**	**106.5**	**94.1**	**4.20**	**5**
Khersonska	5.8	6.4	6.0	7.2	8.9	9.7	9.6	12.4	17.8	17.8	0.80	16
Khmelnytska	18.7	16.4	17.2	17.1	18.3	21.7	21.1	22.1	20.3	18.2	0.81	14
Cherkaska	62.2	69.4	73.1	66.7	57.5	52.3	48.3	57.9	51.8	51.4	2.30	9
Chernivetska	3.8	2.9	2.7	2.5	3.2	3.0	3.3	2.7	2.4	1.8	0.08	24
Chernihivska	49.5	45.8	43.7	41.9	33.9	37.1	31.6	29.7	27.5	20.9	0.93	15
The city of Kyiv	33.3	32.9	31.9	31.4	26.7	34.3	45.5	29.2	22.3	25.5	1.14	13

* The given data donot include the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories in Donetska and Luhanska regions.

Note: Calculated using data from the State Statistics Service of Ukraine [40]

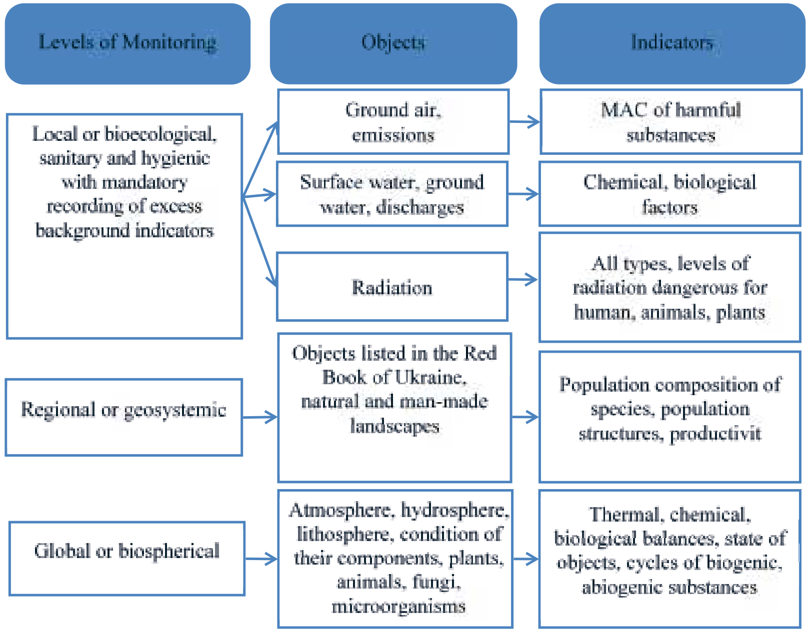
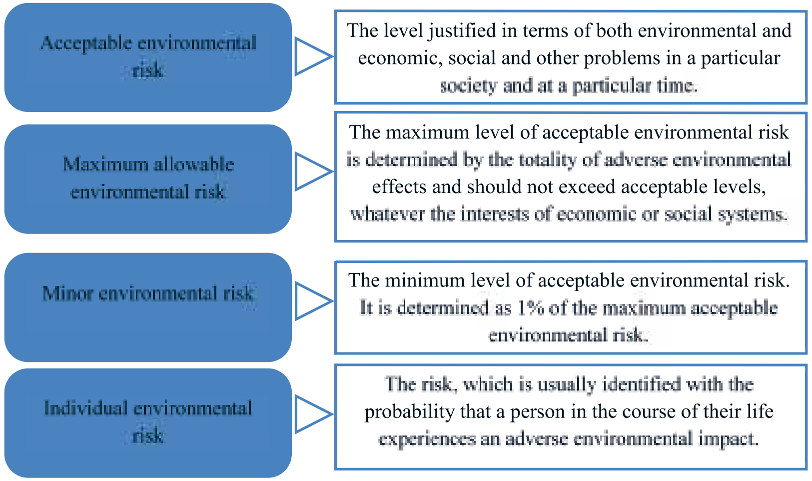


Figure 4.3. The structure of the state environmental monitoring
Note: Developed by the author based on source [20]



The level justified in terms of both environmental and economic, social and other problems in a particular society and at a particular time.

The maximum level of acceptable environmental risk is determined by the totality of adverse environmental effects and should not exceed acceptable levels, whatever the interests of economic or social systems.

The minimum level of acceptable environmental risk. It is determined as 1% of the maximum acceptable environmental risk.

The risk, which is usually identified with the probability that a person in the course of their life experiences an adverse environmental impact.

Figure 4.4. Types of environmental risk
Note: Developed by the author based on source [110]

Table 4.4 — The main environmental issues in Ukraine according to the Strategy of the State Environmental Policy of Ukraine for the period up to 2030 [19]

Item No.	Issues
1	Subordination of environmental priorities to economic feasibility; failure to take into consideration environmental impacts in legislative and regulatory and legal acts, in particular in decisions of the Cabinet of Ministers of Ukraine and other executive bodies.
2	The predominance of resource- and energy-intensive industries in the structure of the economy with a largely negative impact on the environment, which is exacerbated by the lack of regulation in the transition to market conditions.
3	The wear and tear and obsolescence of fixed assets in all sectors of the national economy.
4	An inefficient public administration system in the field of environmental protection and regulation of the use of natural resources, in particular the inconsistency of actions of central and local executive authorities and local self-government bodies; the unsatisfactory state of the state environmental monitoring system.
5	A low level of understanding in society of environmental priorities and benefits of balanced (sustainable) development, imperfection of the environmental education and education system.
6	An inadequate level of compliance with environmental legislation and environmental rights and responsibilities of citizens.
7	Inadequate control over compliance with environmental legislation and failure to ensure the inevitability of liability for its violation.
8	Insufficient funding from state and local budgets for environmental protection measures; funding these measures on a residual basis.

Environmental monitoring provides identification and prevention of environmental risks, which may to some extent reduce the probability of negative changes in the environment caused by man-made impacts.

Environmental risk according to the author of the dissertation research is the probability of the occurrence of negative phenomena, processes or changes in the natural environment under the impact of man-made objects that threaten the environmental safety of a region or a state as a whole, and public health (Table 4.5) [76, 152, 187, 204].

Table 4.5 — Interpreting the category of environmental risk

Item No.	Author	Interpreting the category
1	—	This is an assessment at all levels from local to global of the probability of the occurrence of negative changes in the environment caused by man-made or other impacts. Environmental risk is also understood as a possible measure of the risk of environmental damage in the form of possible losses over a specified period of time.
2	Ustimenko V. M. [187]	This is the probability of the occurrence of an event that is caused by external factors and human activities and leads to negative consequences.
3	Pavelko A., Sirotyuk M. [152]	This is a circumstance (event) of natural or man-made nature, which is likely to lead to environmentally hazardous consequences for the environment and human.
4	Dobrovolsky V. V. [76]	The probability of adverse environmental effects from any changes in natural objects and factors.
5	Yarchak V. V. [204]	The probability of negative consequences for the environment and/ or human because of the activities of the subjects of environmental relations or the impact on the objects of increased environmental hazards of natural factors.

It should also be noted that environmental risk is often considered in two aspects, potential risk and actual risk. A potential environmental risk is a phenomenon of the danger of disrupting the relationship between living organisms and the environment because of natural or man-made factors. An actual environmental risk is formed by a potential risk with regard to the probable frequency of its occurrence. According to the nature of its manifestation, environmental risk can be sudden-onset (man-made accident, earthquake, etc.) or slow-onset (landslide, flooding, erosion, etc.) [76, 152, 187, 204].

There are four types of environmental risk, which are shown in Fig. 4.4.

An important component of risk assessment is the identification of hazards. Its main task is to identify (based on information about the facility, the results of expert examination and the operating experience of these systems) and a detailed description of all the inherent hazards of the system [76, 152, 187, 204].

Along with environmental monitoring, in order to prevent negative impacts on the environment, technical and technological and organizational monitoring should be considered, through which one can identify man-made facilities that are in critical condition for operation and as a result cause damage to the environment.

Technical monitoring is a systematic monitoring of the condition of a facility to assess compliance with the design solutions, regulatory requirements and physical condition (Fig. 4.5).

Technical monitoring is conducted to determine the operational suitability of man-made facilities in this case.

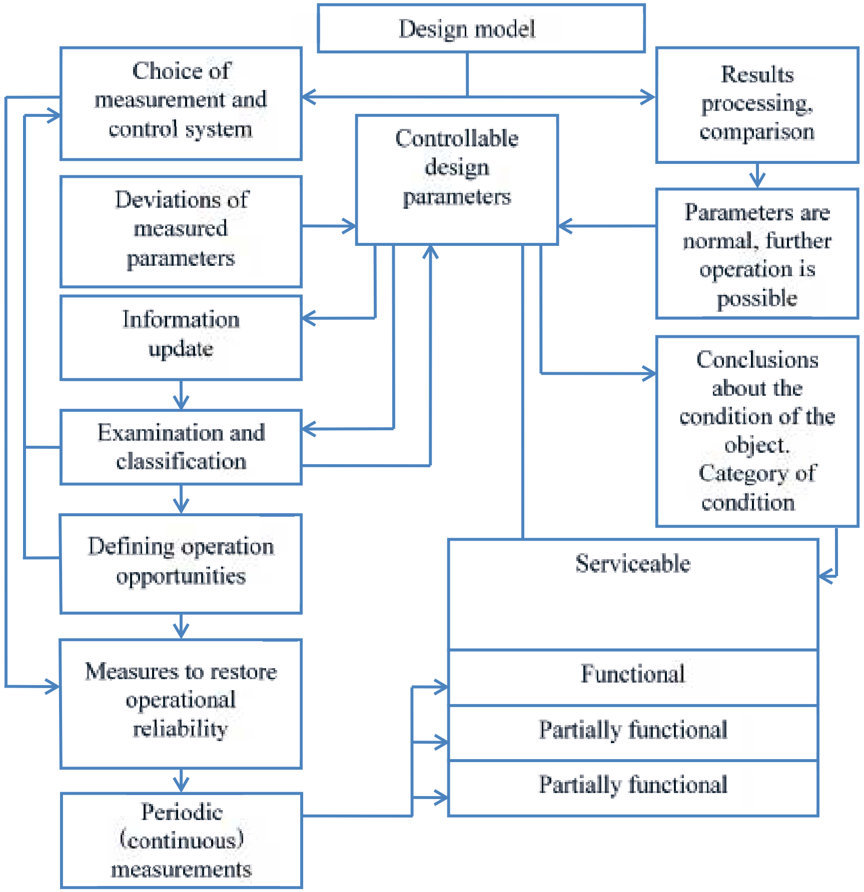


Figure 4.5. A block diagram of a technical condition monitoring procedure (technical monitoring)

Typically, monitoring includes a number of various methods to assess the technical condition of a facility in dynamics terms based on periodic observations.

Technical monitoring includes the following main stages.

1. Initial monitoring of the degree of deformation of facilities and other parameters.
2. Visual inspection of structures; detection and classification of their defects and damage.
3. Instrumental inspection of structures for cracks, for the number and size of cracks.
4. Development of measures to ensure the strength and durability of facilities.

According to the results of the expert examination (technical monitoring) a report should be prepared with the main provisions as follows.

- A textual part with a detailed description of the research and the data obtained.
- Drawings of the object of research.
- Defect and cross-section maps drawn up during monitoring.
- Photo and / or video report with a detailed description of visual materials.
- Tables containing test data and analysis results of the collected information.
- A list of measures required to eliminate the negative trends identified during the work of experts [212–215].

Given the area of the dissertation research, it should be noted that all rules regarding sewer shaft technical monitoring are regulated in accordance with Order No. 30 dated July 05, 1995 of the State Committee of Ukraine for Housing and Utility Services [212–215] “On approval of the rules of the technical operation for water supply and wastewater disposal systems in settlements in Ukraine”, which states what is required to ensure the smooth and economic operation of water supply and wastewater disposal systems (Table 4.6).

It should also be noted that the poor technical condition of water supply and wastewater disposal networks and facilities often results in failures and disruptions in their operation, thus reducing the reliability of the quality of services provided.

Reliability is a property of a facility to perform specified functions and maintain the specified performance values over time within the specified limits, which comply with the specified operating modes and conditions of use. A facility can be understood as a system and its individual elements, structures, mechanisms, and equipment. The physical meaning of reliability is the ability of a facility to maintain its original technological characteristics during operation [212–215].

Table 4.6 — Requirements for the technical monitoring of the sewerage networks and facilities [100, 114, 143]

Item No.	Requirements
1	Up-to-date metrological toolkit for measuring the flow rate and quantity of drinking water and wastewater, which includes appropriate measuring instruments and measurement methods
2	Highly qualified technicians who comply with the requirements of job descriptions, rules of technical operation and occupational health and safety regulations
3	Control and analysis of current working conditions, primarily economic
4	Arranging rational modes of operation of networks and facilities that ensure the improvement and intensification of their operation, the maximum use of reserves, the implementation of advanced technology based on latest advances in science and technology
5	Mechanization and automation of production processes, measures to reduce losses of water, resources and materials
6	Preventive inspection and planned and preventive repair of networks and facilities, their components and equipment
7	Continuous monitoring of the quality and quantity of wastewater discharged by companies into the municipal sewer system
8	Continuous monitoring of fish protection devices
9	Continuous monitoring of the quality and quantity of drinking water supplied to the water supply network and sold to consumers
10	Continuous monitoring of the quality and quantity of treated wastewater discharged into water bodies
11	Taking measures to prevent, timely detect and eliminate accidents
12	Systematic recording and analysis of the causes of disruptions and accidents

In terms of reliability, the technical condition of a facility can be as follows: serviceable, faulty, operational, non-operational, and critical (Table 4.7).

Table 4.7 — The conditions of a facility in terms of reliability

Item No.	Condition	Fearures
1	Serviceable	The condition of the object, in which it meets all the requirements of regulatory and technical and (or) design (project) documents
2	Faulty	If the object does not meet at least one of the requirements for serviceable condition set out by the regulatory and technical and (or) design (project) documents
3	Operational	The condition of the object, in which the value of all parameters describing the ability to perform the specified functions meets the requirements of regulatory and technical and (or) design (project) documents
4	Non-operational	The condition of the object, in which the value of at least one parameter describing the ability to perform the specified functions does not meet the requirements of regulatory and technical and (or) design (project) documents
5	Critical	Due to the physical impossibility of further operation of the facility, or an unacceptable decrease in its efficiency, or safety requirements and is determined by the established limit state criterion. An event consisting in a disruption of the operability of a system or element is called a failure. Reliability implies non-failure operation of an object within a given period of operation or the number of failures should be minimized. By the way, a failure is also a decrease in the performance of the system below the established limit. In the theory of reliability of technical devices, the main concept for assessing performance is a probabilistic assessment of failure-free operation during a given time interval. The failure is due not only by a number of assumed (deterministic) factors, but also by a number of random factors that took place during the design, construction, debugging and operation of the facility. The impact of random factors cannot be accurately accounted for, so the deterministic estimate is replaced by a probabilistic one. Consequently, the results of observations of objects are of a probabilistic nature, hence the reliability theory is based on elements of probability theory and mathematical statistics. It should be noted that failure is not only random, but also a rare event

Random phenomena, processes and quantities, and methods of their numerical estimation are the main object considered in probability theory. Random variables may be discrete (ξ), if there is a finite or countable number of values $x_1, x_2, \ldots x_p$; and continuous, when a random variable can take any numerical value.

A discrete variable may be taken with the corresponding probability of occurrence of $P_1, P_2 \ldots P_p$, and $\Sigma P_n = 1$.

The distribution for random variables is as follows:

$$(x_1, x_2, \ldots, x_p \ldots)$$
$$(P_1, P_2, \ldots, P_p \ldots).$$

The mathematical expectation (average value) of a random variable is as follows:

$$M_\xi = \Sigma x_k \times P_k . \tag{4.1}$$

For example, the moment of parallel order is as follows:

$$M^2_\xi = \Sigma x^2_k \times P_k .$$

The correspondence of the obtained static regularities to the law theoretically largely depends on the duration of the observation, the probability and accuracy of the initial data. The longer the series of observations and the higher their accuracy, the closer the static dependences will be obtained to the objective distribution law that exists for the category of random events under consideration. With an unlimited increase in the number of observations, the obtained static dependences approach the theoretical distribution function.

The study and analysis of the actual operation of existing water supply and wastewater disposal systems makes it possible to obtain some numerically expressed characteristics of the change in time in the volumes of water supply and wastewater disposal for cities that differ in population, climate zone, degree of industrialization, etc. Based on the collected and processed statistical materials, it is possible to obtain some patterns of change in the volume of water consumption over time, to estimate the probability of occurrence of their different values, and the repeatability and duration [100, 114, 143].

As a result of the observations or tests conducted, not only the very fact of an occurring event can be established, but also certain numerical values of the parameters describing the probability of its occurrence and repetition. Depending on the nature of the process under study, sometimes the very fact of the appearance (occurrence) of some event may be more interesting. For example, the failure of any element of the system can be considered as a random event. The number of accidents of the element under consideration obtained as a result of observations or experience for a certain period of time is a random variable [212–215].

When observing the configurations of the amounts of water supply and wastewater disposal, the obtained numerical values are random variables. The continuous random variables are amount of water consumption, amount of wastewater disposal; source water consumption; water level in the river. The number of failures (accidents) of elements of water supply and wastewater disposal systems is a discrete random value.

The variance of a random variable ξ is as follows:

$$D\xi = M(\xi - M\xi)^2 = M\xi^2 - (M\xi)^2. \tag{4.2}$$

The variance is a measure of the spread of possible values of a random variable: if D is small, then large deviations from the expected result are unlikely.

As for the continuous random variable, if it can take any numerical values from some interval [A, B], which can be infinite.

The probability of a continuous random variableis as follows:

$$P_{(a,\,b)} = \int_a^b f(x)\,dx, A \le a \le b \le B, \tag{4.3}$$

where:
$f(x)$ — is the probability density function (f(x)≥ 0).

The distribution function of a random variable ξ is as follows:

$$F(x) = \int_a^b f(x)\,dx. \tag{4.4}$$

The basic theoretical laws of the distribution of random variables are listed below. About 160 laws of the distribution of the probability density are known. In practice, some of the most common are used: binomial, Poisson, exponential, normal distributions [100, 114, 143].

The binomial distribution takes place when the probability of the occurrence of an event (x) in (n) independent experiments is constant and equal to (P). The probability of the occurrence of (x) events in a series of (n) trials corresponds to the distribution function:

$$f(x) = \frac{n!}{x!\,(n-x)!}\, p^x q^{(n-x)}, \tag{4.5}$$

where:
p — are the probable failures;
$q - 1 - p$ — is the probability of the occurrence of an event.

The mean value is $\mu = n \times p$; the standard deviation is $\sigma = \sqrt{(n \times p \times q)}$.

If p is small, such as $p = 0.02$ i $q = 1$, and μ is much greater than p, the binomial distribution becomes as follows:

$$f(x)\,\frac{e^{-\mu}}{x\,!}\;;\ \mu = n \times p;\ \ \sigma = \sqrt{n \times p} = \sqrt{\mu}\,. \tag{4.6}$$

This is the so-called Poisson distribution, which is characteristic of the number of the occurrence of rare events of a discrete random variable [212–215]. If p is great and, accordingly, $n \times p$ is great too, for example: $p \geq 0.5$, and $n \times p \geq 5$, the binomial distribution can be represented as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{(x-\mu)^2}{2\sigma}};\quad \mu = n;\ \sigma = \sqrt{npq}. \tag{4.7}$$

This is a normal or Gaussian distribution.

The exponential distribution law is as follows:

$$\begin{cases} f(x) = \lambda\, e^{-\lambda x} & \text{at}\ \ x > 0 \\ f(x) = 0 & \text{at}\ \ x < 0 \end{cases};\ \mu = 1/\lambda;\ \sigma = 1/\lambda, \tag{4.8}$$

where:
λ — is the failure rate parameter.

When solving practical problems, it is often sufficient to determine only the mathematical expectation, variance, and standard deviation [100, 114, 143].

The mathematical expectation of discrete random variables is determined by:

$$m_x = M(X) = \sum_{i=1}^{n} x \times P_i\,. \tag{4.9}$$

The mathematical expectation of discrete random variables is determined by:

$$m_x = M(X) = \int_{-\infty}^{\infty} x\, f(x)\, d\,x\,. \tag{4.10}$$

The mathematical expectation of the binominal distribution is as follows:

$$m_x = n \times p. \tag{4.11}$$

The variance of the discrete random variables is as follows:

$$D(x) = \sum_{i=1}^{n} (x_i - m_x)^2\, P_i\,. \tag{4.12}$$

The variance of the continuous random variables is as follows:

$$D(x) = \int_{-\infty}^{\infty} (x - m_x)^2 f(x)\, d\,x\,. \tag{4.13}$$

The variance of the variables for the binomial distribution is as follows:

$$D(x) = n \times p \times q. \tag{4.14}$$

The standard deviation is as follows:

$$\sigma_x = \sqrt{D_x}\,. \tag{4.15}$$

The sewerage network monitoring involves regular checks of the technical condition of the facilities and their operation; one of the main tasks in the operation of the wastewater disposal network. This control is the organization of periodic reviews of the network. There are two types of monitoring: external and internal [25, 30, 65, 83], the features of which are shown in Table 4.8.

Table 4.8 —The features of external and internal monitoring of sewerage networks

Content	Network external monitoring	Network internal monitoring
1	2	3
Goal	Identify and timely prevent the disruption of the normal operation of the sewerage network; find out the reasons that threaten its structural integrity	Identify defects in the technical condition and hydraulic conditions of the sewerage network. Carefully inspect all the wells inside, the mouths of pipelines, the through channels; check the operation of equipment and fittings, and eliminate minor faults by the crew
Inspection frequency	At least once a month	According to a special work schedule: at least once a year; through canals to be inspected at least once every two or three years
Inspection group	A squad of two walking inspectors, sometimes of one walking inspector	A crew of at least three people: a foreman and two workers

Table 4.8 (continued)

1	2	3
Monitoring features	Four to five days before the onset of floods, sewer manhole covers should be cleaned of dirt and debris, and the manhole covers themselves should be inspected and thoroughly checked for tight fitting to the top of the shaft manholes. If needed, the existing gaps between the manhole cover and the manhole body are caulked with a rag or felt impregnated with bitumen. Sometimes, at the request of the authorities of the Sewerage disposal service, walking inspectors inspect departmental sewerage networks and check how the housing offices,companies, and organizations comply with the instructions on measures to prepare for floods issued earlier by the Maintenance service. The main purpose of these inspections is to prevent meltwater and snow, crushed ice and so on from draining down and discharging in the inspection chambers in the spring season	The worker, who descends into the shaft, carefully inspects the condition of the walls, floors and inverts, the mouths of the pipelines. In this way, the worker draws attention to the presence of cracks in the places where the pipelines adjoin the walls of the shaft, the appearance in the inverts of ledges or thresholds that complicate the movement of wastewater. Further, the worker cleans the walls of the shaft and the inverts of accumulated deposits, debris and dirt. Special shafts in the network (emergency outlets, siphons, pressure pipelines, etc.) are inspected within the time limits established by a special schedule. In this case, the valves and gates should be checked for the ease of opening; the rubbing parts should be lubricated
Inspection recording	All defects detected by walking inspectors during the external inspection of the network should be recorded daily in a special logbook. It records the nature of the defect, the location in the network where it has been detected, and the time of its elimination. When drawing up a schedule of current and major repair in the network, managers of the maintenance service should use information from these logbooks.	The results of the technical inspection of the wastewater disposal network are recorded in the logbooks or special reports. Inspection records must be accurate, detailed and exhaustive. They must describe the features of individual structures and details of facilities. Some results of technical inspections, such as checking emergency outlets, siphons, and other structures, are recorded in special reports. If a technical inspection of the network which is constructively connected with other structures (crossings over railways, bridges) is performed, a bilateral report is signed with the participation of a representative of the organization that operates these structures. Similar reports are issued if defects are found in the courtyard and production networks or if the rules of sewerage network use are violated

Note: Compiled by the author based on source [35]

For a more detailed study of the monitoring of sewerage networks attention should be paid to the organizational and technological aspect [25, 30, 65, 83].

Organizational and technological monitoring for sewer shafts involves complying with the State Construction Standard DBN B.2.5-75 : 2013 Sewerage, External networks and facilities. Basic design provisions [212–215] approved by the Ministry of Regional Development of Ukraine in 2013.

In case the operation of the sewer system or its individual elements cannot be shut down, measures should be provided to ensure their uninterrupted operation (Table 4.9) [212–215].

Table 4.9 — Measures to ensure the uninterrupted operation of the sewerage networks and facilities

Item No.	Measures
1	Providing reliable electric power supply (using two independent power supply sources, a standby stand-alone power plant, batteries, etc.)
2	Providing redundancy of utilities, designing switches, bypasses, bypass lines, etc.
3	Designing emergency reservoirs with their subsequent emptying when operating in normal mode
4	Sectioning the facilities operating in parallel with a number of sections to provide the necessary capacity without reducing the efficiency of wastewater treatment when disabling one section for repair or emergency work
5	Providing necessary redundancy of working equipment
6	Forecasting potential accidents and designing measures

Conducting various types of sewerage monitoring (environmental, technical, organizational and technological) is due to the need to assess the impact of sewage treatment plants on the environment.

An environmental monitoring system is a system meant to observe, collect, process, transfer, store and analyze information on the condition of the environment, forecast its changes and develop scientificallysound recommendations for decision-making to prevent negative changes in the condition of the environment and comply with the environmental safety requirements [96, 107, 145].

Environmental and social monitoring for wastewater treatment-related industries will be conducted to ensure compliance with the requirements of the legislation during their reconstruction and further operation, and to implement all measures to minimize their impact and consequences on the environment and social environment. The overall goal of monitoring the environmental and social aspects of this project is to ensure and guarantee that all measures aimed at mitigating and minimizing impacts and consequences are successfully implemented and are effective and adequate [212–215].

Environmental and social monitoring also involves the timely identification of new issues and concerns. Monitoring should take place at several levels and anticipate potential environmental threats and / or identify during its implementation the impacts that were not foreseen before. The environmental monitoring program will work during the reconstruction and further operation of a facility (shown in Table 4.10, Fig. 4.6).

Table 4.10 — A monitoring program at the stages of construction and operation

Monitoring at the construction stage			
Parameter to be monitored	**Monitoring intervals**	**Monitoring conducted by**	**Compliance with current legislation**
1	2	3	4
Atmospheric air			
Atmospheric air quality within the boundaries of the sanitary protection zone	4 times a year	Research laboratory (Ministry of Health of Ukraine (MoH)): certified/ specialist laboratory	Compliance with the established maximum allowable concentration of chemical substances
Pollutant content in the exhaust gases from motor vehicle	Once a year	Service stations	Compliance with DSTU 4276: 2004 and DSTU 4277 : 2004
Air quality in premises where waste is temporarily stored	Once a year	Research laboratory (MoH): certified/ specialist laboratory	Compliance with GOST 12.1.005-88
Soil			
Soil condition within the boundaries of the sanitary protection zone	Once a year	Research laboratory (MoH): certified/ specialist laboratory	Compliance with the established maximum allowable concentrations of chemical and biological substances
Waste			
Temporary waste storage sites	Daily	A company's environmental specialist or a person appointed responsible for Environmental Protection	Conditions for waste storage must meet the requirements of the Law of Ukraine "On Waste"
	According to the inspection plan and at unplanned intervals	Representatives of the State Food and Consumer Service, the State Ecological Service, representatives of local authorities and local NGOs	
Noise			
At the construction site	4 times a year	Research laboratory (MoH): certified/ specialist laboratory	Compliance with GOST 12.1.003-2014
At the boundary of the sanitary and technical area	4 times a year	Research laboratory (MoH): certified/ specialist laboratory	Compliance with the standards set out in Order No.173 dated September 19, 1996 of the Ministry of Health of Ukraine
Monitoring at the operation stage			
Atmospheric air			
Atmospheric air quality within the boundaries of the sanitary protection zone	4 times a year	Research laboratory (Ministry of Health of Ukraine (MoH)): certified/ specialist laboratory	Compliance with the established maximum allowable concentration of chemical substances
Laboratory and instrumental control of emissions from stationary emission sources	Once a year	Certified laboratory according to the signed contract	Compliance with the conditions of Permits for air emissions from stationary emission sources
	According to the inspection plan and at unplanned intervals	Certified laboratory, State Ecological Service	

Table 4.10 (continued)

1	2	3	4
Pollutant content in the exhaust gases from motor vehicle	Once a year	Service stations	Compliance with DSTU 4276:2004 and DSTU 4277:2004
Soil			
Soil condition within the boundaries of the sanitary protection zone	Once a year	Research laboratory (Ministry of Health of Ukraine (MoH)): certified/ specialist laboratory	Compliance with the established maximum allowable concentrations of chemical and biological substances
Water			
Water testing from the monitored wells	4 times a year	Research laboratory (Ministry of Health of Ukraine (MoH)): certified/ specialist laboratory	Compliance with the established maximum allowable and background concentrations of pollutants
Waste			
Temporary waste storage sites	Daily/ according to the inspection plan/at unplanned intervals	A company's environmental specialist or a person appointed responsible for Environmental Protection Representatives of the State Food and Consumer Service, the State Ecological Service, representatives of local authorities and local NGOs	Conditions for waste storage must meet the requirements of the Law of Ukraine "On Waste"
Noise			
At the boundary of the sanitary and technical area	4 times a year	Research laboratory (MoH): certified / specialist laboratory	Compliance with the standards set out in Order No.173 dated September 19, 1996 of the Ministry of Health of Ukraine; DSTU 2867-94

Note: Sourced by [39]

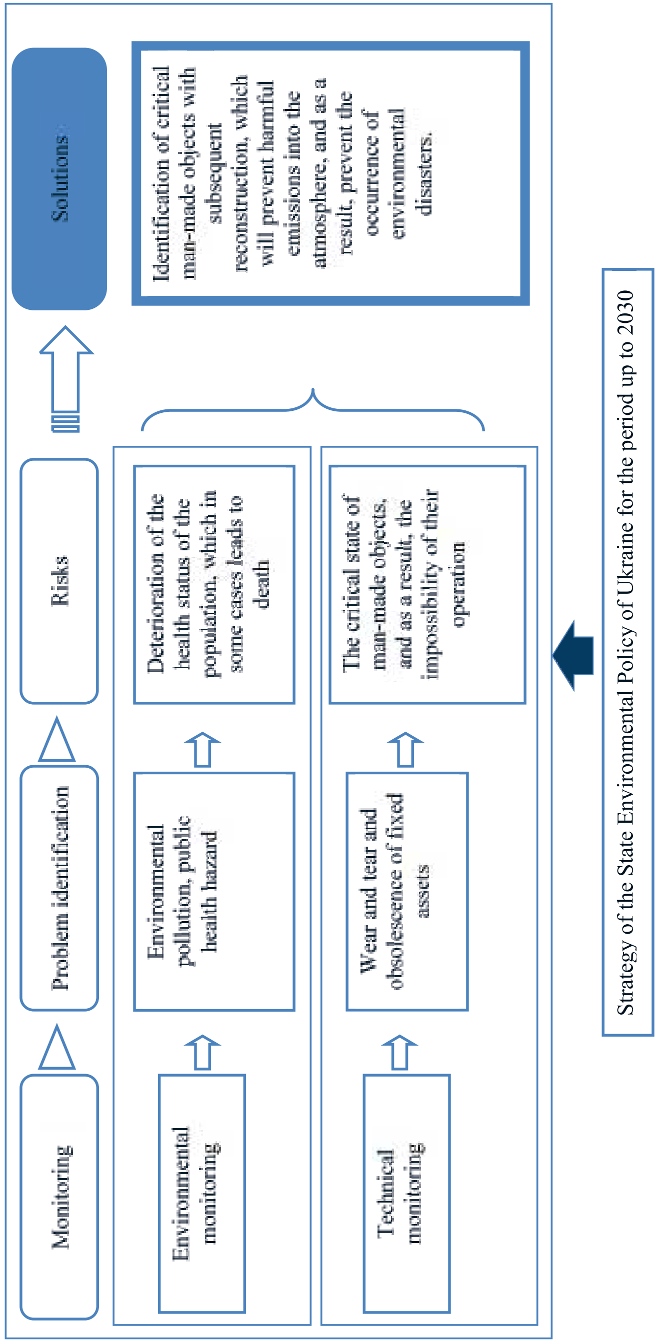


Figure 4.6. Contribution of the dissertation research to the implementation of the Strategy of the State Environmental Policy of Ukraine for the period up to 2030

Note: Developed by the author based on source [114]

4.2. Organizational and Economic Foundations of Developing Indicative Estimates of the Implementation of a System of Organizational and Technological Monitoring of the stable operation of the Sewerage Networks and Facilities

One of the main tasks of reforming the sewerage industry is to find ways to ensure the appropriate amount of rehabilitation for sewerage networks and facilities, and to improve the efficiency of their operation. To retfofit the sewer system engineering facilities is a particularly challenging issue. One way to address the issue is to develop and effectively implement a system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities, where the main tool is a system of indices of the efficiency of its implementation and as a result, to steadily provide centralized wastewater disposal services to consumers [15, 69, 115, 189].

The system of the organizational and technological monitoring of the stable operation of the sewerage networks and facilities is a set of organizational and technological measures aimed at monitoring the stable operation of the sewerage networks and facilities based on the indicative assessments that provide a multifactor diagnosis of their actual condition both in individual areas to be rehabilitated and as a whole. The customer of the above system can be local authorities, public utility companies and privately-owned operating companies [15, 69, 115, 189]. The goals and objectives of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities are based on the need to achieve stable operation, ensure the necessary level of quality standards while providing the technical and economic availability of reliable wastewater disposal services to the population.

Sewerage networks and facilities should be developed and rehabilitated in compliance with the principles of as follows:

- Clearly stating the target provisions, qualitative and quantitative tasks of the statement of work, which then become the basis for monitoring its implementation.
- Improving the percentage of rehabilitation for sewerage networks and facilities relative to the total length of networks.
- Using modern technical and economic technologies of rehabilitation to maintain the stable operation of sewerage networks and facilities.

- Ensuring that a significant part of the return on investment is provided not by increasing tariffs, but by reducing the cost of rehabilitation work.
- Shifting the focus from control over the dynamics of tariff changes to control over the compliance of charges according to the actual cost of wastewater conveyance services.
- Ensuring the balance of needs and economic opportunities [15, 69, 115, 189].

The system of the organizational and technological monitoring of the stable operation of the sewerage networks and facilities in the strategic perspective is aimed at solving the tasks as follows [15, 69, 115, 189]:

- Creating conditions for formation and development of the program of rehabilitation for the sewerage networks and facilities for short-term and long-term periods.
- Implementing effective technologies in terms of technical and economic indices to rehabilitate the linear part of the urban wastewater disposal system.
- Improving the quality and reliability of wastewater disposal services to the population, providing opportunities for building and modernization of the public utility infrastructure in existing residential areas to ensure the target parameters for their improvement.
- Creating the efficient tariff regulation system.

Achieving the goals of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities will require solving a number of tasks, including as follows: identifying the need for amounts and cost of rehabilitation work in sewerage networks and facilities; determining cost parameters, sources of funding, monitoring their implementation, etc. [15, 69, 115, 189].

In this case, the main measures should be aimed at:

- Attracting budgetary and extra-budgetary funds to maintain the comprehensive development of the sewerage networks and facilities;
- Implementing the mechanisms that provide for the planned repair, rehabilitation and comprehensive renovation (retrofitting) of the existing sewerage networks and facilities of the municipal infrastructure of a city.

Effective mechanisms for financing investment projects for the development of the public utility infrastructure to ensure the stable operation of sewerage networks and facilities mean attracting extra-budgetary resources for their implementation and should include measures to make them more attractive to lenders, such as the World Bank for Reconstruction and Development when it comes to the municipal form of ownership.

The national support for measures to rehabilitate the sewerage networks and facilities is ensured by providing budget funds in the form of subventions to local budgets. These funds are provided to operating companies for the implementation of investment projects for rehabilitating the sewerage networks and facilities on the principles of co-financing with other sources [212–215].

As part of the implementation of this monitoring system, it is planned to ensure the reliable and stable operation of the sewerage networks and facilities, and to reduce the wear and tear of public utility facilities. As a result of the program, it is planned to maximize the needs for rehabilitation, to carry out planned and preventive repair of networks and facilities, rather than emergency and rehabilitation work in areas where problems occur.

One of the main obstacles in solving the issues of the integrated development of the sewerage networks and facilities is the insufficient development of mechanisms for monitoring and control of the implementation of relevant measures.

Monitoring as a process of collecting and analyzing information is a powerful control and management tool, the use of which is meant to ensure the evaluation of the feasibility of rehabilitation, price formation and further regulation of tariffs for wastewater disposal services, and solve other, no less important tasks of evaluating the stability of operation. This is possible if the following conditions are met.

— Compliance with the methodological foundations for monitoring and assessing the quality of wastewater disposal services to be provided.
— Interaction between the implementation of the monitoring system and the mechanisms for assessing the quality of services to be provided.
— Use of end-to-end indices of the characteristics of the operation of a public utility company.
— Adequate interpretation of indices and monitoring results [212–215].

The method of monitoring describes the methodology and models on which the system of analysis of the implementation of rehabilitation measures is based, and is a periodic collection of information to determine the

effectiveness of production functions and centralized wastewater disposal services, changes that occur in this case, and costs associated with these processes [83, 87, 96, 102–103].

The methodological approach to monitoring consists in disclosing the structure and description of the constituent elements.

The immediate objectives of monitoring the stable operation of the sewerage networks and facilities include.

— Fulfilling the planned amounts of centralized wastewater disposal services of proper quality provided to consumers.
— Complying with the composition and list of scheduled work on the planned rehabilitation of the sewerage networks and facilities.
— Preventing accidents during operation.
— Complying with the standards and rules of environmental protection, implementing environmental protection measures.
— Using modern technologies of construction work in terms of technical and economic indices.
— Implementing financial plans for recovery (in the amount and structure of disbursed funds) for the implementation of the program of a public utility company [83, 87, 96, 102–103].

The task of monitoring is to track changes that occur over time, in resources, processes and end results, through accounts, a regular reporting system, and investigations conducted when operating the sewerage networks and facilities [89, 147, 221].

To assess and measure the degree of achievement of the objectives set for monitoring the implementation of the system, a number of indices are to be calculated and used.

— Change of indices (resources, processes, results) over time, which are defined as absolute deviations of the relevant indices or rates of their growth or decline.
— Change in the structure of a set of indices.
— Compliance (non-compliance) of interrelated indices.
— Ratio of indices.
— Comparative characteristics of indices and so on.

An index is an indicative value, a measure that allows, to some extent, for prediction of the direction the development of processes may be heading.

There are many different indices in different areas of the economy and production of the micro- and macroenvironment of a company. Thus, to assess the socio-economic condition of the regions according to statistical data, indices of economic, financial and integrated levels of development are to be calculated, along with standards of living [83, 87, 96, 102–103].

Indicative planning for sewerage utilities is non-directive, adfvisory, indicative planning. This is the planning that operates with indices, in particular, indices of change in quantities, structural relationships, and so on. Indicative plans, which are forecast plans, are elaborated to help sewerage utility operating companies to target the right area, elaborate their own plans, based on the vision of the future by government agencies and scientific organizations involved.

Indicative planning can also be considered as the implementation of centralized objectives to coordinate investments, and production plans.

The implementation of indicative planning, which determines the rates of growth and development of the sewerage networks and facilities, is based on the formalization of the system of indices that show the technical and economic condition of the sewerage networks and facilities at the time of the adoption of the program and at the time of its completion. The introduction of indicative planning means improving the parameters of the balance (optimality) for the structure of the sewerage networks and facilities, improving their stability and reliability, technical and economic efficiency, the quality of services and the quality of functioning, the availability of centralized wastewater disposal services and compliance of their cost with actual cost indices [127, 129, 134 , 169].

The system of indices should describe the technical condition of the sewerage networks and facilities, their safety and the favorable conditions for the operation of subsistence systems, the financial stability, and the economic affordability of the proposed organizational and technological measures. In comparative analysis, the system of indices should meet the criteria of the completeness of description, the compactness, while the quantitative indices should be comparable both in terms of time and with regard to the location of the sewerage networks and facilities, which largely contributes to determine the target values of the indices.

The research work has developed indices for the implementation of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities by the groups as follows [11, 25, 30].

- Availability of sewerage networks and facilities to the city.
- Indices of funding from various sources.
- Indices of the effectiveness of rehabilitation work for the sewerage networks and facilities.

- Indices of the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities.
- Indices of the environmental safety of operating the sewerage networks and facilities.
- Indices of the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities.
- Indices of the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities.

The first group of indices describes the availability of sewerage networks and facilities to the area (utility lines of various diameters such as sewer networks, sewers, sewer tunnels, sewer shafts and stilling chambers). It is calculated as the ratio of the length of utilities to the total area of the city, and the ratio of the number of utilities to the total area, respectively. When calculating the value of the index, the following data are used: the length or number of each type of engineering structures of the sewerage networks and facilities throughout the city in kilometers (units) and the total area of the city in square kilometers [11] (Table 4.11).

The second group of indices includes indices of funding from various sources such as the municipal budget, the budget of the operating company, the European Bank for Reconstruction and Development, the partial contribution of construction companies (in case of additional load on the city's utility lines when connecting new construction facilities). Here, the share of each source of funding in the total amount of funding is identified. The data are given based on the information on the comprehensive development of the sewerage networks and facilities (Table 4.12).

The third group of indices shows the effectiveness of rehabilitation work for the sewerage networks and facilities. It is calculated as the ratio of the actually completed and planned amount of work in percent terms (Table 4.13).

The fourth group includes the indices of the effectiveness of work performance to eliminate accident-caused damage to the sewerage networks and facilities. This group is also represented by all components of the sewerage networks and facilities: utility lines of various diameters, networks, sewers, sewer tunnels, sewer shafts, and stilling chambers. It is calculated as the ratio of the number of accident-caused damage to individual components of sewerage networks and facilities to the total number of accidents in percentage terms [11]. These indices describe the efficiency of work performance (Table 4.14).

The fifth group indicates the environmental safety of operating sewerage networks and facilities based on the calculations according to the environmental risk method to assess the environmental hazards of operating sewerage networks and facilities, which will be shown in detail in Chapter 5. This group also describes all components of sewerage networks and facilities. It is calculated as the ratio of the level of environmental risk of operating a facility to the total level of operation risk for sewerage networks and facilities (Table 4.15).

Table 4.11 — Availability of the sewerage networks and facilities to the city

Item No.	Parameter	Calculation formula	Unit of meas
1.1	Level of availability of sewer networks to the city	$U_{K1} = L_{K1} / S$, where U_{K1} — is the level of availability of sewer networks; L_{K1} — is the length of the sewerage network, km; S — is the area of the city, km^2	km / km^2
1.2	Level of availability of sewers to the city	$U_{K2} = L_{K2} / S$, where U_{K2} — is the level of availability of sewers; L_{K2} — is the length of the sewerage network, km; S — is the area of the city, km^2	km / km^2
1.3	Level of availability of sewer tunnels to the city	$U_{K3} = L_{K3} / S$, where U_{K3} — is the level of availability of gas networks; L_{K3} — is the length of the gas network, km; S — is the area of the city, km^2	km / km^2
1.4	Level of availability of sewer shafts to the city	$U_{\text{Ш}} = L_{\text{Ш}} / S$, where $U_{\text{Ш}}$ — is the level of availability of sewer shafts; $L_{\text{Ш}}$ —is the number of sewer shafts, units; S — is the area of the city, km^2	units / km^2
1.5	Level of availability of stilling chambers to the city	$U_{\Gamma} = L_{\Gamma} / S$, where U_{Γ} — is the level of availability of stilling chambers; L_{Γ} — is the number of stilling chambers, units; S — is the area of the city, km^2	units / km^2

Table 4.12 — Indices of funding from various sources

Item No.	Parameter	Calculation formula	Unit of meas
2.1	Share of funding from the municipal budget	$U_{\text{ФБ}} = Q_{\text{ФБ}} / Q_{\text{ЗАГ}} \times 100\ \%$, where $Q_{\text{ФБ}}$ — is the amount of funding from the municipal budget, thousand UAH; $Q_{\text{ЗАГ}}$ — is the total amount of funding, thousand UAH	%
2.2	Share of funding from the budget of the operating company	$U_{\text{ЕП}} = Q_{\text{ЕП}} / Q_{\text{ЗАГ}} \times 100\ \%$, where $Q_{\text{ЕП}}$ — is the amount of funding from the operating company, thousand UAH; $Q_{\text{ЗАГ}}$ — is the total amount of funding, thousand UAH	%
2.3	Share of funding from the European Bank for Reconstruction and Development	$U_{\text{ЄБРР}} = Q_{\text{ЄБРР}} / Q_{\text{ЗАГ}} \times 100\ \%$, where $Q_{\text{ЕБРР}}$ — is the amount of funding from the European Bank for Reconstruction and Development, thousand UAH; $Q_{\text{ЗАГ}}$ — is the total amount of funding, thousand UAH	%
2.4	Share of funding from the partial contribution of construction companies	$U_{\text{ЧУ}} = Q_{\text{ЧУ}} / Q_{\text{ЗАГ}} \times 100\ \%$, where $Q_{\text{ЧУ}}$ — is the amount of funding from the partial contribution of construction companies, thousand UAH; $Q_{\text{ЗАГ}}$ — is the total amount of funding, thousand UAH	%

Table 4.13 — Indices of the effectiveness of rehabilitation work for sewerage networks and facilities

Item No.	Parameter	Calculation formula	Unit of meas
1	2	3	4
3.1	Index of the effectiveness of rehabilitation work for sewer networks	${I^{K1}}_{B} = {V^{K1}}_{\text{ФАКТ}} / {V^{K1}}_{\text{ПЛАН}} \times 100\ \%$, where ${V^{K1}}_{\text{ФАКТ}}$ — is the actually completed amount of rehabilitation work for sewer networks; ${V^{K1}}_{\text{ПЛАН}}$ — is the planned amount of rehabilitation work for sewer networks	%

Table 4.13 (continued)

1	2	3	4
3.2	Index of the effectiveness of rehabilitation work for sewers	$I^{\text{К2}}_{\text{В}} = V^{\text{К2}}_{\text{ФАКТ}} / V^{\text{К2}}_{\text{ПЛАН}} \times 100\ \%$, where $V^{\text{К2}}_{\text{ФАКТ}}$ — is the actually completed amount of rehabilitation work for sewers; $V^{\text{К2}}_{\text{ПЛАН}}$ — is the planned amount of rehabilitation work for sewers	%
3.3	Index of the effectiveness of rehabilitation work for sewer tunnels	$I^{\text{К3}}_{\text{В}} = V^{\text{К3}}_{\text{ФАКТ}} / V^{\text{К3}}_{\text{ПЛАН}} \times 100\ \%$, where $V^{\text{К3}}_{\text{ФАКТ}}$ — is the actually completed amount of rehabilitation work for sewer tunnels; $V^{\text{К3}}_{\text{ПЛАН}}$ — is the planned amount of rehabilitation work for sewer tunnels	%
3.4	Index of the effectiveness of rehabilitation work for sewer shafts	$I^{\text{Ш}}_{\text{В}} = V^{\text{Ш}}_{\text{ФАКТ}} / V^{\text{Ш}}_{\text{ПЛАН}} \times 100\ \%$, where $V^{\text{Ш}}_{\text{ФАКТ}}$ — is the actually completed amount of rehabilitation work for sewer shafts; $V^{\text{Ш}}_{\text{ПЛАН}}$ — is the planned amount of rehabilitation work for sewer shafts	%
3.5	Index of the effectiveness of rehabilitation work for stilling chambers	$I^{\text{Г}}_{\text{В}} = V^{\text{Г}}_{\text{ФАКТ}} / V^{\text{Г}}_{\text{ПЛАН}} \times 100\ \%$, where $V^{\text{Г}}_{\text{ФАКТ}}$ — is the actually completed amount of rehabilitation work for stilling chambers; $V^{\text{Г}}_{\text{ПЛАН}}$ — is the planned amount of rehabilitation work for stilling chambers	%

Table 4.14 — Indices of the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities

Item No.	Parameter	Calculation formula	Unit of meas
1	2	3	4
4.1	Index of the effectiveness of eliminating accident-caused damage to sewer networks	$I^{\text{К1}}_{\text{А}} = V^{\text{К1}}_{\text{А}} / V^{\text{ЗАГ}}_{\text{А}} \times 100\ \%$, where $V^{\text{К1}}_{\text{А}}$ — is the number of cases of accident-caused damage in sewer networks, cases/year; $V^{\text{ЗАГ}}_{\text{А}}$ — is the total number of cases of accident-caused damage, cases / year	%
4.2	Index of the effectiveness of eliminating accident-caused damage to sewers	$I^{\text{К2}}_{\text{А}} = V^{\text{К2}}_{\text{А}} / V^{\text{ЗАГ}}_{\text{А}} \times 100\ \%$, where $V^{\text{К2}}_{\text{А}}$ — is the number of cases of accident-caused damage in sewers, cases / year; $V^{\text{ЗАГ}}_{\text{А}}$ — is the total number of cases of accident-caused damage, cases / year	%
4.3	Index of the effectiveness of eliminating accident-caused damage to sewer tunnels	$I^{\text{К3}}_{\text{А}} = V^{\text{К3}}_{\text{А}} / V^{\text{ЗАГ}}_{\text{А}} \times 100\ \%$, where $V^{\text{К3}}_{\text{А}}$ — is the number of cases of accident-caused damage in sewer tunnels, cases / year; $V^{\text{ЗАГ}}_{\text{А}}$ — is the total number of cases of accident-caused damage, cases / year	%
4.4	Index of the effectiveness of eliminating accident-caused damage to sewer shafts	$I^{\text{Ш}}_{\text{А}} = V^{\text{Ш}}_{\text{А}} / V^{\text{ЗАГ}}_{\text{А}} \times 100\ \%$, where $V^{\text{Ш}}_{\text{А}}$ — is the number of cases of accident-caused damage in sewer shafts, cases / year; $V^{\text{ЗАГ}}_{\text{А}}$ — is the total number of cases of accident-caused damage, cases / year	%
4.5	Index of the effectiveness of eliminating accident-caused damage to stilling chambers	$I^{\text{Г}}_{\text{А}} = V^{\text{Г}}_{\text{А}} / V^{\text{ЗАГ}}_{\text{А}} \times 100\ \%$, where $V^{\text{Г}}_{\text{А}}$ — is the number of cases of accident-caused damage in stilling chambers, cases / year; $V^{\text{ЗАГ}}_{\text{А}}$ — is the total number of cases of accident-caused damage, cases / year	%

The sixth group of indices covers the indices of the efficiency of the application of funds of the stable operation of the sewerage networks and facilities in total in monetary terms. The factor is calculated as the ratio of the actual value of the allocated funds for performing work to the planned value [11]. The regulatory value is equal to 100 %. The value greater than one indicates the efficient application of funds and even overfulfillment of the planned amount. If the value is less than one, one can say that the funds are not fully applied (Table 4.16).

The seventh group includes the indices of the efficiency of implementing the system of the organizational and technological monitoring of the stable operation of sewerage networks and facilities. In this case, calculations should be performed at selected intervals to investigate the dynamicity of changes in the indices (Table 4.17).

Table 4.15 — Indices of the environmental safety of operating the sewerage networks and facilities

Item No.	Parameter	Calculation formula	Unit of meas
5.1	Index of the environmental safety of operating sewer networks	$I^{K1}_{E} = V^{K1}_{E} / V^{ЗАГ}_{E} \times 100\ \%$, where V^{K1}_{E} — is the level of environmental risk of operating sewer networks; $V^{ЗАГ}_{E}$ — is the total level of operation risk for sewerage networks and facilities	%
5.2	Index of the environmental safety of operating sewers	$I^{K2}_{E} = V^{K2}_{E} / V^{ЗАГ}_{E} \times 100\ \%$, where V^{K2}_{E} — is the level of environmental risk of operating sewers; $V^{ЗАГ}_{E}$ — is the total level of operation risk for sewerage networks and facilities	%
5.3	Index of the environmental safety of operating sewer tunnels	$IK3E=VK3E/\ V3AГE \times 100\ \%$, where V^{K3}_{E} — is the level of environmental risk of operating sewer tunnels; $V^{ЗАГ}_{E}$ — is the total level of operation risk for sewerage networks and facilities	%
5.4	Index of the environmental safety of operating sewer shafts	$I^{Ш}_{E} = V^{Ш}_{E} / V^{ЗАГ}_{E} \times 100\ \%$, where $V^{Ш}_{E}$ — is the level of environmental risk of operating sewer shafts; $V^{ЗАГ}_{E}$ — is the total level of operation risk for sewerage networks and facilities	%
5.5	Index of the environmental safety of operating stilling chambers	$I^{Г}_{E} = V^{Г}_{E} / V^{ЗАГ}_{E} \times 100\ \%$, where $V^{Г}_{E}$ — is the level of environmental risk of operating stilling chambers; $V^{ЗАГ}_{E}$ — is the total level of operation risk for sewerage networks and facilities	%

Table 4.16 — Indices of the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities

Item No.	Parameter	Calculation formula	Unit of meas
1	2	3	4
6.1	Coefficient of efficiency for application of funds allocated of the stable operation of sewer networks	$K_{K1} = X^{Ф} / X^{ПЛ} \times 100\ \%$, where K_{K1} — is the coefficient of efficiency for application of funds allocated for rehabilitation and elimination of accident-caused damage to sewer networks; $X^{Ф}$ — is the actual amount of funds allocated for performing work for sewer networks, thousand UAH; $X^{ПЛ}$ — is the planned amount of funds allocated for performing work for sewer networks, thousand UAH	%
6.2	Coefficient of efficiency for application of funds allocated of the stable operation of sewers	$K_{K2} = X^{Ф} / X^{ПЛ} \times 100\ \%$, where K_{K2} — is the coefficient of efficiency for application of funds allocated for rehabilitation and elimination of accident-caused damage to sewers; $X^{Ф}$ — is the actual amount of funds allocated for performing work for sewers, thousand UAH; $X^{ПЛ}$ — is the planned amount of funds allocated for performing work for sewers, thousand UAH	%
6.3	Coefficient of efficiency for application of funds allocated of the stable operation of sewer tunnels	$K_{K3} = X^{Ф} / X^{ПЛ} \times 100\ \%$, where K_{K3} — is the coefficient of efficiency for application of funds allocated for rehabilitation and elimination of accident-caused damage to sewer tunnels; $X^{Ф}$ — is the actual amount of funds allocated for performing work for sewer tunnels, thousand UAH; $X^{ПЛ}$ — is the planned amount of funds allocated for performing work for sewer tunnels, thousand UAH	%

Table 4.16 (continued)

1	2	3	4
6.4	Coefficient of efficiency for application of funds allocated of the stable operation of sewer shafts	$K_{Ш} = X^{Ф} / X^{ПЛ} \times 100\ \%$, where $K_{Ш}$ — is the coefficient of efficiency for application of funds allocated for rehabilitation and elimination of accident-caused damage to sewer shafts; $X^{Ф}$ — is the actual amount of funds allocated for performing work for sewer shafts, thousand UAH; $X^{ПЛ}$ — is the planned amount of funds allocated for performing work for sewer shafts, thousand UAH	%
6.5	Coefficient of efficiency for application of funds allocated of the stable operation of stilling chambers	$K_{Г} = X^{Ф} / X^{ПЛ} \times 100\ \%$, where $K_{Г}$ — is the coefficient of efficiency for application of funds allocated for rehabilitation and elimination of accident-caused damage to stilling chambers; $X^{Ф}$ — is the actual amount of funds allocated for performing work for stilling chambers, thousand UAH; $X^{ПЛ}$ — is the planned amount of funds allocated for performing work for stilling chambers, thousand UAH	%

Table 4.17 — Indices of the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities

Item No.	Parameter	Calculation formula	Unit of meas
1	2	3	4
7.1	Index of the efficiency of implementing the system	$E = Q_{ОСВ} / Q_{ЗАГ1} \times 100\ \%$, where $Q_{ОСВ}$ — is the amount of applied funds, million UAH; $Q_{ЗАГ1}$ — is the total amount of allocated funds, million UAH	%

Table 4.17 (continued)

1	2	3	4
7.2	Index of the innovative implementation of the system	$I_{ІНОВ} = Q_{ІНОВ} / Q_{ЗАГ2} \times 100\ \%$, where $Q_{ІНОВ}$ — is the amount of rehabilitating sewerage networks and facilities using new technology; $Q_{ЗАГ2}$ — is the total amount of rehabilitating sewerage networks and facilities	%
7.3	Index of the utilization of domestic technology	$I_{ВІТЧ} = Q_{ОСВ}\ /\ Q_{ЗАГ3} \times 100\ \%$, where $Q_{ВІТЧ}$ — is the amount rehabilitating sewerage networks and facilities using domestic technology; $Q_{ЗАГ3}$ — is the total amount of rehabilitating sewerage networks and facilities	%

At the next stage, each index of implementing the system of the organizational and technological monitoring of the stable operation of sewerage networks and facilities was assigned with limiting values according to the definition (Table 4.18).

Table 4.18 — Indices of the effectiveness of the implementation of the organizational and technological monitoring system to ensure the stable operation of the sewerage networks and facilities

Item No.	Parameter	Index value by facility	
		Definition	Score
1	2	3	4
1.1	Level of availability of sewerage networks to the city	Unsatisfactory	0–2
		Satisfactory	> 2–3
		Good	> 3–10
1.2	Level of availability of sewers to the city	Unsatisfactory	0–2
		Satisfactory	> 2–3
		Good	> 3–10
1.3	Level of availability of sewer tunnels to the city	Unsatisfactory	0–2
		Satisfactory	> 2–3
		Good	> 3–10

Table 4.18 (continued)

1	2	3	4
1.4	Level of availability of sewer shafts to the city	Unsatisfactory	0–2
		Satisfactory	> 2–3
		Good	> 3–10
1.5	Level of availability of stilling chambers to the city	Unsatisfactory	0–2
		Satisfactory	> 2–3
		Good	> 3–10
2.1	Share of funding from the municipal budget	Insufficient	0–20
		Moderate	> 20–80
		Sufficient	> 80–100
2.2	Share of funding from the budget of the operating company	Insufficient	0–20
		Moderate	> 20–80
		Sufficient	> 80–100
2.3	Share of funding from the European Bank for Reconstruction and Development	Insufficient	0–20
		Moderate	> 20–80
		Sufficient	> 80–100
2.4	Share of funding from the partial contribution of construction companies	Insufficient	0–20
		Moderate	> 20–80
		Sufficient	> 80–100
3.1	Index of the effectiveness of rehabilitation work for sewer networks	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
3.2	Index of the effectiveness of rehabilitation work for sewers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
3.3	Index of the effectiveness of rehabilitation work for sewer tunnels	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
3.4	Index of the effectiveness of rehabilitation work for sewer shafts	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
3.5	Index of the effectiveness of rehabilitation work for stilling chambers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100

Table 4.18 (continued)

1	2	3	4
4.1	Index of the effectiveness of eliminating accident-caused damage to sewer networks	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
4.2	Index of the effectiveness of eliminating accident-caused damage to sewers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
4.3	Index of the effectiveness of eliminating accident-caused damage to sewer tunnels	Critical	0-20
		Satisfactory	> 20-80
		Moderate	> 80-100
4.4	Index of the effectiveness of eliminating accident-caused damage to sewer shafts	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
4.5	Index of the effectiveness of eliminating accident-caused damage to stilling chambers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
5.1	Index of the environmental safety of operating sewer networks	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
5.2	Index of the environmental safety of operating sewers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
5.3	Index of the environmental safety of operating sewer tunnels	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
5.4	Index of the environmental safety of operating sewer shafts	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
5.5	Index of the environmental safety of operating stilling chambers	Critical	0–20
		Satisfactory	> 20–80
		Moderate	> 80–100
6.1	Coefficient of efficiency for application of funds allocated for the stable operation of sewer networks	Unsatisfactory	0–30
		Satiisfactory	> 30–70
		Good	> 70–100

Table 4.18 (continued)

1	2	3	4
6.2	Coefficient of efficiency for application of funds allocated for the stable operation of sewers	Unsatisfactory	0–30
		Satiisfactory	> 30–70
		Good	> 70–100
6.3	Coefficient of efficiency for application of funds allocated for the stable operation of sewer tunnels	Unsatisfactory	0–30
		Satiisfactory	> 30–70
		Good	>70–100
6.4	Coefficient of efficiency for application of funds allocated for the stable operation of sewer shafts	Unsatisfactory	0–30
		Satiisfactory	> 30–70
		Good	> 70–100
6.5	Coefficient of efficiency for application of funds allocated for the stable operation of stilling chambers	Unsatisfactory	0–30
		Satiisfactory	> 30–70
		Good	> 70–100
7.1	Index of the efficiency of implementing the system	Unsatisfactory	0–20
		Moderate	> 20–80
		High	> 80–100
7.2	Index of the innovative implementation of the system	Unsatisfactory	0–20
		Moderate	> 20–80
		High	> 80–100
7.3	Index of the utilization of domestic technology	Unsatisfactory	0–20
		Moderate	> 20–80
		High	> 80–100

Conclusions to Chapter 4:

1. The theoretical and methodological fundamentals of the category of monitoring have been investigated;
2. The specific features of the external and internal monitoring of sewerage networks and facilities have been reviewed;
3. The contribution of the dissertation research to the implementation of the Strategy of the State Environmental Policy of Ukraine for the period up to 2030 has been determined;
4. The organizational and economic fundamentals of the development of indicative estimates for the implementation of the system of the organizational and technological monitoring for the stable operation of sewerage networks and facilities have been investigated;
5. The indices of the implementation of the system of the organizational and technological monitoring for the stable operation of sewerage networks and facilities have been developed and classified into the groups as follows.

— Availability of sewerage networks and facilities to the city.
— Indices of funding from various sources.
— Indices of the effectiveness of rehabilitation work for sewerage networks and facilities.
— Indices of the effectiveness of eliminating accident-caused damage to sewerage networks and facilities.
— Indices of the environmental safety of operating sewerage networks and facilities.
— Indices of the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to sewerage networks and facilities.
— Indices of the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of sewerage networks and facilities.

CHAPTER 5

APPLYING THE ENVIRONMENTAL RISK METHODOLOGY TO ASSESS THE LEVEL OF ENVIRONMENTAL HAZARD POSED BY SEWER SHAFTS

5.1. Assessing Environmental Risk to the Natural Environment

The purpose of assessing the environmental risks of accidental emissions and discharges that may enter the natural environment (NE) due to accidents in sewer networks is to identify hazardous factors of impact, obtain and summarize information on the levels and consequences of their action, and determine the probability of consequences to prevent the development of adverse effects to justify management decisions to reduce the level of risk. The procedure for assessing the environmental risks of impact on NE objects should be arranged in three stages: hazard identification, risk assessment and risk profile (Fig. 5.1) [76, 83–85, 88].

Hazard identification is the initial stage of the risk assessment procedure, which involves establishing the ability of a hazardous factor to cause adverse effects or consequences in the components of NE. The main task of this stage is to assess the completeness and reliability of existing data, collect and analyze information on quantitative indicators of hazardous factors of impact (concentration, dose, intensity of damage), determine priority data, for instance, based on preliminary cluster analysis. The initial data obtained at the hazard identification stage are then used to assess the risk of impact of hazardous factors on NE objects and human health [110, 114, 143, 187].

The second stage of the risk assessment procedure, the impact risk assessment stage, identifies causal links between the impact of a potentially hazardous factor and the development of adverse effects and consequences of the object of impact, assesses a quantitative risk in terms of the probability of occurrence of a threat to the condition of the NE components (atmospheric air, soils, water bodies) and human health (Fig. 5.2). This stage is essential to provide output data on the final hazard assessment.

The third stage assesses risks according to different categories and types. Based on the generalization of the obtained data, recommendations are proposed that are necessary for the development of risk management measures [76, 83–85, 187].

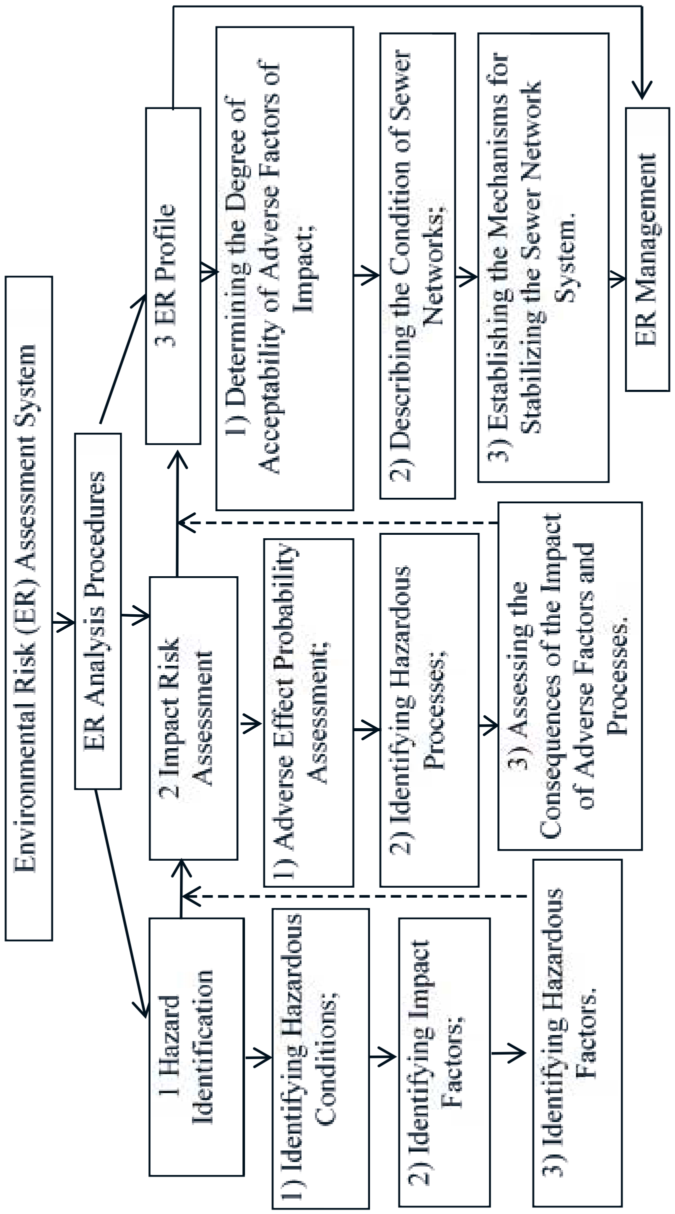


Figure 5.1. A flow diagram for the environmental risk assessment procedure
→ — information and management links in a system object of research,
---→ — information links

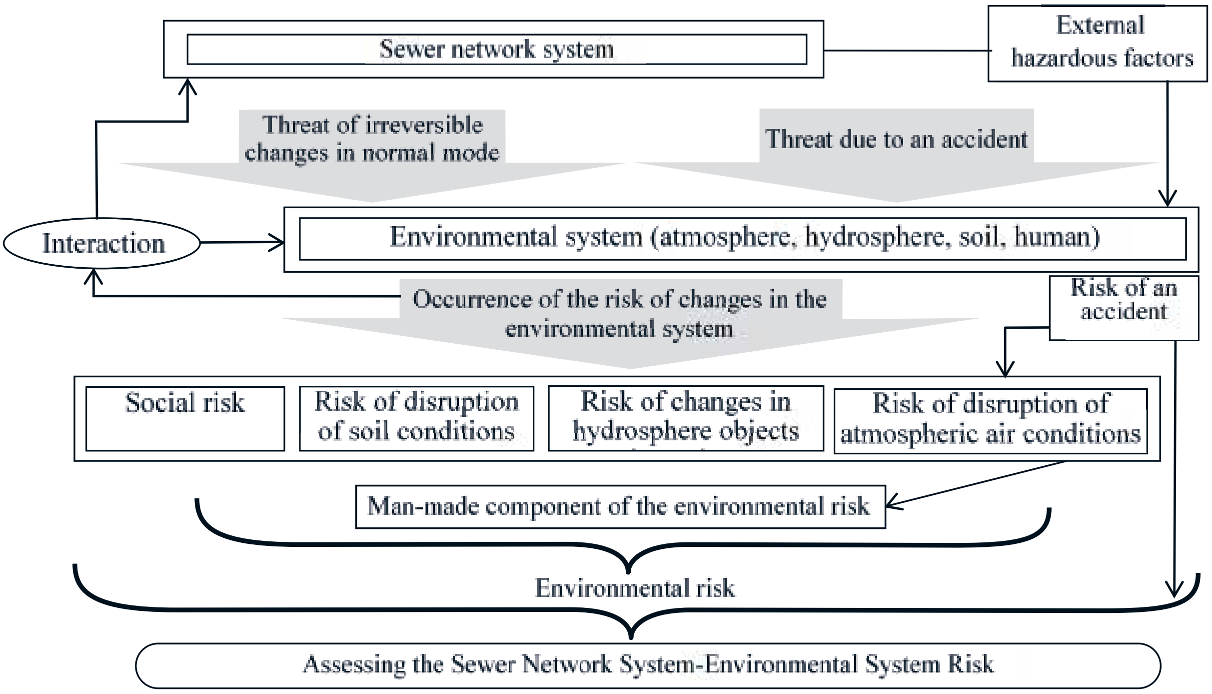


Figure 5.2. A conceptual diagram for identifying environmental risks
Double contour: interacting systems; Solid line: the features of the normal operation of a facility;
Dashed line: the features of an accident.

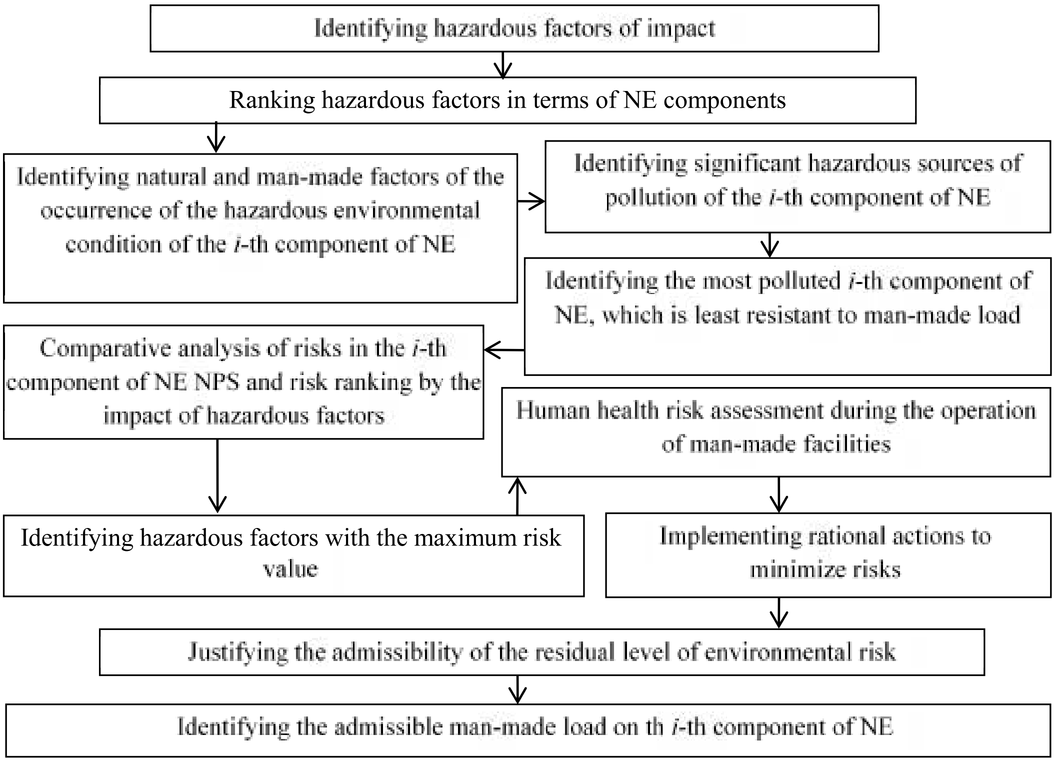


Figure 5.3. A general framework for environmental risk management

Environmental risk assessment is a generalized characteristic of the impact of sewer networks on NE and the consequences of their operation [84].

The application of the principles of environmental risk management involves the rational allocation of resource costs to reduce the level of violations and negative consequences, which is achieved under the existing economic conditions, social conditions and technological options at a man-made facility (sewer network) (Fig. 5.3) [187].

The probabilistic approach corresponds to the classical definition of the concept of risk and allows considering the variability and uncertainty of the distribution of the negative impact factor in the NE objects. The result of the assessment of this risk is the calculated probability of adverse effects from the identified violations in the NE systems during the period of the negative impact from all sources of pollution. The loading factors on the natural component of NE are identified according to the results of the assessment of the safety condition of atmospheric air, water environment and soils. A quantitative analysis of compliance with the environmental requirements of a man-made facility is proposed to be conducted as a consistent assessment of the causes of negative changes with the establishment of regulatory actions to stabilize the condition of the NE components (Fig. 5.4) [98–101, 187].

Based on the obtained calculations of the levels of non-compliance with the established regulatory quality indicators, the total environmental risk of the condition of a facility may be determined (Fig. 5.5) [99].

The overall level of environmental risk on the basis of process flow indices in the research system is assessed accordint to a verbal-point scale of levels of environmental risk (Table 5.1) [99].

Table 5.1 — A scale for determining the overall level of environmental risk

Value	**Risk assessment**
0 to 1	No risk
1 to 1.5	Low risk
1.5 to 3.0	Moderate risk
3 to 4	High risk
> 4	Maximum risk

The environmental risk assessment according to load factors is interpreted on a scale that has several levels (Table 5.2).

Table 5.2 — A scale for determining environmental risks with regard to the processes in the research system

Value	**Risk assessment**
0 to 10–8	Minimum risk
10–8 to 10–6	Low risk
10–6 to 10–4	Moderate risk
> 10–4	High risk

According to the algorithm shown in Fig. 5.5, and according to the environmental risk identification scale with regard to the processes in the system of research (sewer networks), an environmental assessment of the condition of man-made facilities has been obtained based on the monitoring of 11 sewer tunnel shafts with determination of hazardous impact indicators. The assessment was conducted using the monitoring data on concentrations of environmentally hazardous gaseous substances formed in sewer tunnels during wastewater conveyance. The chemical laboratory of Public Utility Company Kharkivvodokanal periodically measures the concentrations of environmentally hazardous gaseous compounds such as hydrogen sulfide (H_2S), sulfur dioxide (SO_2), carbon dioxide (CO_2) and methane (CH_4). The developed algorithmic support of risk assessment of a man-made facility takes into consideration the origin of the adverse impact factors, and the consequences of an adverse factor for the NE components. Table 5.3 shows the results of the overall and factor-by-factor assessment of the environmental risk of the impact of sewer tunnel shafts on atmospheric air [76, 114, 143, 187].

As can be seen from Table 5.3, Shaft No. 3 of the Avtozapchastyna Plant tunnel, Shaft No. 1 of the Osnovianskyi sewer tunnel, Shaft No. 5 on Zubareva street, Shaft No.3 of the Main tunnel, Shaft No. 4 of the tunnel of the Northern group of plants and Shaft No. 4a of the tunnel of the Northern group of plants show a low level of risk; Shaft No. 10 of the KhTZ tunnel, Shaft No. 12 of the KhTZ tunnel show a moderate level of risk. Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt, Shaft No. 5 of the KhTZ tunnel, Shaft No. 4 of the KhTZ tunnel show a high level of risk. According to the results of the overall and factor-by-factor assessment of the environmental risk of the impact of the sewer tunnel shafts on atmospheric air, hydrogen sulfide and sulfur dioxide are found to be the most important load and hazard factors. Figures 5.6 and 5.7 show the diagrams of the environmental risks of the impact of sulfur dioxide and hydrogen sulfide on atmospheric air.

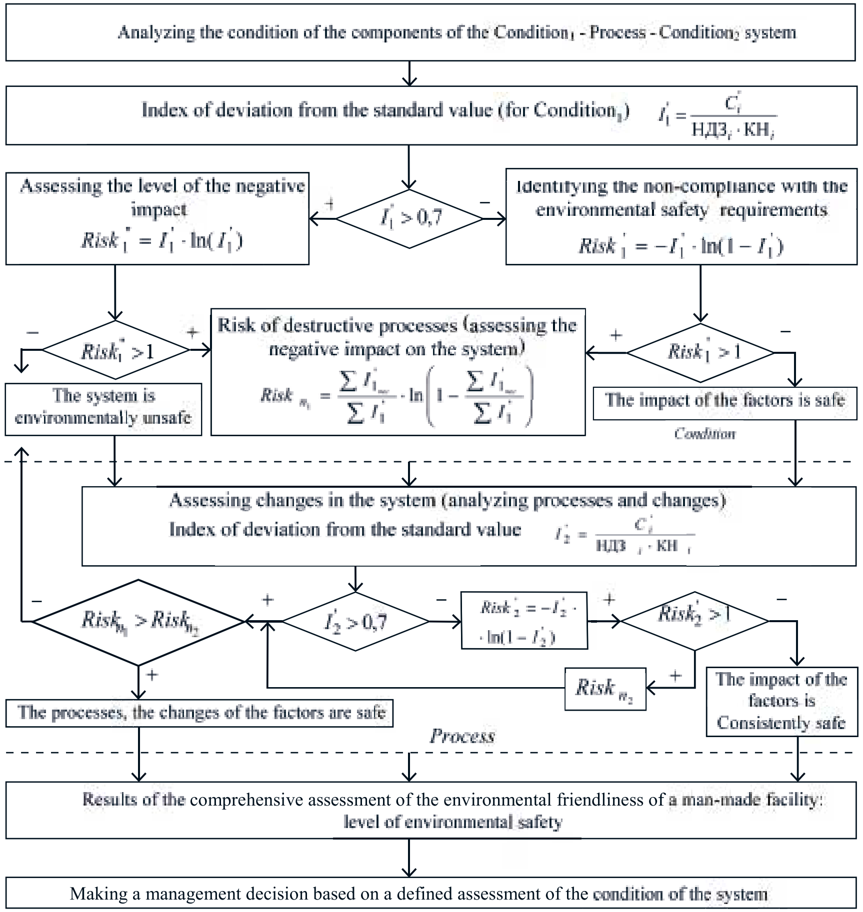


Figure 5.4. A flow diagram for the algorithm of risk assessment of the environmental friendliness of man-made facilities.

НДЗ$_i$ — the standard permissible value (including MPC) for the *i*-th component; КН$_i$ — the hazard class of the i-th component; Risk'$_1$ — the risk for Condition$_1$ of the system as non-compliance of its functionality with natural qualities according to the specified regulatory framework; Risk''$_1$ — the risk for Condition$_1$ as assessment of the degree of the negative impact on the NE objects; Risk$_{n1}$ — the risk as deviation of a set of negative factors from the general characteristics of the processes of transition of the system to Condition$_2$; Risk'$_2$ — the risk for Condition$_2$ as assessment of the consistency of the factors impacting the final condition of the system; Risk$_{n2}$ — the risk from the standpoint of transformation in the internal space of destabilizing factors that lead to stabilization or destabilization of the final "System – NE" condition

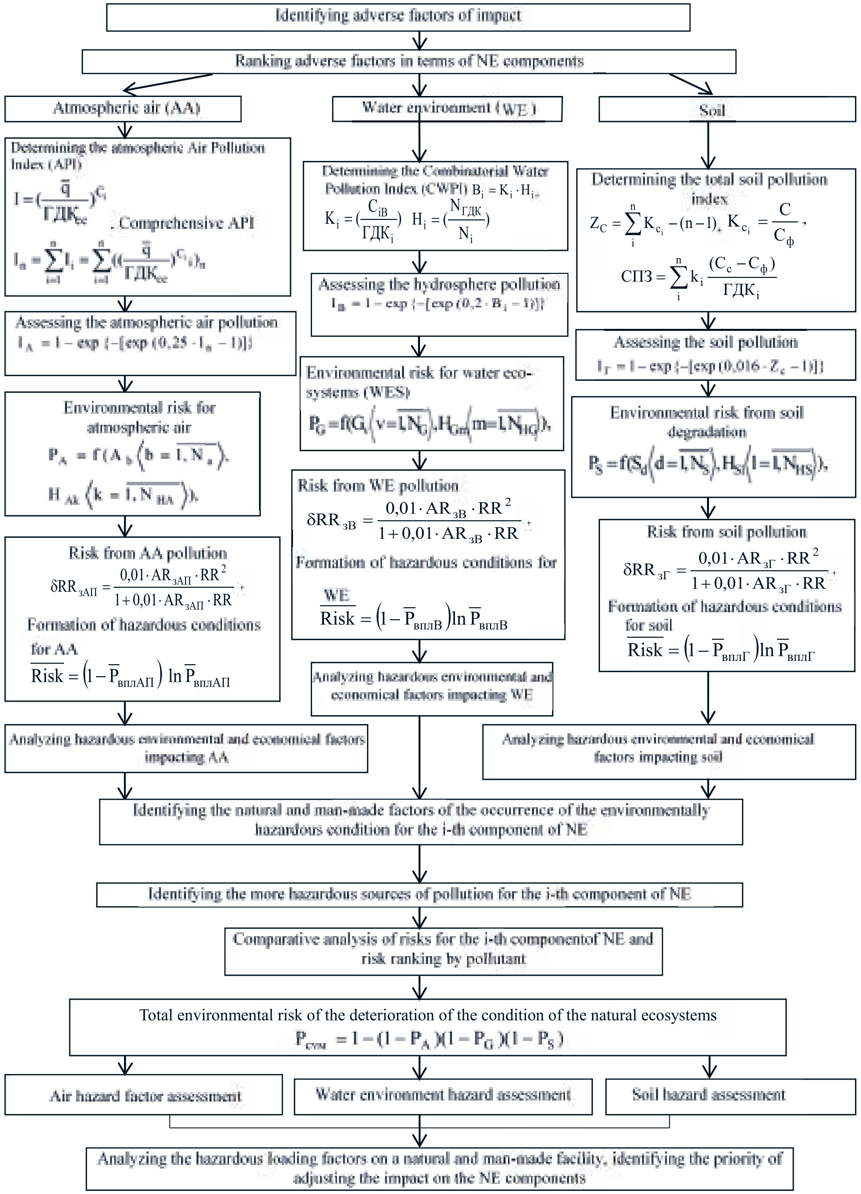


Figure 5.5. A flow diagram for the algorithmic support for the environmental risk

Table 5.3 — The results of the overall and factor-by-factor risk assessment of the environmental risk of the impact of the sewer tunnel shafts on atmospheric air

Overall risk	CH_4, wt %	CO_2, wt %	H_2S, mg/m³	SO_2, mg/m³	Substance
3.08	7.14×10^{-6}	7.72×10^{-6}	10^{-3}	1.09×10^{-5}	Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt
2.99	7.13×10^{-6}	7.63×10^{-6}	5.16×10^{-3}	10^{-5}	Shaft No.5 of the KhTZ tunnel
3.10	7.2×10^{-6}	7.93×10^{-6}	3.18×10^{-3}	1.12×10^{-5}	Shaft No.4 of the KhTZ tunnel
0.54	7.15×10^{-6}	7.79×10^{-6}	1.28×10^{-5}	8.47×10^{-6}	Shaft No. 3 of the Avtozapchastyna Plant tunnel
0.45	7.09×10^{-6}	7.71×10^{-6}	8.27×10^{-6}	7.08×10^{-6}	Shaft No. 1 of the Osnovianskyi sewer tunnel
0.48	7.08×10^{-6}	7.24×10^{-6}	8.09×10^{-6}	7.37×10^{-6}	Shaft No. 5 on Zubareva street
2.79	7.18×10^{-6}	7.77×10^{-6}	5.16×10^{-3}	9.72×10^{-6}	Shaft No. 10 of the KhTZ tunnel
2.07	7.75×10^{-6}	1.05×10^{-5}	3.51×10^{-3}	1.21×10^{-5}	Shaft No. 12 of the KhTZ tunnel
0.51	7.12×10^{-6}	7.69×10^{-6}	1.08×10^{-5}	8.06×10^{-5}	Shaft No. 3 of the Main tunnel
0.27	7.26×10^{-6}	8.37×10^{-6}	10^{-5}	8.3×10^{-6}	Shaft No. 4 of the tunnel of the Northern group of plants
0.85	7.38×10^{-6}	8.98 × 10-6	5.66×10^{-5}	8.8×10^{-6}	Shaft No. 4a of the tunnel of the Northern group of plants

The risk assessment has taken into consideration the 12 most environmentally hazardous substances, for which the maximum allowable concentrations are found to be exceeded. Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt, Shaft No. 1 of the Osnovianskyi sewer tunnel, Shaft No. 5 on Zubareva street, Shaft No. 10 of the KhTZ tunnel, and Shaft No. 12 of the KhTZ tunnel are located in the sewers that convey wastewater to municipal sewage treatment plant No. 1 “Dykanivski treatment facilities” (MSTP1).

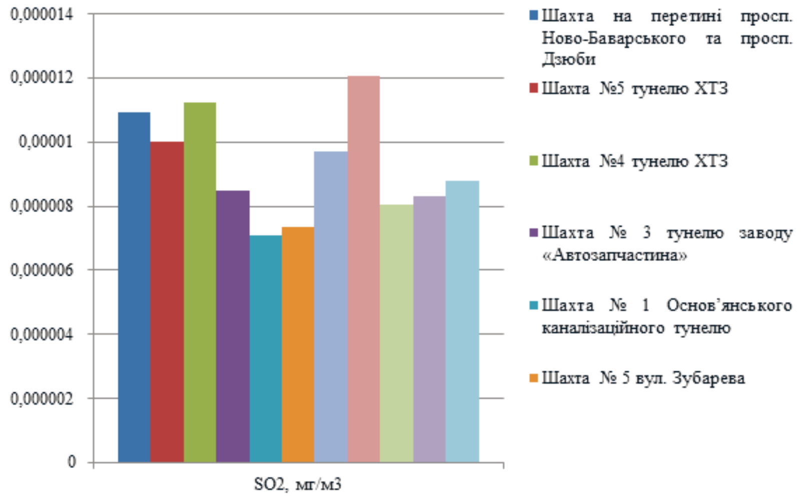


Figure 5.6. The values of the environmental risks of the impact of sulfur dioxide on atmospheric air

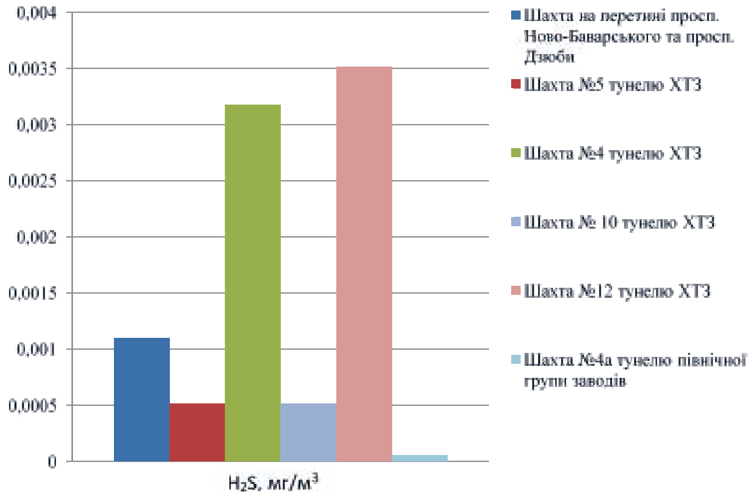


Figure 5.7. The values of the environmental risks of the impact of hydrogen sulfide on atmospheric air

Shaft No. 5 of the KhTZ tunnel, Shaft No. 4 of the KhTZ tunnel, Shaft No. 3 of the tunnel of Avtozapchastyna Plant, Shaft No. 3 of the Main tunnel, Shaft No. 4 of the tunnel of the Northern group of plants, and Shaft No.4a of the tunnel of the Northern group of plants are located in the sewers that convey wastewater to municipal sewage treatment plant No. 2 "Bezlyudivski treatment facilities" (MSTP2).

Table 5.4 shows the results of the risk assessment of the impact of the sewer shafts on water bodies and soils that may occur in the event of an accident in sewer tunnels. Risks may arise owing to an accidental discharge of wastewater conveyed through sewer networks to the surface and its entry into surface waters, groundwater aquifers and soil. The qualitative composition of wastewater is monitored according to 21 indicators. The concentrations of the following pollutants and values are measured: ammonium nitrogen, total BOD, BOD5, suspended solids, petroleum products, dry residue, nitrates, nitrites, chlorides, sulfates, total iron, trivalent chromium, hexavalent chromium, nickel, zinc, phosphates, copper, synthetic surfactants (SS), phenols, COD, dissolved oxygen.

Table 5.4 — The results of the risk assessment of the impact of the sewer tunnel shafts on water bodies and soils

	BOD5	Petroleum products	Nitrates	Nitrites	Chlorides	Sulfates	Hexavalent chromium	Nickel	Zinc	Phosphates	Copper	SS
MSTP1	9.6×10^{-5}	9.5×10^{-5}	8.1×10^{-5}	8.3×10^{-5}	8.5×10^{-5}	8.8×10^{-5}	8.4×10^{-5}	9.1×10^{-5}	9.2×10^{-5}	1.9×10^{-3}	8.1×10^{-5}	1.6×10^{-3}
MSTP2	10^{-3}	8.4×10^{-5}	8.1×10^{-5}	8.2×10^{-5}	8.5×10^{-5}	8.7×10^{-5}	8.2×10^{-5}	8.4×10^{-5}	8.2×10^{-5}	1.2×10^{-3}	8.1×10^{-5}	1.5×10^{-3}

As can be seen from Table 5.4, phosphates and SS are found to be the most significant factors in terms of load and hazard to the water environment and soils.

Figure 5.8 shows the values of the environmental risks of the impact of phosphates and SS on the water environment and soils.

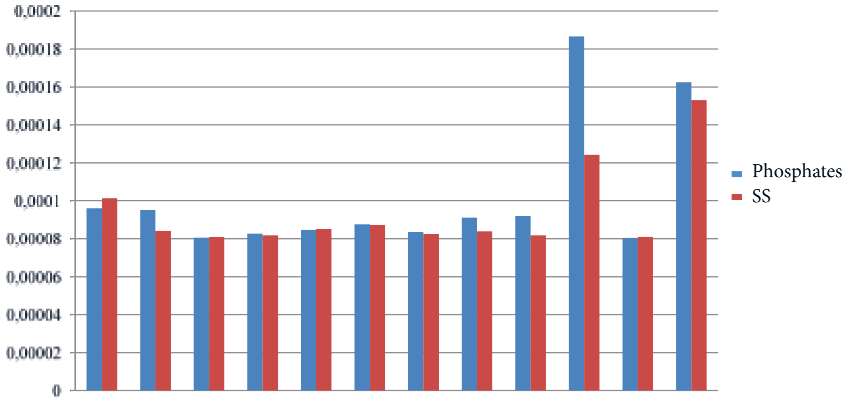


Figure 5.8. The values of the environmental risks of the impact of phosphates and SS on the water environment and soils

5.2. Assessing Environmental Risk to Human Health

According to the level of environmental risk, the probability of adverse effects of harmful factors on human health is determined. The main purpose of these calculations is to identify emissions of harmful substances that are allowable in terms of the environmental friendliness of NE, provided they have no impact on living organisms and humans, with regard to the intensity of the primary source of homeostasis disruption (Fig. 5.9) [76, 143].

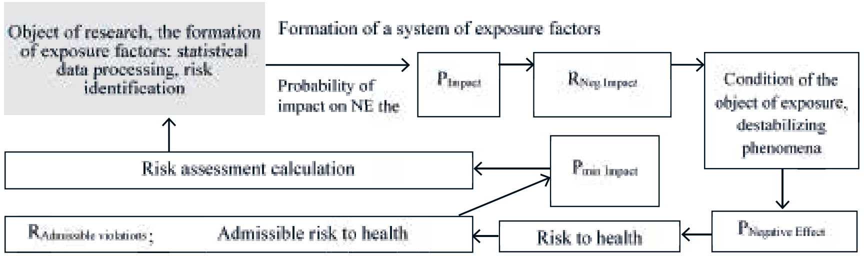


Figure 5.9. A risk analysis for the human — environment system. P — probability; R— risk

To calculate the effects associated with long-term (chronic) exposure to pollutants, the data on their average annual concentrations are used. To justify the standards of the maximum content of harmful impurities in atmospheric air by the effect of chronic exposure, the mathematical processing of the results is based on the principle of determining the concentration-time-effect dependence.

When rating the pollutants contained in atmospheric air, the safety factor (Кз) values were taken depending on the class of hazard as follows: 7.5 for substances of Class 1; 6 for Class 2; 4.5 for Class 3; and 3 for Class 4. The equation for calculating the risk of chronic intoxication is as follows [76]:

$$R = 1 - \exp(\ln(0{,}84) \times C / (\text{ГДК} \times \text{Кз})), \qquad (5.1)$$

where:
C — is the average annual concentration of pollutants affecting human health, mg / m^3;
ГДК — is the maximum allowable concentration of a pollutant, mg / m^3;
Кз — is the safety factor (Кз) depending on the class of hazard.

To assess the risk of the combined impact of several pollutants on human health the formula is used as follows:

$$R_{\text{сум}} = 1 - (1 - R_1) \times (l - R_2) \times (1 - R_3) \times \ldots \times (l - R_n), \qquad (5.2)$$

where:
$R_{\text{сум}}$ — is the risk of combined impact of a pollutant;
$R_1 \ldots R_n$ — is the risk of effect of each individual substance.

The level of the potential risk of long-term (chronic) effect of pollutants on human health is assessed according to the following criteria (Table 5.5).

According to the results of the overall risk assessment of the combined impact on public health, it was found that the risk level of people living close to Shaft No. 4 of the KhTZ tunnel and Shaft No. 12 of the KhTZ tunnel is dangerous. There is a reliable increase in non-specific pathology with the appearance of a large number of cases of specific pathology, and a tendency to increase the mortality of the population. The risk level for those living close to Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt, Shaft No. 5 of the KhTZ tunnel, Shaft No. 10 of the KhTZ tunnel, Shaft No. 4 of the tunnel of the Northern group of plants, and Shaft No.4a of the tunnel of the Northern group of plants is unsatisfactory. There is a reliable trend towards the growth of non-specific pathology with the appearance of single cases of specific pathology (Figure 5.10, 5.11).

Thus, the use of methods for assessing environmental risks based on indicators of the negative impact on the NE components and the state of public health makes it possible to comprehensively solve the problem of identifying risks and determining measures for their regulation (Table 5.6).

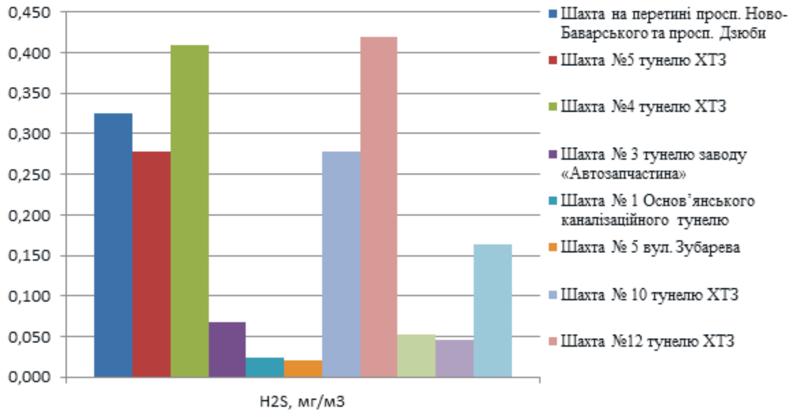


Figure 5.10. The values of the risks of the impact of hydrogen sulfide on human health

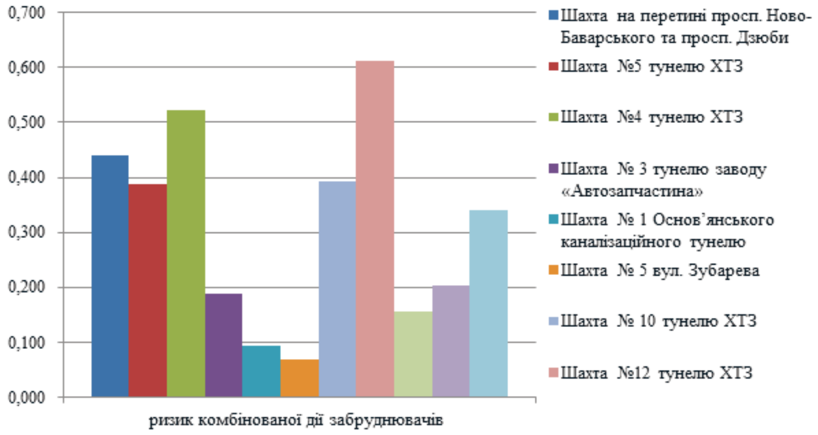


Figure 5.11. The values of the risk assessment of the combined impact of pollutants on public health

Table 5.5 — Health risk assessment scale

Risk value	Risk level
0 to 0.05	Admissible
0.05 to 0.16	Satisfactory
0.16 to 0.50	Unsatisfactory
0.50 to 0.90	Dangerous
0.90 to 1	Most dangerous

Table 5.6 — Results of the overall and factor-by-factor risk assessment of the combined impact of pollutants in sewer tunnel shafts on public health

Substance	Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt	Shaft No.5 of the KhTZ tunnel	Shaft No.4 of the KhTZ tunnel	Shaft No. 3 of the Avtozapchastyna Plant tunnel	Shaft No. 1 of the Osnovianskyi sewer tunnel	Shaft No. 5 on Zubareva street	Shaft No. 10 of the KhTZ tunnel	Shaft No. 12 of the KhTZ tunnel	Shaft No. 3 of the Main tunnel	Shaft No. 4 of the tunnel of the Northern group of plants	Shaft No. 4a of the tunnel of the Northern group of plants
SO_2, mg/m^3	0.106	0.090	0.110	0.054	0.004	0.017	0.084	0.123	0.042	0.049	0.063
H_2S, mg/m^3	0.324	0.279	0.409	0.068	0.024	0.022	0.279	0.420	0.053	0.046	0.163
CO_2, wt %	0.059	0.053	0.074	0.064	0.059	0.023	0.063	0.189	0.058	0.099	0.130
CH_4, wt %	0.014	0.014	0.020	0.015	0.010	0.009	0.017	0.062	0.012	0.024	0.034
Overall risk	0.440	0.387	0.523	0.187	0.094	0.068	0.392	0.613	0.155	0.203	0.341

5.3. Impact of Hazardous Emissions From Sewerage Networks on Natural Environment Objects and Public Health

Pollutants that pose the greatest environmental hazard to the natural environment objects and human health have been identified by risk assessment. Hydrogen sulfide, sulfur dioxide, phosphates and synthetic surfactants (SS) have been identified as hazardous factors.

Hydrogen sulfide is a substance of Class 2 hazard. Hydrogen sulfide has an unpleasant odor. If accumulated in the operating environments of concrete sewage pipelines (in wastewater, in the sub-vault space, in condensate moisture in the vault), hydrogen sulfide, its derivatives and oxidation products can initiate biogenic sulfuric acid corrosion of the vault, thus dramatically reducing the service life of pipelines (from the eexpected 50 years down to 10–15 years only). Biogenic corrosion is the cause of 70–75 % of accidents in wastewater disposal reinforced concrete pipelines, which are followed by ground collapses and failures in residential building and transport system areas, the disruption of urban utility lines, the pollution of the atmospheric air surface layer, soil and aquatic environments [76]. Hydrogen sulfide has a negative effect on human health. Table 5.7 shows the impact of hydrogen sulfide concentrations contained in the atmosphere on human health.

When an emergency situation occurs in the sewerage networks, both the employees of the water utility's operating company and the residents living in the immediate vicinity of the sewer shafts experience the toxic effects of hydrogen sulfide.

Sulfur dioxide is a substance of Class 3 hazard. In the atmosphere, sulfur dioxide undergoes a number of chemical transformations, the most important of which are oxidation and acid formation. This results in eventual acid rains, which destroy plants, acidify soils, and increase the acidity in reservoirs. Plants are covered with small necrotic spots, which are drops of H_2SO_4.

The positive aspects of the presence of sulfur oxides in the atmosphere consist in reducing the effect of greenhouse gases on increasing the average temperature.

With an average content of sulfur dioxide in the air, the plants become yellowish. Coniferous and deciduous forests are most sensitive to it. Pines are drying out at high concentrations of SO_2 in the air.

Sulfur dioxide poses a serious health threat. Sulfur dioxide can cause diseases of the respiratory tract and mucous membranes of humans. Skin irritation may occur if this compound comes into contact with skin. Exposure to sulfur dioxide in concentrations above the maximum allowable concentrations may lead to a significant increase in various respiratory diseases, affect the mucous membranes, initiate inflammation of the nasopharynx, bronchitis, cough, hoarseness and sore throat. Particularly high sensitivity to sulfur dioxide is observed in people with chronic respiratory disorders, and with asthma.

Table 5.7 — The impact of hydrogen sulfide contained in atmospheric air on human health [110, 114, 143, 187]

Impact on humans	Exposure time	Atmospheric concentration, ppm
Odor perception threshold	A few hours with no significant health issues	0.0001–0.002
Level of onset of odor perception		0.13
Weak, but perceptible odor of rotten eggs		1.0
Perceptible, increasing, distinct odor		5.0
Maximum allowable concentration for 8 hour exposure time		10
Unpleasant and strongly perceptible odor		30
Headache, nausea, and eye, nose and throat irritation; unbearable odor		10–50
No odor perceived by humans (the odor is less strong and unpleasant at higher concentrations)	No more than 60 minutes with no significant health issues	> 100
Eye and respiratory injuries		50–300
Convulsions and loss of consciousness, danger to life	Dangerous to life after 30 minutes of exposure	300–500
Immediate death	Dangerous to life after a few minutes / seconds of exposure	> 700

Phosphates pose a major threat to the environment. Once in water bodies, phosphates promote the proliferation of blue-green algae. Blue-green algae cover the surface of water bodies with a film that prevents the entry of oxygen and sunlight into the water. When decomposing, algae emit large quantities of methane, ammonia, and hydrogen sulfide into the water which kill all living things in water bodies. One gram of tripolyphosphate encourages the production of five to ten kilograms of blue-green algae.

When getting into water bodies, phosphates change the acid-base balance thereof. When the pH value drops to 4.5 to 5.0, a significant number of aquatic organisms that form the basis of the food chain may disappear. This, in turn, affects the number of birds, fish, reptiles, and mammals to which extinct species serve as food sources.

There are two aspects of harmful effects of phosphates on humans: internal and external.

If found in water used for bathing and washing up, phosphates may cause dermatitis and irritation. Phosphates may result in exacerbations in people with skin prone to atopic conditions.

When using detergents containing phosphates, the acid-base balance of the protective layer of the cells is disrupted, which may lead to dermatological diseases. By penetrating through the pores of the skin, phosphates enter the blood and change the percentage of hemoglobin content and the density of the blood serum, thereby disrupting the functions of the kidneys and liver, which results in severe poisoning and exacerbation of chronic diseases. Phosphorus compounds interact with the lipid-protein membranes of the cells and penetrate into the cells, thus causing profound changes in biochemical and biophysical processes.

Synthetic surfactants give water a persistent specific odor and taste, and some of them can stabilize offensive odors due to other compounds [99]. Once in the human body, synthetic surfactants may cause disorders in protein, carbohydrate and fat metabolism. Anionic surfactants are particularly aggressive in their effects. They can cause severe immune disorders, allergies, and brain, liver, kidney and lung damage. Phosphate surfactants lead to excessive degreasing of the skin, more active disruption of the cell membranes, and dramatically reduce the barrier function of the skin. Moreover, anionic surfactants can accumulate in organs. Specifically, 1.9 % of the total amount of anionic surfactants, which gets on the unprotected skin, is deposited in the brain, and 0.6 % in the liver. Synthetic surfactants can cause severe immune disorders, allergies, and brain, liver, kidney, and lung damage. The functions of the liver, kidneys, and skeletal muscles are disrupted, which in turn leads to severe poisoning and exacerbation of chronic diseases.

Harmful effects of synthetic surfactants on the environment and living organisms are unpredictable owing to the low rate of decomposition. Once in water bodies and watercourses, synthetic surfactants have a significant impact on the physical and biological condition thereof affecting the oxygen regime and organoleptic properties. Wastewater containing products of hydrolysis of polyphosphate synthetic surfactants may cause an intense plant growth, resulting in water body pollution and subsequent decay of plants, which in turn worsens the conditions for the existence of hydrobionts.

5.4. Forecasting the occurrence of accidents in sewerage networks using the multivariate regression analysis

To evaluate the impact of hazardous factors on NE objects in the future periods, a forecast model based on the multivariate regression analysis has been proposed. The impact of the operation of sewer tunnel shafts has been forecast for the next five years.

It has been found that in 2025 the emissions of all pollutants to atmospheric air from Shaft No. 10 of the KhTZ tunnel will increase by an average of 3.8 times; this is the most hazardous shaft. SO_2 emissions from Shaft No. 5 on Zubareva street, Shaft No. 3 of the Main tunnel, Shaft No. 4 of the tunnel of the Northern group of plants, and Shaft No. 4a of the tunnel of the Northern group of plants will increase by 1.45, 1.56, 1.61, and 1.87 times, respectively. H_2S emissions from Shaft No. 3 of the Main tunnel, Shaft No. 4 of the tunnel of the Northern group of plants, and Shaft No. 4a of the tunnel of the Northern group of plants will increase by 1.2, 1.48, and 1.5 times, respectively. CO_2 emissions from Shaft No. 4 of the KhTZ tunnel and Shaft No. 3 of the Avtozapchastyna Plant tunnel will increase by 1.3 and 2.2 times, respectively. CH_4 emissions from Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt, Shaft No.5 of the KhTZ tunnel and Shaft No. 3 of the Main tunnel will increase by an average of 2.3 times (Tables 5.8, 5.9).

Based on the calculated data on the amounts of emissions, the overall risk has been assessed: Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt, Shaft No.5 of the KhTZ tunnel, Shaft No.4 of the KhTZ tunnel, and Shaft No. 5 on Zubareva street show a moderate level of risk, while Shaft No. 10 of the KhTZ tunnel shows a high level of risk (Table 5.10, Figs. 5.12 and 5.13).

It has been found that in 2025 the emissions to the water environment and soils from MSTP1 and MSTP2 will increase by an average of 1.44 times and 1.37 times, respectively. BOD5 emissions from MSTP1 and MSTP2 emissions will increase by 1.54 and 1.86 times, respectively; nitrate emissions will increase by 1.81 and 1.84 times, respectively; nitrite emissions from MSTP1 will increase by 2.88 times; phosphate emissions will increase by 2.03 times; copper emissions from MSTP2 will increase by 2.84 times (Tables 5.11 and 5.12).

Table 5.8 — A regression equation for forecasting the amounts of pollutant emissions to atmospheric air

Shaft	SO_2, mg/m^3	H_2S, mg/m^3	CO_2, wt %	CH_4, wt %
1	2	3	4	5
Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt	$y = -0.0003x^6 - 0.0087x^5 + 0.4338x^4 - 5.3201x^3 + 25.99x^2 - 46.32x + 43.328$	$y = -0.0607x^6 + 1.9404x^5 - 23.815x^4 + 140.94x^3 - 416.53x^2 + 582.28x - 245.07$	$y = -8 \times 10^{-5}x^6 + 0.0028x^5 - 0.0418x^4 + 0.3203x^3 - 1.3618x^2 + 2.9571x - 1.6511$	$y = 0.0004x^6 - 0.0125x^5 + 0.1688x^4 - 1.1145x^3 + 3.6497x^2 - 5.2796x + 2.9788$
Shaft No.5 of the KhTZ tunnel	$y = 0.0159x^6 - 0.5614x^5 + 7.6643x^4 - 50.703x^3 + 165.68x^2 - 239.04x + 128.64$	$y = -0.0099x^6 + 0.1988x^5 - 1.0886x^4 - 0.4847x^3 + 16.475x^2 - 27.021x + 40.954$	$y = 0.0002x^6 - 0.0063x^5 + 0.0816x^4 - 0.5076x^3 + 1.51x^2 - 1.8438x + 1.0036$	$y = 0.0002x^6 - 0.0057x^5 + 0.0767x^4 - 0.4917x^3 + 1.526x^2 - 2.0575x + 1.3291$
Shaft No.4 of the KhTZ tunnel	$y = 0.0058x^6 - 0.2043x^5 + 2.8334x^4 - 19.461x^3 + 67.15x^2 - 100.79x + 69.269$	$y = 0.0142x^6 - 0.4933x^5 + 6.691x^4 - 45.31x^3 + 158.89x^2 - 241.87x + 165.26$	$y = 5 \times 10^{-5}x^6 - 0.0016x^5 + 0.0229x^4 - 0.1578x^3 + 0.4979x^2 - 0.4593x + 0.3345$	$y = 0.0002x^6 - 0.0065x^5 + 0.0868x^4 - 0.5675x^3 + 1.8148x^2 - 2.447x + 1.4961$
Shaft No. 3 of the Avtozapchastyna Plant tunnel	$y = 0.0038x^6 - 0.1115x^5 + 1.2286x^4 - 6.4407x^3 + 17.627x^2 - 25.618x + 19.658$	$y = 0.0025x^6 - 0.076x^5 + 0.8427x^4 - 4.4094x^3 + 12.554x^2 - 22.256x + 31.414$	$y = -0.0003x^6 + 0.0121x^5 - 0.1643x^4 + 1.0866x^3 - 3.5906x^2 + 5.362x - 2.0896$	$y = -0.0005x^6 + 0.018x^5 - 0.2536x^4 + 1.7556x^3 - 6.1189x^2 + 9.6959x - 4.4803$
Shaft No. 1 of the Osnovianskyi sewer tunnel	$y = -0.3681x^5 + 6.7153x^4 - 45.757x^3 + 142.28x^2 - 195.37x + 92.5$	$y = -0.2181x^5 + 4.0069x^4 - 27.674x^3 + 87.993x^2 - 124.61x + 66.5$	$y = -0.0039x^5 + 0.0879x^4 - 0.7037x^3 + 2.4021x^2 - 3.2023x + 1.62$	$y = 0.0115x^5 - 0.1895x^4 + 1.1418x^3 - 3.1255x^2 + 3.9942x - 1.7325$
Shaft No. 5 on Zubareva street	$y = -0.4771x^6 + 11.292x^5 - 104.99x^4 + 485.42x^3 - 1161.5x^2 + 1346.9x - 573.75$	$y = -0.0554x^6 + 1.479x^5 - 15.608x^4 + 82.474x^3 - 227.09x^2 + 304.2x - 134.4$	$y = 0.0102x^6 - 0.1914x^5 + 1.3669x^4 - 4.6406x^3 + 7.5354x^2 - 4.9747x + 0.9442$	$y = -0.0069x^6 + 0.169x^5 - 1.6253x^4 + 7.8193x^3 - 19.601x^2 + 23.995x - 10.7$
Shaft No. 10 of the KhTZ tunnel	$y = 0.0145x^6 - 0.4845x^5 + 6.3579x^4 - 41.448x^3 + 137.67x^2 - 204.49x + 108.32$	$y = 0.0082x^6 - 0.2556x^5 + 3.1373x^4 - 19.54x^3 + 63.73x^2 - 90.971x + 55.975$	$y = 0.0001x^6 - 0.0041x^5 + 0.0501x^4 - 0.3108x^3 + 0.9814x^2 - 1.308x + 0.8577$	$y = 0.0001x^6 - 0.0032x^5 + 0.041x^4 - 0.2745x^3 + 1.0096x^2 - 1.7621x + 1.3747$

Table 5.8 (continued)

1	2	3	4	5
Shaft No. 12 of the KhTZ tunnel	$y = -0.0069x^6 + 0.2468x^5 - 3.5112x^4 + 25.188x^3 - 95.282x^2 + 178.92x - 95.394$	$y = 0.0516x^6 - 1.5581x^5 + 17.692x^4 - 94.159x^3 + 236.87x^2 - 227.46x + 102.57$	$y = 0.0002x^6 - 0.0063x^5 + 0.0809x^4 - 0.5154x^3 + 1.6426x^2 - 2.2128x + 1.381$	$y = 8 \times 10^{-5}x^6 - 0.003x^5 + 0.0468x^4 - 0.376x^3 + 1.5554x^2 - 2.9043x + 2.37$
Shaft No. 3 of the Main tunnel	$y = 0.0035x^6 + 0.0013x^5 - 0.9678x^4 + 9.0222x^3 - 29.609x^2 + 37.188x - 10.255$	$y = -0.028x^6 + 0.7713x^5 - 8.2607x^4 + 43.318x^3 - 114.56x^2 + 141.66x - 50.926$	$y = -2 \times 10^{-5}x^6 + 0.0011x^5 - 0.0143x^4 + 0.0558x^3 - 0.0101x^2 - 0.1767x + 0.4788$	$y = 0.0008x^6 - 0.0181x^5 + 0.1588x^4 - 0.6406x^3 + 1.1845x^2 - 0.8913x + 0.6715$
Shaft No. 4 of the tunnel of the Northern group of plants	$y = -0.0111x^6 + 0.3513x^5 - 4.3393x^4 + 26.148x^3 - 78.564x^2 + 110.68x - 49.118$	$y = -0.0154x^6 + 0.3822x^5 - 3.6741x^4 + 17.569x^3 - 43.817x^2 + 53.238x - 5.0759$	$y = 0.0006x^6 - 0.0168x^5 + 0.1826x^4 - 0.9755x^3 + 2.6623x^2 - 3.4383x + 2.4597$	$y = -2 \times 10^{-5}x^6 + 0.0035x^5 - 0.0801x^4 + 0.6849x^3 - 2.5498x^2 + 3.8114x - 0.6691$
Shaft No. 4a of the tunnel of the Northern group of plants	$y = -0.0678x^6 + 2.0749x^5 - 24.651x^4 + 142.63x^3 - 411.59x^2 + 542.61x - 238.56$	$y = -0.2713x^6 + 7.9037x^5 - 89.37x^4 + 493.72x^3 - 1373$	$y = 0.0005x^6 - 0.0158x^5 + 0.1947x^4 - 1.2135x^3 + 3.9343x^2 - 5.8961x + 3.3862$	$y = -0.0008x^6 + 0.0254x^5 - 0.2943x^4 + 1.64x^3 - 4.4766x^2 + 5.4708x - 1.7666$

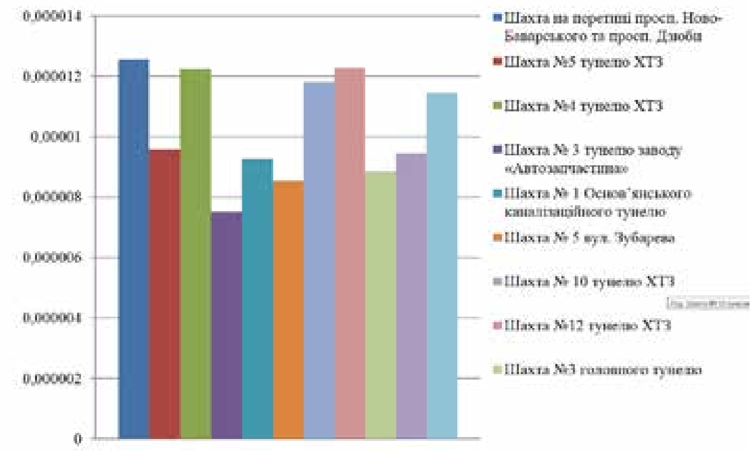


Figure 5.12. The forecast values of the environmental risk of the impact of sulfur dioxide on atmospheric air

Table 5.9 — Changes in the amount of pollutant emissions to atmospheric air in 2025

Substance	Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt	Shaft No.5 of the KhTZ tunnel	Shaft No.4 of the KhTZ tunnel	Shaft No. 3 of the Avtozapchastyna Plant tunnel	Shaft No. 1 of the Osnovianskyi sewer tunnel	Shaft No. 5 on Zubareva street	Shaft No. 10 of the KhTZ tunnel	Shaft No. 12 of the KhTZ tunnel	Shaft No. 3 of the Main tunnel	Shaft No. 4 of the tunnel of the Northern group of plants	Shaft No. 4a of the tunnel of the Northern group of plants
SO_2, mg/m^3	1.23	0.90	1.14	0.42	0.69	1.45	3.38	1.02	1.56	1.61	1.87
H_2S, mg/m^3	0.94	0.48	0.87	0.57	1.00	0.47	3.31	0.75	1.20	1.48	1.50
CO_2, wt %	0.95	1.11	1.29	2.14	0.86	0.12	4.72	0.53	0.99	0.99	0.58
CH_4, wt %	2.41	2.08	1.10	0.80	0.99	1.13	3.88	0.39	2.24	0.96	1.34

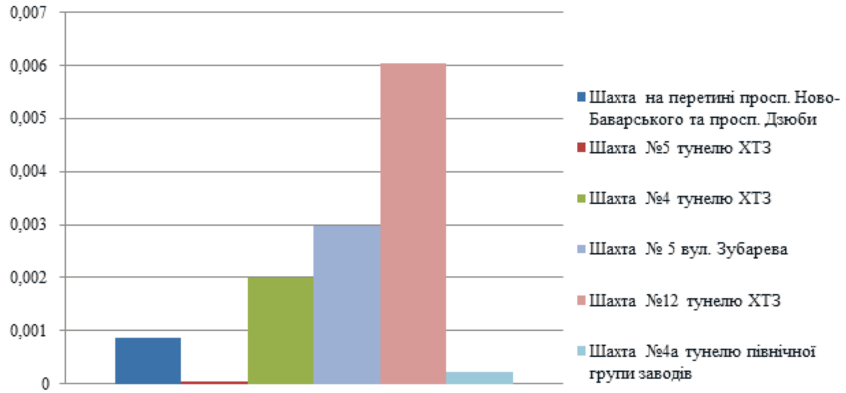


Figure 5.13. The forecast values of the environmental risk of the impact of hydrogen sulfide on atmospheric air

Table 5.10 — The forecast values of the overall and factor-by-factor risk assessment of the impact of the sewer tunnel shafts on atmospheric air

Substance	Shaft at the intersection of Novo-Bavarskyi prospekt and Dzyuby prospekt	Shaft No.5 of the KhTZ tunnel	Shaft No.4 of the KhTZ tunnel	Shaft No. 3 of the Avtozapchastyna Plant tunnel	Shaft No. 1 of the Osnovianskyi sewer tunnel	Shaft No. 5 on Zubareva street	Shaft No. 10 of the KhTZ tunnel	Shaft No. 12 of the KhTZ tunnel	Shaft No. 3 of the Main tunnel	Shaft No. 4 of the tunnel of the Northern group of plants	Shaft No. 4a of the tunnel of the Northern group of plants
SO_2, mg/m^3	1.25×10^{-5}	10^{-5}	1.22×10^{-5}	7.52×10^{-6}	9.26×10^{-6}	8.54×10^{-6}	1.18×10^{-5}	1.21×10^{-5}	8.85×10^{-5}	9.3×10^{-6}	1.2×10^{-5}
H_2S, mg/m^3	10^{-4}	4.12×10^{-5}	1.98×10^{-3}	9.54×10^{-6}	8.27×10^{-6}	8.09×10^{-6}	2.97×10^{-3}	6.05×10^{-3}	1.08×10^{-5}	10^{-5}	2.19×10^{-3}
CO_2, wt %	7.72×10^{-6}	7.63×10^{-6}	7.93×10^{-6}	7.79×10^{-6}	7.71×10^{-6}	7.24×10^{-6}	7.77×10^{-6}	1.05×10^{-5}	7.69×10^{-6}	8.37×10^{-6}	8.98×10^{-6}
CH_4, wt %	7.37×10^{-6}	7.31×10^{-6}	7.23×10^{-6}	7.12×10^{-6}	7.09×10^{-6}	7.3×10^{-6}	7.18×10^{-6}	7.26×10^{-6}	7.29×10^{-6}	7.25×10^{-6}	7.38×10^{-6}
Overall risk	2.88	2.07	2.75	0.28	0.12	0.07	4.40	3.01	0.43	0.33	1.00

Table 5.11 — A regression equation for forecasting the amounts of pollutant emissions to the water environment and soils

Substance	**MSTP1**	**MSTP1**
BOD5	$y = 26.483x + 132.54$	$y = 26.767x + 186.08$
Petroleum products	$y = 0.6675x + 4.5983$	$y = 0.0267x + 1.6092$
Nitrates	$y = 0.15x + 0.425$	$y = 0.0225x + 1.0858$
Nitrites	$y = 0.1417x + 0.0517$	$y = 0.0233x + 0.1558$
Chlorides	$y = 1.25x + 123.5$	$y = 15.458x + 109.54$
Sulfates	$y = -3x + 246.58$	$y = 5.3333x + 220.25$
Hexavalent chromium	$y = 0.0005x + 0.0259$	$y = -0.0012x + 0.0194$
Nickel	$y = 0.0161x + 0.1006$	$y = -0.002x + 0.0493$
Zinc	$y = 0.0392x + 0.2758$	$y = -0.004x + 0.0543$
Phosphates	$y = 6.125x + 11.55$	$y = 0.575x + 11.942$
Copper	$y = 9 \times 10^{-5}x + 0.0073$	$y = -0.0005x + 0.0459$
Synthetic surfactants (SS)	$y = -0.1742x + 2.04$	$y = 0.2825x + 0.9975$

Table 5.12 — Changes in the amount of pollutant emissions to the water environment and soils in 2025

	BOD5	Petroleum products	Nitrates	Nitrites	Chlorides	Sulfates	Hexavalent chromium	Nickel	Zinc	Phosphates	Copper	SS
MSTP1	1.54	1.42	1.81	2.88	1.03	0.96	1.07	1.45	1.41	2.03	1.04	0.66
MSTP2	1.86	0.31	1.84	1.03	1.49	1.02	0.50	0.32	0.10	0.71	2.84	1.35

According to the calculated data on the values of the amounts of pollutant emissions, the overall risk assessment was found: the risk level for MSTP2 is moderate; the risk level for MSTP1 is maximum (Table 5.13).

Table 5.13 — The results of the forecast values of the overall and factor-by-factor risk assessment of the impact of the sewer tunnel shafts on the water environment and soils

Item	BOD5	Petroleum products	Nitrates	Nitrites	Chlorides	Sulfates	Hexavalent chromium	Nickel	Zinc	Phosphates	Copper	SS	Overall risk
MSTP1	10^{-3}	10^{-3}	8.1×10^{-5}	8.6×10^{-5}	8.5×10^{-5}	8.7×10^{-5}	8.4×10^{-5}	9.6×10^{-5}	9.6×10^{-5}	4.1×10^{-3}	8.1×10^{-5}	1.3×10^{-3}	4.4
MSTP2	10^{-3}	8.4×10^{-5}	8.1×10^{-5}	8.2×10^{-5}	8.7×10^{-5}	8.7×10^{-5}	8.2×10^{-5}	8.4×10^{-5}	8.2×10^{-5}	1.3×10^{-3}	8.1×10^{-5}	2.3×10^{-3}	2.9

Conclusions to Chapter 5:

1. The environmental risk to the natural environment was assessed, in particular, a conceptual pattern for determining environmental risks, an algorithm for risk assessment of the environmental friendliness of man-made objects, and an algorithmic support for analysing environmental risks in the operation of sewer facilities such as shafts and stilling chambers were developed.
2. An environmental risk to human health was assessed. According to the results of the overall risk assessment of the combined impact of pollutants on public health, it was found that the risk level for people living close to Shaft No. 4 of the KhTZ tunnel and Shaft No. 12 of the KhTZ tunnel is dangerous. Thus, the use of methods for assessing environmental risks based on indicators of the negative impact on the NE components and the state of public health makes it possible to comprehensively solve the problem of identifying risks and determining measures for their regulation.
3. The occurrence of accidents in sewer networks was forecast using the multivariate regression analysis. It was found that the operation of sewer tunnel shafts in the future increase the load on the NE objects.

CHAPTER 6

DEVELOPING ORGANIZATIONAL AND TECHNOLOGICAL SOLUTIONS FOR REHABILITATING THE SEWERAGE NETWORKS AND FACILITIES

6.1. Developing and Investigating a New Method of Cleaning Sewers of Varying Degrees of Clogging

When reviewing the existing repair and rehabilitation work, one can conclude that the main methods of cleaning sewers are mechanical and hydraulic. To remove clogging, the ROTHENBERGER company (Germany) [89–92] proposes to use the method of hydrodynamic flushing of the pipeline, which easily removes the remnants of the mechanically destroyed clogging. Many types of clogging, such as fat and sludge deposits, are most effectively removed using the hydrodynamic method. These compact high-pressure devices operating on alternating current are designed to clean pipelines of 150 to 200 mm in diameter and max. 40 meters in length, and to clean the surfaces of vehicles, machinery, buildings, and foundations. The devices feature a water suction function (water head up to 2 m). HELLMERS GmbH (Germany) proposes using a combined-type pipe flushing machine for flushing water supply and sewer pipelines. The machine is mounted on the MAN truck chassis and used for labor-intensive washing operations where the fully automatic cleaning process provides continuous recirculation of flushing water. In addition to the recirculation work, the machine can also flush sewer pipes with diameters from 100 to 1.000 mm. Mechanical method for cleaning pipelines is widely used in Ukraine [89–92, 249].

For the centrifugation method, a chain carousel is used which allows cleaning sewers with a diameter of 125 to 450 mm at a recommended pump capacity of 120 l /100 bar [92]. When equipped with the appropriate additional equipment, it may be used in sewers with a diameter up to 2.000 mm at a recommended pump capacity of 260 l / 100 bar. In this case, deposits are broken off and washed away in the direction of driving. The uniform advance of the centrifugal machine is provided by means of the winch. The carousel guide slide comprises five individually adjustable guide rails. Extremely sharp self-sharpening chains, owing to the design of chain carousels, do not damage the surface of the pipe, which makes it possible to use this tool for pipes of any material [79, 151, 241].

It is worth noting that not all operating companies own diagnostic facilities, which include television systems for inspecting underground sewer networks.

The pulling method uses scraping and cutting tools under continuous flushing of the pipeline [37]. In this case, hard deposits are scraped off and washed away. This method requires special cable winches and pulling ropes to be used.

The disadvantages of this machine include some difficulties in the process of the high-level cleaning of the walls and the inability to clean intricate pipe systems; furthermore, it is used only for water pipelines. Moreover, this kind of equipment has an elevated price tag and increased energy consumption during operation.

It is also increasingly more common to apply a hydrodynamic method of cleaning sewer pipelines using a hydraulic machine equipped with special nozzles, which create point pressure in the pipeline [52]. This ensures that sludge deposits are washed away from the walls of the pipeline.

The hydraulic machine can be used only at temperatures no lower than –5 °C, which is a disadvantage and limits the use to restricted climatic conditions. Moreover, the hydrodynamic method is most effective for sewer pipelines with a diameter not exceeding 500 mm. For pipelines with a diameter of more than 500 mm, and for very sludgy pipelines, this method does not allow for sludge deposits to be completely removed. By continuously using high-pressure fluid, this method is associated high energy and resource consumption, which is found to be not cost-effective.

The research work [52] describes a hydrodynamic method which uses a flow restriction device during cleaning with the existing sewage flow to create turbulence in the pipe. As a result, the material is placed in a suspension and moved downstream, where it is removed and delivered to the designated site for waste removal. When using this method, the system may be cleaned with access to only a few manholes in the system.

The disadvantages of using the hydrodynamic cleaning method can include the high cost of work and the cost of water and electricity supply.

The research work [92] considers the eco-technical repair of the sewerage system. The proposed method involves integrating a set of prefabricated sandwich panels or composite shells in the existing sewerage system. This

method can improve the operating life of the sewers but will in no way protect against contamination and deterioration on the inside thereof. However, repair work may be carried out only after thoroughly cleaning sewers.

After reviewing the existing technologies for cleaning sewers and sewer pipes, and the reasons for their emergence [249], one may conclude that cleaning is mainly based on two technologies, mechanical and hydrodynamic. Both alternatives may be effective only under limited conditions and also require large capital investments, time and labor expenditures.

A promising option to overcome the described shortcomings when conducting work on sewer cleaning is to improve the operating life of the sewerage distribution system. The development of alternative repair technologies will ensure its steady operation in the conditions of limited funding, which will be economically advantageous compared to the existing technologies, which require large capital investments.

After considering the above methods of cleaning sewers, one may conclude that the best method will be a mechanical method of cleaning pipelines, but the merits of the hydrodynamic method should not also be neglected. The question therefore arises as to what equipment should be chosen to suit the work.

To begin with, consider the metal container proposed in the research [92, 249]. The container is made in the shape of a hollow half-cylinder with its ends connected with two lifting beams to which lifting slings are attached. One of the ends of the half-cylinder is connected with a bridge, on which a valve is arranged, which is made in the shape of a semicircle rotatable by 90°. The valve opens in the process of cleaning from sludge deposits in the forward direction, and when it is full, the container moves back and the valve closes. This design of the container allows cleaning only from sludge deposits in small areas.

When it comes to cleaning sewers with a diameter of over 400 mm, where there is stone sludge. In addition to sludge deposits, this kind of bucket may not be appropriate.

To accomplish the task, it is proposed to equip the metal container in the front part with cutting blades for cutting chunks of debris, and with a steel sewer rod for supplying working fluid under pressure through the holes.

The bucket for cleaning sewers (Fig. 6.1) [92] comprises the bucket body 1, which is designed as a metal hollow half-cylinder. The ends of the bucket are provided with the holes 2 to attach the pulling rope from the starting pit, and the holes 6, 7 to attach the pulling rope from the target pit. The steel sewer rod 3 to supply the working fluid under pressure is attached to the inner surface of the bucket body 1. In the front part of the body, the steel sewer rod 3 are provided with the holes 4 to supply the working fluid under pressure and the cutting blades 5 knives to cut debris.

This design allows for work to be performed both purely mechanically and with additional supply of fluid under pressure, which is inherent in the hydrodynamic method. The proposed design will also allow for savings in resources, time required for work, and in labor costs during operation.

The method considered in the research work was used as a basis for cleaning sewers. The method is implemented as follows. First, three consecutive sewer manholes are prepared (Fig. 6.2): the first manhole 1, the middle manhole 2 and the third manhole 3. To do that, the hatches are opened; the

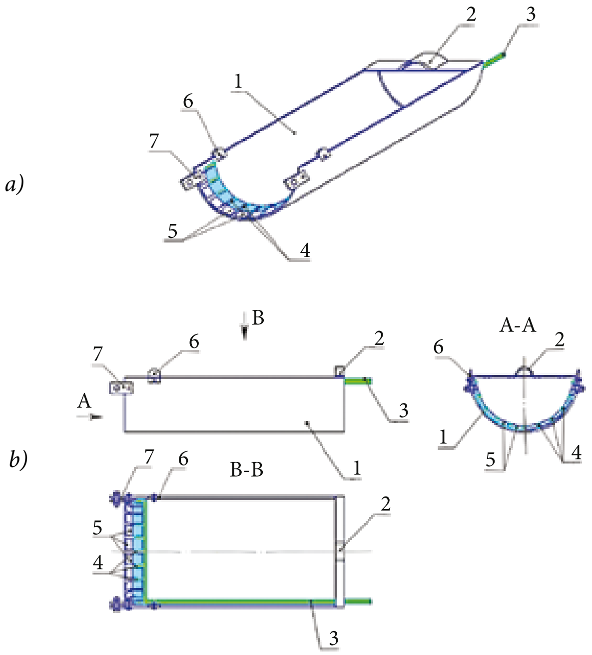


Figure 6.1. Sewer cleaning bucket:
(a) general view; (b) projection of the bucket in space;
1 – housing; 2 – holes for attaching the pulling rope from the starting pit; 3 – steel sewer rod; 4 – holes for supplying working fluid under pressure; 5 – cutting blades for cutting debris; 6, 7 – holes for attaching the pulling rope from the target pit

condition of the bottom of the manhole is checked. The stop 4 with the blocks 5 is set up in the first sewer manhole 1 and in the third manhole 3. On the surface, above the first manhole 1 and the third manhole 3 the winches 6 are set up, the rope 7 from both winches is brought in the middle manhole 2; the metal container 8 is also lowered therein.

The metal container 8 is pulled through in the direction of the first manhole 1 at a distance that allows for the container 8 to be filled up. While being moved, the metal container 8 cuts the layer of sludge until the container is completely filled. Then the filled container 8 is pulled back to the middle manhole 2, where the container is emptied of sludge deposits. Next, the middle manhole is cleaned of sludge deposits.

This method is effective, but only for pipelines with a diameter of not more than 500 mm. If the diameter is larger, then before carrying out work, the water should be first removed from the manholes and sewer pipeline.

Therefore, we believe that this method of cleaning cannot be used in sewers with complicated clogging and of large diameters, which is less cost-effective in technical terms. The proposed method using a bucket for cleaning sewers of new design will be more effective, which will reduce the duration of cleaning, and allow using this method under any conditions. Improving the cleaning method, using a bucket of new design, is that when the bucket enters the sewer, the bucket begins to move forward, using a pulling winch, from the starting to the target pit. Debris in the pit are cleaned using cutting blades. In case the cleaning process is complicated pressure cleaning fluid is

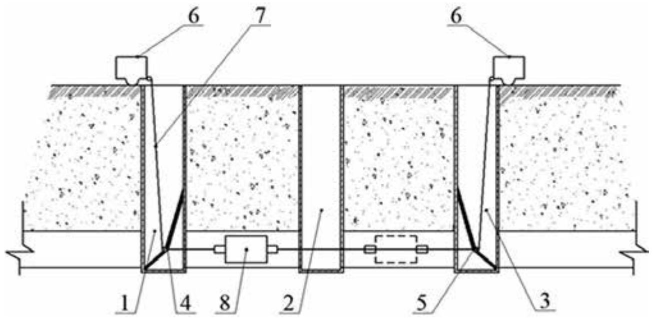


Figure 6.2. Sewer cleaning method:
1 – the first well; 2 – the second well; 3 – the third well; 4 – stop; 5 – blocks; 6 – winch; 7 – pulling rope; 8 – metal container

supplied from the holes, which helps to deform the clogging and facilitates the operation of the cutting blades. The cleaning process is repeated until the sewer is completely cleaned.

The advantages of using this method involving the proposed design of the bucket is its versatility in the process of work depending on the degree of clogging. The sewer cleaning process can be performed purely mechanically, and some areas where there is sludge and hard rock clogging can be passed through very economically by supplying liquid under pressure. That is, for one section of the pipeline one can use one piece of equipment, thus saving on the duration of work, and material and energy costs.

The proposed method for cleaning sewers using a new bucket design (Fig. 6.1) was applied at various facilities with different parameters and working conditions:

— Diameter (600 to 900 mm).
— Sewer material (steel, reinforced concrete, brick).
— Shape of the cross-section shape (round, oval).
— Type of damage to the sewer (pitting corrosion, through corrosion, damage to the butt joint, damage to the invert part of the sewer, corrosion of the arched part of the sewer, corrosion of the shaft walls).
— Method of damage elimination (local repair, steel couplings, sealing of the butt joint, partial pipe replacement, application of corrosion protection coatings).

Figure 6.3. Teleinspection of the sewer on Frunze Prospekt after cleaning using the method proposed by the author (RF1, Kharkiv, Ukraine, 2017)

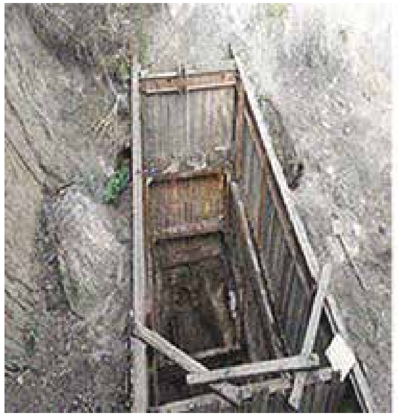


Figure 6.4. The sewer on Seweryn Potocki street before rehabilitation work (RF5, Kharkiv, Ukraine, 2017)

Figure 6.5. Restoring the conveyance capacity of the sewer on Seweryn Potocki street after rehabilitation works (RF5, Kharkiv, Ukraine, 2017)

The type of sewers at different sites and stages of rehabilitation is shown in Figs. 6.3 to 6.5. The main characteristics of the facilities and the outcomes of restoring the conveyance capacity and cleaning sewers (RF for rehabilitated facility) are given in Table 6.1.

An example of the work performed by the proposed method is cleaning of a sewage pipeline with pipe diameter of 600 mm, section length of 460 m laid along Frunze Prospekt from Shcherbakova Street to Volochayevska Street in the city of Kharkiv. The characteristics of this rehabilitated facility are given in Table 6.1 (RF1). The pipeline was in disrepair, 50 % filled with sludge deposits. Cleaning was performed as shown by the diagram in Fig. 6.2. The distanc to which the metal bucket was pulled in direction of the first or the third well was measured with the electric winch previously installed above the third well. The pipeline was completely cleaned of sludge deposits and large clogging within four months. The cleaning efficiency was 100 % [92, 249].

The experience of restoring the conveyance capacity of the sewer made of clinker brick with a complex cross-section on on Seweryn Potocki Street in the city of Kharkiv, is of particular interest. The main technical characteristics of the recovered facility are given in Table 6.1, RF5. The sewer was cleaned by the method proposed by the authors for cleaning the sewers using the new bucket design. The complexity of this work was due to the presence of a turn in the sewer line and absence of a shaft at this site. In this regard, an organizational and technological decision was made on arrangement of a receiving pit to perform cleaning operation (Fig. 6.3). Further, after completing work, a new shaft was built (Fig. 6.4).

In addition to using the author's method of cleaning sewers using the new bucket design, in restoration of the conveyance capacity of sewers RF2, RF3, RF4 in Kharkiv (Table 6.1) conventional cleaning methods such as mechanical and hydrodynamic, were also used.

Table 6.1 — The main parameters of the facilities and the outcomes of performed work to restore the sewers' capacity and clean the sewers (RF)

Item No.	**Parameter**	**Facility No.**				
		RF1	**RF2**	**RF3**	**RF4**	**RF5**
1	**2**	**3**	**4**	**5**	**6**	**7**
Technical Data						
1	Diameter, mm	600	700	700	800	700 / 900
2	Material of sewer	Steel	Steel	RC	RC	Brick
3	Cross section	Round	Round	Round	Round	Oval
4	Technical condition	Satisfactory				
5	Number of damages in the last five years, Cases	3	4	4	2	5
6	Scheduled teleinspection	Yes	Yes	Yes	Yes	Yes
7	Type of damage*	A, C, F	B, C, F	D, E	D, E, F	E, F
8	Method of damage elimination**	b, c, e	a, b, d, e	d, e	d, e	a, e
9	Number of line connections to the sewer, Nos.	3	3	4	2	1
10	Turns in the sewer line	Yes	No	Yes	Yes	Yes
11	Line gradient	0.002	0.003	0.002	0.002	0.003
Organizational and technological indicators						
12	Section length to be cleanned, m	460	75	100	60	70
13	Clogging of the sewer cross-section, %	50 %	30 %	25 %	35 %	60 %
14	Type of clogging	Construction and household waste				
15	Number of target shafts or pits for cleaning, Nos.	9	2	3	2	3
16	Distance between the target pits, m	50, 60	75	40, 60	60	35, 35
17	Cleaning method	developed by the authors	mechanical	Hydrodynamic	Hydrodynamic	developed by the authors
18	Equipment parameters	depending on the section to be cleaned	power: 2,200 W	working pressure 150 bar	working pressure 150 bar	varies from cleaning area
19	Working tool	Bucket	Brush	Nozzle / Cutter	Nozzle / Cutter	Bucket
20	Working tool drive	Rope	Rods	Rope	Rope	Rope
21	The need for fluid supply	Yes / No	No	Yes	Yes	Yes / No

Notes:

* type of damage: pitting corrosion (A); through corrosion (B); damage to the butt joint (C); damage to the invert part of the sewer (D); corrosion of the arched part of the sewer (E); corrosion of the shaft walls (F);

** method of damage elimination: local repair (a); steel coupling (b); sealing of the butt joint (c); partial replacement of the pipe (d); application of corrosion protection coating (e) [249].

Based on the summatrized technical, organizational and technological characteristics of the networks, the most significant factors that affect the efficiency of using the method for cleaning sewers were determined. Symbols F1 ... F7 were assigned to the factors (Table 6.2). Using the expert evaluation method, the factors were ranked in an order of increase or decrease of any inherent property [91, 92]. When ranking, experts in the subject area arranged the factors influencing the efficiency of using the method for cleaning sewers in the order that they deem to be the most rational and assigns ranks to these. In this case, rank No. 1 obtains the highest degree of significance of the factor influence on efficiency of rehabilitation work, and rank No. N obtains the lowest degree. Consequently, the ordinal scale obtained as a result of ranking is to meet the condition where the number of ranks "7" is equal to the number of ranked factors "*n*". Further, a summary table of ranks was compiled for all experts of the group (Table 6.3).

Table 6.2 — The factors affecting the efficiency of using the method for cleaning sewers

Item No.	Factor
F1	Diameter of the existing sewer
F2	Material of the worn-out sewer
F3	Overall technical condition of the sewer (disruption to the integrity of the lining system)
F4	Degree of clogging (reduction in per cent of the conveyance capacity of the sewer);
F5	Type of clogging (sludge, construction waste, etc.)
F6	Profile of the section to be rehabilitated (presence of turns, section length, the need for arranging additional pits)
F7	Conditions of work performance (location and time of work)

Table 6.3 — Expert survey results

Factor	Expert							Score
	1	**2**	**3**	**4**	**5**	**6**	**7**	
F1	5	4	6	6	4	3	5	33
F2	7	6	7	7	6	5	7	45
F3	4	5	5	4	5	6	4	33
F4	3	2	2	1	2	4	3	17
F5	1	1	3	2	1	1	2	11
F6	2	3	1	3	3	2	1	15
F7	6	7	4	5	7	7	6	43
Total:	28	28	28	28	28	28	28	—

To determine the consistency of experts, the concordance coefficient W was used, the calculation method for which is described in Paragraph 2.4. According to the analysis of the table of standardized ranks and the calculations made, the concordance coefficient of 0.839 was obtained, which indicates a high degree of agreement of opinions in the selected group of experts. The diagram of the total ranks of the studied factors based on the results of expert evaluation is shown in Fig. 6.6.

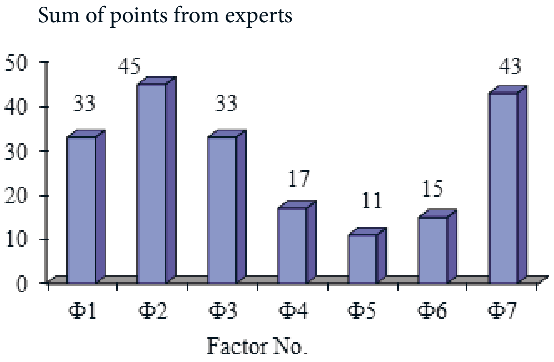


Figure 6.6. The diagram of the total ranks of the studied factors according to the results of expert evaluation

From the data obtained, it should be noted that of the above-mentioned 7 factors, factors F4, F5, F6 (the total rank of these phenomena is minimum) have the highest degree of significance on the efficiency of the method for cleaning sewers, in particular.

- — Degree of clogging (reduction in per cent of the conveyance capacity of the sewer).
- — Type of clogging (sludge, construction debris, etc.).
- — Profile of the section to be rehabilitated (presence of turns, section length, the need for arranging additional pits or shafts for rehabilitation).

The above factors directly affect technical and economic indicators (TEI) of the work: cost price, labor intensity, and duration of recovery of the conveyance capacity of the sewer. This is due to the fact that the set of parameters can change TEI in various dynamics through the cleaning work stages. So, for example, the degree and type of clogging may differ depending on the section of the recovered sewer which will affect labor intensity and duration of work and as a result the cost price. In view of this, only a comprehensive assessment of all factors impacting rehabilitation work can show the expediency of using the cleaning method with the new bucket design proposed by the authors.

Table 6.4 shows the technical and economic indicators of the facilities where the conveyance capacity was restored and the sewers were cleaned by various methods in the city of Kharkiv.

Table 6.4 — Technical and economic indicators of the facilities where the conveyance capacity was restored and the sewers were cleaned (RF)

Item No.	Parameter	Facility No.				
		RF1	RF2	RF3	RF4	RF5
1	Section length, m	460	75	100	60	70
2	Duration of work at RF, days	90	8	8	12	30
3	Duration of work for restoring the conveyance capacity per 10 rm of the sewer, days	1.95	1.06	0.9	2	0.64
4	Cost of cleaning 1 rm of the header, c, u	430	1550	1800	1950	500

It should be noted that the duration of work includes preparatory and main periods. The main period of work includes cleaning the sewer, and arranging new shafts. The cost of work depends on the working conditions, diameter of the existing sewer, the degree of its clogging and the type of sediments. On the example of operating companies in Kharkiv, it can be observed that the use of traditional methods for cleaning sewers (hydrodynamic and mechanical) is inferior in terms of technical and economic indicators to the alternative method proposed by the authors for cleaning sewers using the new bucket design. This is due, first of all, to the high cost of imported equipment for hydrodynamic and mechanical cleaning.

The effectiveness of cleaning sewers by these methods and restoring the conveyance capacity of the pipeline is 100 %. In turn, a significant disadvantage of using these methods is the high cost of equipment and rehabilitation work.

When comparing the results of the existing methods of cleaning sewers with the results obtained using the proposed method, one can conclude as follows: 1) the proposed method integrates the advantages of the existing methods and may be used both only mechanically and with involvement of hydraulic mechanisms; 2) the proposed method may be used for cleaning sewers of various diameters and types; 3) the proposed method makes it possible to reduce duration of work and energy costs for cleaning operations.

The shortcomings of the investigation include the fact that the method was tested for large diameter sewers with their cross-section and their section profile. However, they do not significantly affect quality of work, which was confirmed by the expert evaluation method. In the future, investigations should be conducted to widen the capabilities of the above method, that is, to test it under the effect of different indicators of the performance efficiency.

6.2. Improving the Stable Operation of the Sewerage Networks and Facilities on Grekivska Street and Near the Khtz Plant in Kharkiv

Developing the Organizational and Technological Solutions to Remediate the Accidental Damage on Grekivska Street in Kharkiv

In January 2018, a significant soil subsidence occurred on Grekivska Street (Kharkiv, Ukraine), which was caused by the collapse of the sewer tunnel on the wastewater disposal network section (Fig. 6.7) [244, 245]. As a result of the accident in the reinforced concrete sewer tunnel built in 1972, a failure was after a short time formed with an approximate depth of 10 m and a diameter of 20 m, followed by the collapse of the adjacent house (Fig. 6.8, 6.9).

The arched tunnel, the diameter of which is D = 2540 / 2850 mm (live section D = 2140 / 2450 mm), is made of precast concrete structures (con-

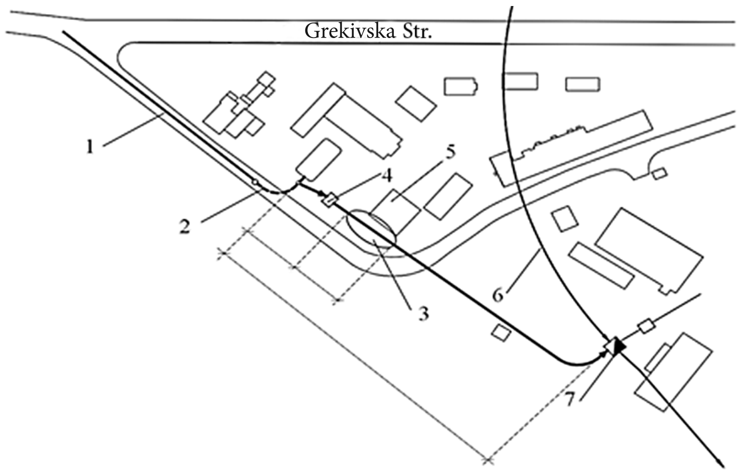
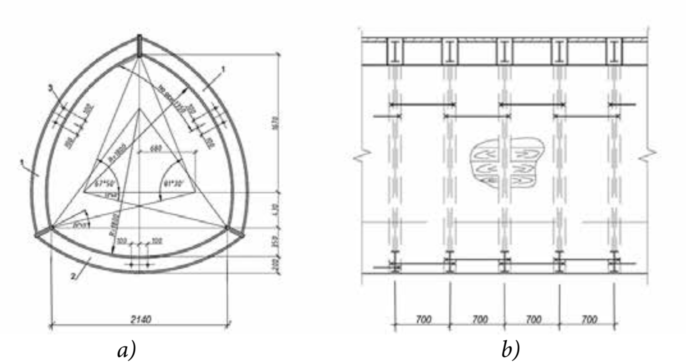


Figure 6.7. A schematic drawing of the wastewater disposal network: 1 – main collector; 2 – brick tunnel built in 1912; 3 – collapsed area; 4 – shaft No. 8; 5 – building in the area of the accident; 6 – main sewer tunnel; 7 – shaft No. 2

crete grade = M300) by tunneling using a ПЩ-3,2 TBM. In the geological section of the soil, the tunnel is laid at a depth of 15 m in semi-solid clay and fine watered sand at the groundwater level [245].

The accidental damage occurred at the switching section of Main sewer laid on Grekivska street with deep-layed Main sewer tunnel in shafts No. 8 and No. 2 (Figs. 6.10, 6.11). The distance between shaft No. 8 and shaft No. 2 is 130 m. The damaged site is located in close proximity to the stilling chamber (shaft No. 8) of the wastewater flow. The main cause of the local collapse is damage to the reinforced concrete structure of the vault of the tunnel as a result of exposure to biogenic corrosion. As a result of the delamination of the stream, sulfuric gas is actively released, which in subsequent reactions turns into sulfuric acid of a high degree of concentration. With no anti-corrosion protection, there is damage to the concrete lining of the tunnel, bearing the load from the soil mass. As a result of the deterioration of the supporting vaults of the structure, the soil rock was taken out into the body of the tunnel, followed by the collapse and failure of the adjacent building.

Figure 6.8. Soil failure due to the accident in the reinforced concrete tunnel; and disruption of the bearing capacity of the adjacent house due to local damage to the vault of the tunnel



a) *b)*

Figure 6.9. Design features of the arched tunnel:
(a) arch assembly; (b) section 1–1;
1 – type A prefabricated I-beam design;
2 – Type B prefabricated I-beam design; 3 – hole for tie rods

Shaft No. 8 (Fig. 6.10) is designed to reduce the speed of wastewater flow and reduce the level of wastewater by 12 m (from + 95.9 m to + 83.8 m above sea level). The entrance to the shaft is arranged through an aboveground building measuring 5x4 m in overall dimensions. Around the shaft along the perimeter at ground level, a foreshaft with a thickness of 2.5 m made of concrete M100 is arranged. The walls of the shaft with a thickness

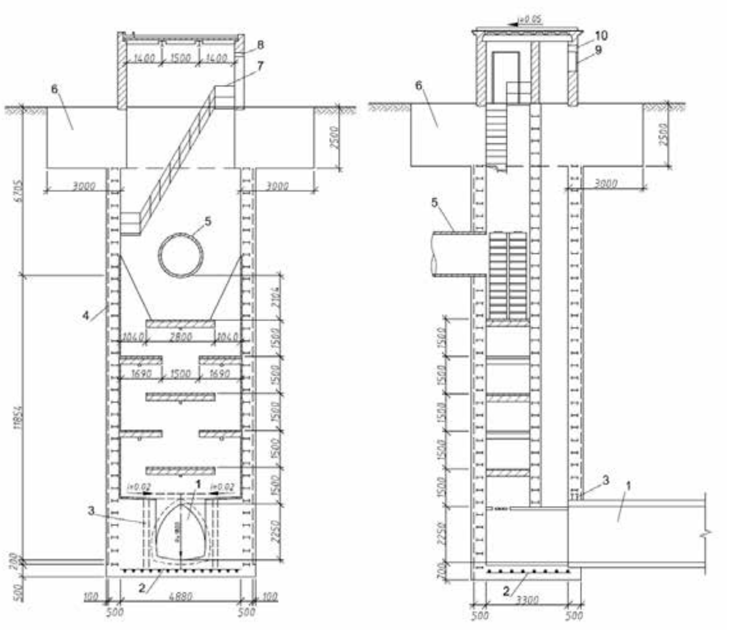


Figure 6.10. Design solution of shaft No. 8:
1 – Grekivska arched type sewer tunnel; 2 – reinforced mesh ø10A II;
3 – chamber frame; 4 – bars; 5 – reinforced concrete pipe; 6 – concrete M100 foreshaft;
7 – steel ladder; 8– bridge; 9 – ventilation grille;
10 – reinforced concrete bridge; 11 – wall ring; 12 – supporting ring

of 0.5 m are made of ФБС 9.5.3 foundation slabs. At elevation + 95.9 m a pipe inlet ø1400 mm is provided. Next there is a system of slabs designed to reduce the speed of wastewater flow in a staggered manner every 1.5 m. At elevation +83.8 m, the outlet of an arched tunnel with dimensions of 2140 / 2450 mm is arranged (Fig. 6.9). Shaft No. 8 is divided into 2 parts, the first of which serves to reduce the speed of the flow, and the second part arranges ventilation to divert poisonous gases to the street [244, 245].

Shaft No. 2 (Fig. 6.11) is a junction-type shaft and is designed to redirect flows from one pipe to the pipe of the main sewer. To enter the shaft, a ø 600 mm manhole is arranged, and then there are two steel steps and steel staircases, which allow you to descend to the very bottom of the shaft. Around the shaft along the perimeter at ground level a foreshaft 3 m thick of concrete M100 is arranged. The walls of the shaft with a thickness of 0.5 m are made of ФБС 9.5.3 foundation slabs. At elevation + 82.8 m an inlet of the arched tunnel pipe is arranged with dimensions of 2140/2450 mm (Fig. 6.9),which flows into the pipe of the ø3.260 mm main sewer [244, 245].

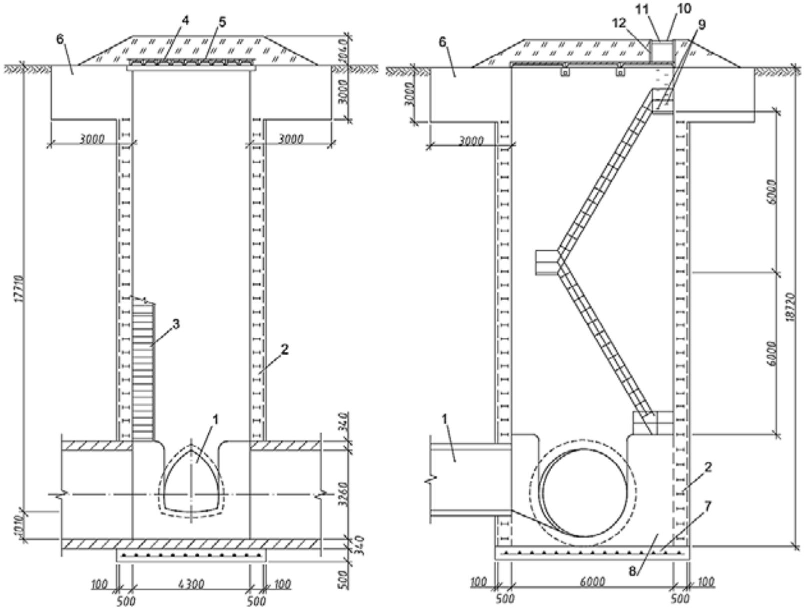


Figure 6.11. Design solution of shaft No. 2
of the switching of the arched-type sewer tunnel to ПЩ-4,0 Main sewer tunnel:
1– arched type sewer tunnel; 2 – existing shaft; 3 – steel ladder; 4 – precast concrete slabs;
5– shaft cover slabs; 6 – concrete M100 foreshaft; 7 – reinforced concrete walls and the bottom of the shaft; 8 – concrete M300 invert; 9 – steps; 10 – cast iron manhole cover;
11 – wall ring; 12 – supporting ring

The procedure for eliminating accidents in sewer networks is provided for by the rules for the technical operation of water supply and wastewater disposal systems of settlements of Ukraine, approved by Order No. 30 of 05.07.1995 "Organizational and technological measures to eliminate local damage in an existing sewer tunnel with an open ground blockage" and consist of preparatory and main work.

At the first stage, it was necessary to stop the flooding of the soil and ensure the removal of wastewater by reconnecting to the redundant sewer or arranging a bypass line. Due to the lack of technical possibility of reconnecting Grekivska tunnel, a bypass line was installed in the shaft, which made it possible to ensure the functioning of the wastewater disposal distribution system (Fig. 6.12) [244, 245]. The main organizational and technological operations at the preparatory stage were as follows.

— Fencing of the site of emergency work.
— Providing wastewater disposal by installing three lines of the PE pipeline D = 300 mm with pumping units.
— Conducting engineering and geological surveys at the damaged site.
— Backfilling of the local collapse with soil to prevent further collapse.
— Conducting geophysical studies on the actual state of the soil mass with the designation of the boundaries of stratification of rocks, karst

Figure 6.12. Arranging temporary wastewater disposal

voids, the presence of groundwater horizons for further adoption of an appropriate design decision on the method of rehabilitation.

According to the report of engineering and geophysical studies of the soil mass along the route of Grekivska tunnel from shaft No. 8 to shaft No. 2, it was found as follows.

1. The absence of karst voids and fissures in the rock above the vault part of the existing tunnel, which indicates the integrity of the reinforced concrete lining of the sewer tunnel, the degree of integrity of which has not been established.
2. Next to the area of collapse above the route of the existing tunnel there are small areas of voids and separation of rock.
3. The survey area is located in the zone of flooding with groundwater. The groundwater horizon is at elevation 98.5. The aquifer is represented by sandstones and marl at elevation 94. The height of the aquifer is 4.5 m [244, 245].

Due to the lack of a detailed study of the size of the consequences of the accident and the unpredictability of conditions, it was decided to completely backfill the place of collapse for further technological decisions on the method of rehabilitating the tunnel on Grekivska street [244, 245]. To eliminate damage, the following organizational and technological solutions are considered.

1. Complete backfilling of the collapsed area, decommissioning of the damaged tunnel, construction of a new sewer tunnel.
2. Driving the blockage and restoration of the collapsed tunnel by the insertion method using short polyethylene pipes.
3. Driving the blockage and restoration of the tunnel using the “pipe in pipe” method with fiberglass pipes.
4. Driving the blockage by jacking and restoring by introducing the lining made of reinforced concrete rings with corrosion-resistant coating into the collapsed tunnel.

The following technological pattern for repairing the collapsed tunnel was proposed by driving the blockage by jacking reinforced concrete rings lined on the inside with ribbed polyethylene into the collapsed tunnel (Figs. 6.13, 6.14). At the first stage, it is necessary to arrange a pit shaft on the curved section of the tunnel route to ensure that work is carried out in two directions. Preliminarily, in stilling chamber No. 8, reinforced concrete slabs are dismantled to ensure the introduction of working equipment and reinforced concrete rings into the body of the tunnel. In the newly assembled pit shaft, the jacking devices, along with reinforced concrete rings, are installed.

The blockage is driven using the jacking method by introducing into the collapsed tunnel reinforced concrete rings from the starting shaft No. 8 and the newly assembled shaft sequentially towards each other. Further, from two working shafts, horizontal wells are drilled through the blockage and steel rods are pulled through them, and secured with a knife part [65, 244, 245]. The traction force of the knife part (ring) provides cutting of the rock and the introduction of the rings deep into the tunnel filled with soil. The supporting part of the reinforced concrete ring creates the required rigidity and strength of the entire structure. The hydraulic jacks arranged in the rear part of the support ring press reinforced concrete rings with an corrosion-resistant coating into the place of the selected soil, while a ready-made area of the lining serves as the stop for the jacks arranged around the circumference of the case (Fig. 6.13). Then the jacks are removed, and the area behind the supporting part is strengthened with reinforced concrete elements, which constitute the lining of the tunnel when eliminating the blockage by jacking. At the next step, after excavating the next portion of the soil, the jacks supported by the newly mounted elements push the knife part further. The technological schematic drawing for the production of work to eliminate the local collapse of the sewer tunnel is shown in Fig. 6.14.

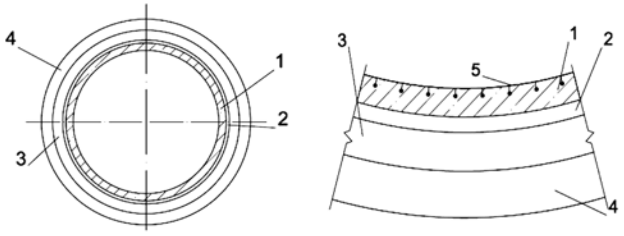


Figure 6.13. Schematic drawing of reinforced concrete rings with corrosion-protection coating:
1– secondary lining from reinforced concrete rings; 2 – annular space to be grouted with cement-sand mixture; 3 – cast in situ reinforced concrete primary lining; 4 – reinforced concrete ring; 5 – corrosion-protection coating made of ribbed polyethylene

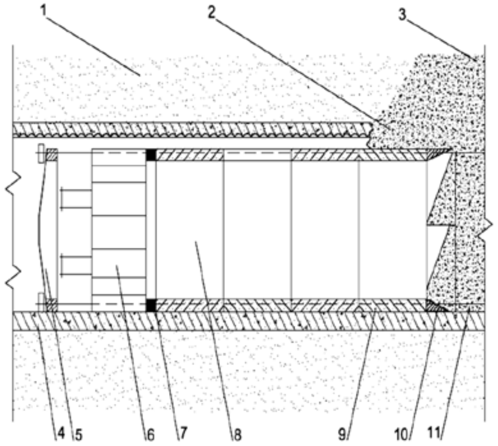


Figure 6.14. A technological schematic drawing showing the elimination of the blockage by jacking method involving the introduction of secondary lining from precast reinforced concrete rings with a corrosion-resistant protective coating into the collapsed tunnel:
1 – water-saturated unstable soil mass; 2 – the collapsed part of the lining; 3 – soil blockage ; 4 – soil excavation; 5 – crossbar; 6 – hydraulic jack; 7 – supporting ring; 8 – reinforced concrete ring; 9 – traction rod; 10 – knife part; 11 – horizontal well for the traction rod

From Fig. 6.14 it can be seen that rehabilitation work is carried out sequentially, with bays equal to the extension length of the hydraulic jack rods. Soil is excavated and removed manually using a mechanized tool by small-sized rock-loading machines [244, 245].

After the blockage is driven and the secondary reinforced concrete lining is erected, the joints between the reinforced concrete rings are caulked with quick-setting expanding cement, and cement-sand mortar is injected into the gap behind the lining. The quality of the primary injection, that is, the filling of voids, is checked by a secondary control injection of cement mortar [244, 245].

When comparing the options for eliminating accidental damage, it was taken into consideration that some organizational and technological operations that took place in all four rehabilitation options can be excluded from the design calculation. It means the preparation of the tunnel for rehabilitation work, including the reconnection of drains from the collapsed tunnel, the preparation of the starting and target shafts, etc. When rehabilitating a sewer tunnel using a trenchless repair method, it was taken into consideration that the filling of the annulus in the options with polyethylene and fiberglass pipes did not differ in size and composition of concrete. In the developed technology for repairing a sewer tunnel by jacking and introducing secondary lining from reinforced concrete rings lined with ribbed polyethylene, the amount of concrete to fill the annular space was comparable to the other methods listed above [244, 245].

The comparison of the duration of rehabilitation work is given in Tables 6.5, 6.6 for each of the options, allows concluding that, according to the duration of the work, it is advisable to use the blockage driving by jacking and rehabilitating by introducing secondary lining from reinforced concrete rings lined with ribbed polyethylene into the collapsed tunnel.

Whatever method of rehabilitating the damaged sewer tunnel is chosen, in the existing curved section of the route it is necessary to build a pit shaft for further work. It is built by open caisson method. Precast reinforced concrete elements are interconnected by locking elements and form a ring of the future pit shaft (Fig. 6.15, 6.16).

Table 6.5 — Cost of materials for the elimination of the accidental damage to the sewer tunnel

Item No.	Rehabilitation method	Description of material	Nominal diameter DN	Un. of measur.	Cost per unit
1	Complete backfilling of the collapsed area, decommissioning of the damaged tunnel, construction of a new sewer tunnel	Spiro polyethylene pipe	1600	rm	35,650.00
2	Driving the blockage and restoration of the collapsed tunnel by the insertion method using short polyethylene pipes	Spiro polyethylene pipe	1600	Rm	29,300.00
3	Driving the blockage and restoration of the tunnel using the “pipe in pipe” method with fiberglass pipes	Fiberglass pipe	1600	rm	28,400.00
4	Driving the blockage by jacking and restoring by introducing the lining made of reinforced concrete rings with anti-corrosion coating into the collapsed tunnel	Reinforced concrete rings with corrosion-resistant coating	1600	rm	9,800.00

Table 6.6 — The duration of work to eliminate the accidental damage to the tunnel on Grekivska street by the methods considered (the length of the section is 100 rm, the diameter of the blockage is 20 rm)

Item No.	Rehabilitation method	Duration in days, with a three-shift work
1	Complete backfilling of the collapsed area, decommissioning of the damaged tunnel, construction of a new sewer tunnel	15
2	Driving the blockage and restoration of the collapsed tunnel by the insertion method using short polyethylene pipes	10
3	Driving the blockage and restoration of the tunnel using the "pipe in pipe" method with fiberglass pipes	12
4	Driving the blockage by jacking and restoring by introducing the lining made of reinforced concrete rings with anti-corrosion coating into the collapsed tunnel	9

Figure 6.15. Precast reinforced concrete segments

Figure 6.16. A shell ring of the future pit shaft

The technology of the work is that under the knife part of the future walls of the pit shaft, soil is excavated in the direction from the center to the perimeter of the structure. Using the grab, the invert part is excavated (Fig. 6.17, 18). As a result, the walls of the open caisson lose support from the inside and the structure sinks under its own weight.

Figure 6.17. Excavating the invert part using the grab

Figure 6.18. Erecting a pit shaft by open caisson method

Figure 6.19. Reinforcing and concreting the bottom of the pit shaft

Figure 6.20. A pit shaft on Grekivska street

After erecting the pit shaft to the design elevation, the bottom should be reinforced and concreted followed by anti-corrosion protection of reinforced concrete structures (Fig. 6.19, Fig. 6.20).

An economically and technologically effective technology for eliminating a local collapse of a sewer tunnel has been developed as a result of the research. To perform rehabilitation work, a method of jacking and rehabiluitation by introducing secondary lining from reinforced concrete rings with a corrosion-resistant coating into the collapsed tunnel. When comparing options for rehabilitation by different methods, it should be noted that the proposed technology using reinforced concrete rings lined with ribbed polyethylene is more economically feasible, compared to the relining method using polyethylene or fiberglass pipes due to their high cost. In the meantime, the duration of work by the proposed method of jacking with the introduction of secondary lining from reinforced concrete rings with corrosion-resistant properties will be reduced by 30% compared to other methods. However, for the effective implementation of further rehabilitation work, a pit shaft shoul be erected by open caisson method.

Improving the Stable Operation of the Sewerage Networks and Facilities Near the KhTZ Plant in Kharkiv

Specifically, the sewer near the KhTZ plant is in disrepair with a degree of wear and tear of 80%, as evidenced by large-scale accidents in it in 2015 and 2017 [55, 59]. Therefore, organizational and technological solutions were developed and implemented for the rehabilitation of this section of the sewer with D=1000 mm with a length of 500 m with the reconstruction of stilling chambers K1 and Ш-1 (Fig. 6.21).

Engineering and geological surveys were not conducted. Materials from archival sources owned by Public Utility Company Kharkivvodokanal were used. In structural and tectonic terms, the area to be rehabilitated is confined to the northeastern part of the Dnipro-Donetsk depression. The absolute elevations of the land surface of the site range from 175.00 to 177.00. Based on a combination of factors and in accordance with State building regulations A.2.1-1-2014 on the basis of Appendix Ж, the site belongs to the second (medium complexity) category in terms of engineering and geological conditions. There is no groundwater. The standard depth of seasonal freezing of clay soils for this area is 1.1 m [55, 59].

The main component of the base of the sewer and the stilling chambers are brownish-gray loams with plant residues (Fig. 6.22).

The complexity of the work is due to the following factors.

1. The sewer is in operation; there is no redundant line (in the preparatory period of work, measures were taken to temporarily divert wastewater (Fig. 6.23, 6.24).

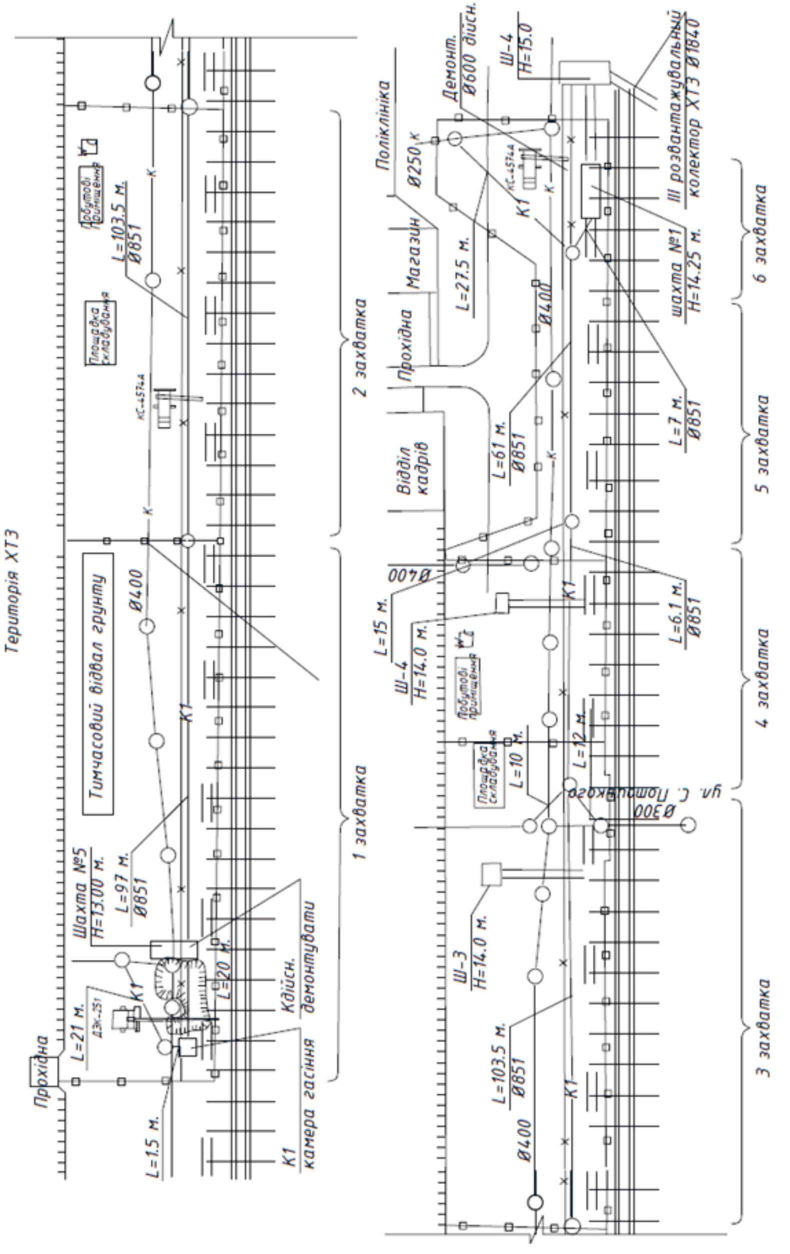


Figure 6.21. A schematic drawing showing work near the KhTZ plant

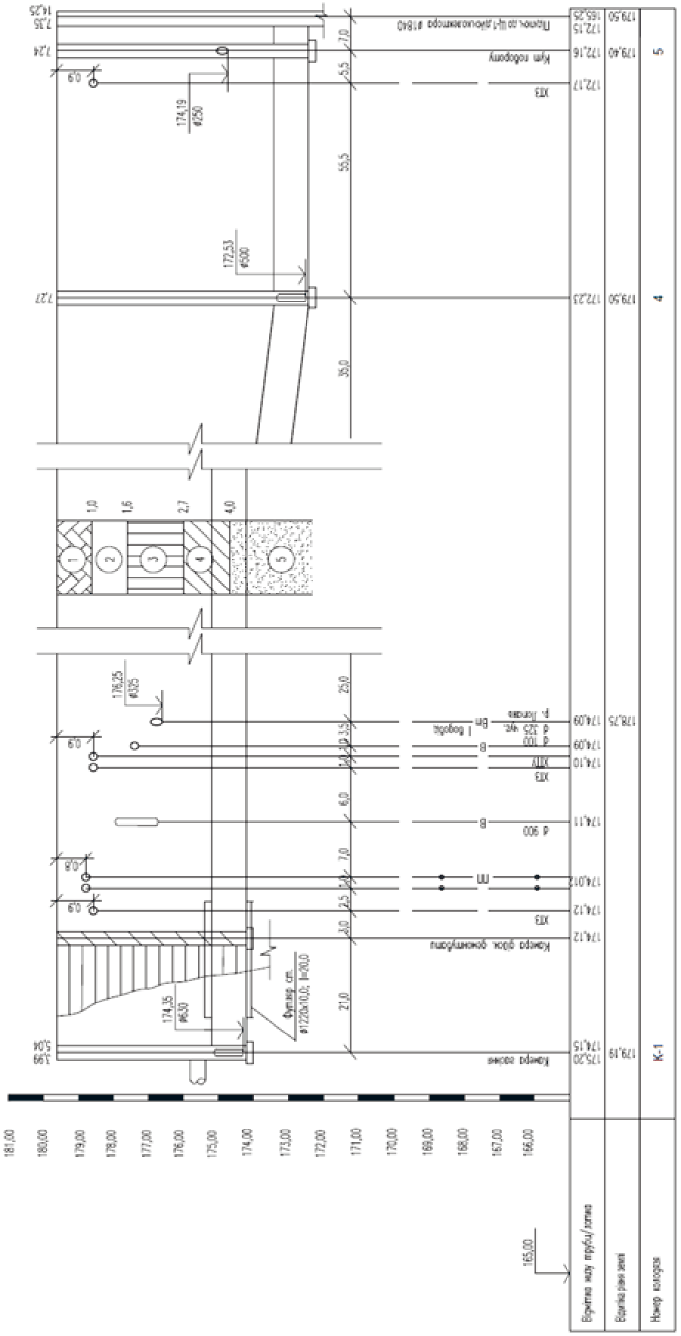


Figure 6.22. A schematic drawing showing work near the KhTZ plant

2. The depth is 13 m.
3. Stilling chambers K1 and Ш-1 require complete reconstruction; the drop shaft requires dismantling with the installation of the existing pipeline (Fig. 6.25).
4. Carrying out work in conditions of soil collapse due to the accident and in close proximity to tram tracks without stopping traffic.

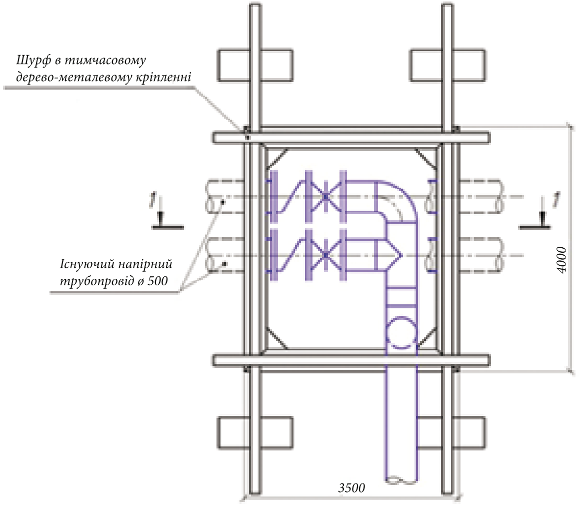


Figure 6.23. Schematic drawing showing the erection of a temporary switching chamber for temporarily diverting wastewater

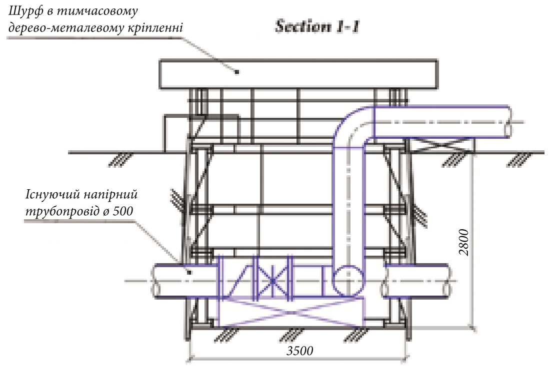


Figure 6.24. A schematic drawing showing the erection of a temporary switching chamber. Arranging a pit. Section 1-1

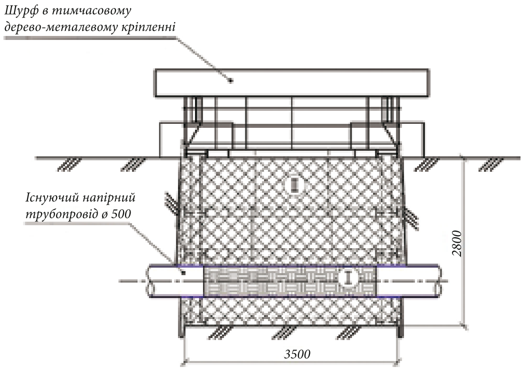


Figure 6.25. Excavating soil and dismantling a section of the existing pipeline.
I – Dismantling a section of the existing ø 500 pipeline; II – Excavating soil

After the direction and axes of pipe laying were visually determined, the pipelines were conventionally broke down into sections to be dismantled according to the conditions of the manufacturability of the performed work and the technical characteristics of the hoisting mechanisms [13]. Owing to a number of factors, rehabilitation work was performed by open cut by laying CORSYS polyethylene pipes of L = 1000 mm, reconstructing stilling chambers K1 and Ш-1 and erecting inspection shafts (Fig. 6.26). The work was conventionally divided into bays No. 1 to No. 6.

The pipes to be broken down into segments are shown in Fig. 6.27. Appropriately, in places where pipes are cut into segments, the trench is expanded; if this is not, a set of measures is taken to further secure the slopes of the trench with inventory elements (Fig. 6.28).

The design solution for the K1 stilling chamber deserve particular attention [13]. In view of the high speed of the wastewater flow and the impossibility of embedding the stilling chamber to provide gravity sewerage because of

Figure 6.26. Rehabilitating ø 1000 mm sewer using CORSYS PE pipes

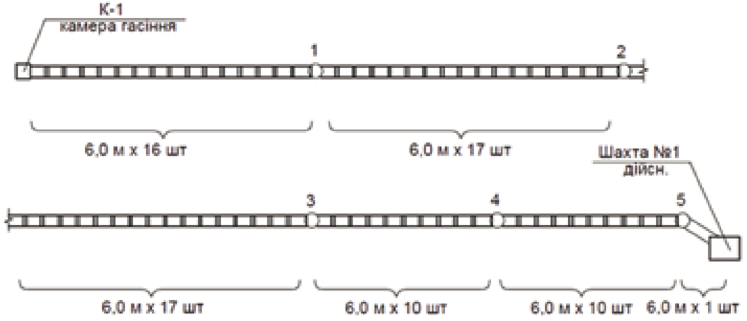


Figure 6.27. CORSYS ø 1000 / 85 pipes to be broken down into segments

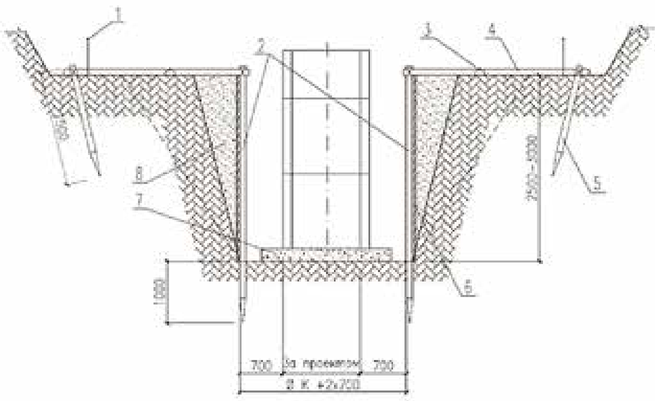


Figure 6.28. Securing the slopes of the trench:
1 – trench fencing; 2 – supporting posts; 3 – comppacting with compacted non-rocky soil; 4 – anchor rod; 5 – pile; 6 – raft; 7 – reinforced concrete slab of the bottom; 8 – backfilling with sandy soil

the depth of laying, a design for a stilling chamber with a corrosion-resistant coating was proposed, which ensured the effective operation of centralized drainage. The stilling chamber structure is made of two steel sleeves with a carrier, due to which the flow speed decreases (Figs. 6.29, 6.30, 6.31).

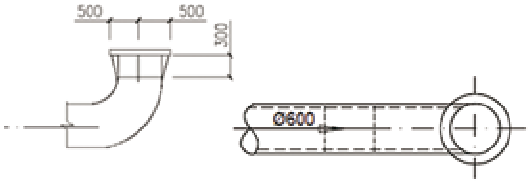


Figure 6.29. Wastewater stilling chamber design

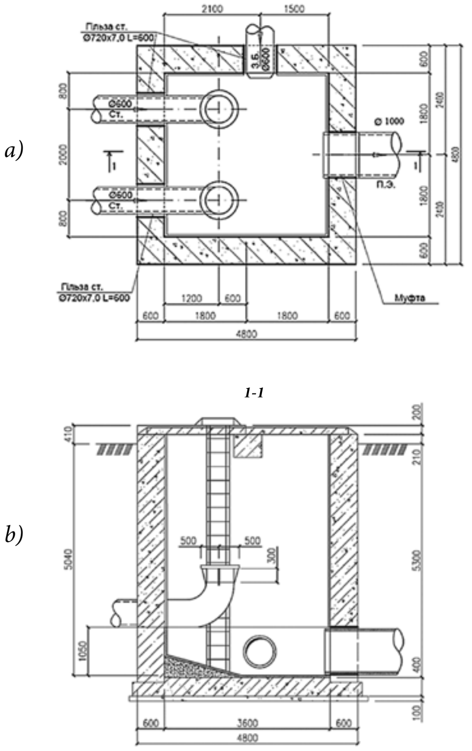


Figure 6.30. Stilling chamber K1: (a) plan; (b) section 1-1

Figure 6.31. Stilling chamber K-1:
general view after rehabilitation work

Due to the high corrosiveness of the sewer environment, a protective corrosion-resistant system for lining the walls of the stilling chamber was proposed: porcelain stoneware + corrosion-resistant solution. In the KhNUCEA laboratory, studies were conducted on the feasibility of using porcelain stoneware, indicating high quality parameters of the material for protection against biogenic corrosion. As a result of the studies [48], the composition of the solution was obtained for its operation in the corrosive environment of the sewer, which includes:

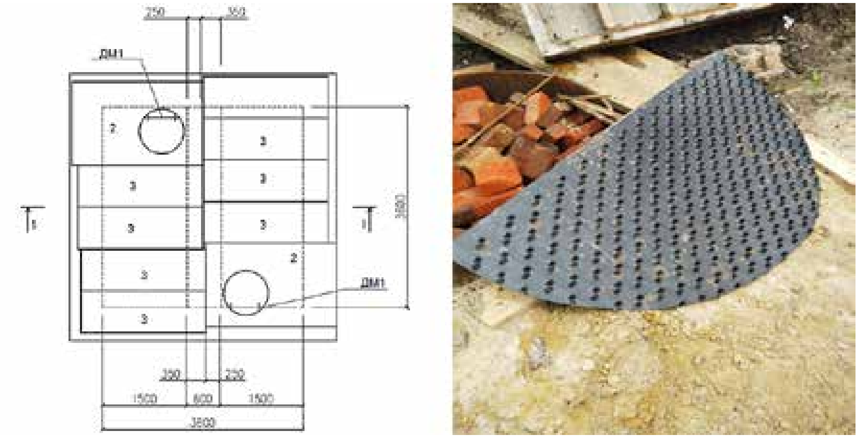
1. Binder: grade M500 Portland cement complying with the requirements of DSTU B V.2.7-46-2010 Cements for general construction purposes. Specifications.
2. Filler: natural quartz sand with a fineness modulus of up to 2.5 mm complying with the requirements of DSTU B V.2.7-32-95 Natural sand for building materials, products, structures and work. Specifications.
3. Expanded clay dust: as an active mineral admixture and filler (20 % by weight of cement), complying with the requirements of DSTU B V.2.7-100-2000 Mineral active admixtures for cements. Specifications.
4. Chemically active admixture (CAA, 7–12 % by weight of cement), brand Viatron, manufacturer Via-Telos LLC, Kharkiv
5. Drinking tap water.

The calculation of materials for 1m3 solution for lining the stilling chamber is as follows: cement with an activity of 450 kgf /cm^2 = 0.675 t per 1 m^3 of sand with a bulk density of kg /m^3; Portland cement M500 — 675 kg; quartz sand — 1450 kg; expanded clay dust — 130 kg; chemically active admixture — 60 kg. The ratio of cement to sand is 1 : 2.15; W/C = 0.4–0.42.

The chamber was covered by reinforced concrete slabs with corrosion-resistant polyethylene coatings, the layout of the slabs is shown in Figs. 6.32.

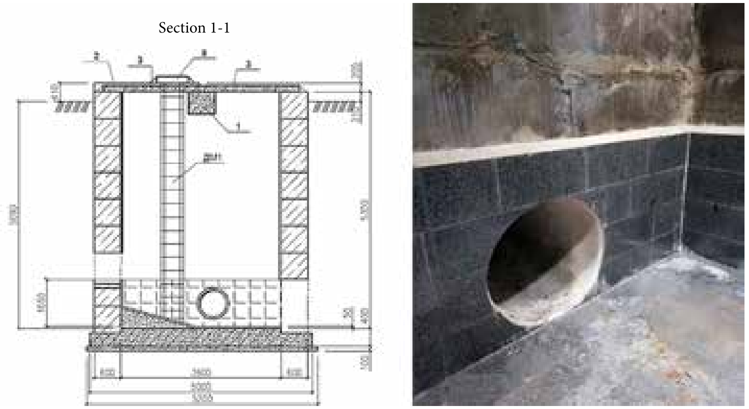
Thus, the inner surface of the chamber and the floor were lined with granite slabs with the solution proposed by the authors [48] to its full height. The other inner surface of the operating sites and stairs is covered with АКВАХИМ corrosion-resistant epoxy polyurethane composition (Fig. 6.33 in accordance with the specification of Table 6.6) [13].

The next stage of improving the stable operation of the sewerage networks and facilities near the KhTZ plant is to rehabilitate the sewer collection tunnel with shaft No. 1 adjacent to pit shaft No. 4 of the 3rd subsidiary sewer, which is driven as a mined tunnel shaft (DN = 1,500 mm) lined with reinforced concrete [13, 55, 59]. The internal waterproofing system is a cast in situ reinforced concrete jacket. The invert laying depth is 14.25 m. The section to be rehabilitated comprises pit shaft No.1 and a tunnel shaft 20 m long; the as-built drawing is shown in Fig. 6.34.



a) b)

Figure 6.32. Stilling chamber K1:
(a) overlapping plan; (b) PE covering for reinforced concrete structure



a) b)

Figure 6.33. Rehabilitating stilling chamber K1:
(a) section 1–1; (b) general view after rehabilitation work

Table 6.7 — Stilling chamber K1 components. Specification

Item No.	Designation	Description	Q-ty	Mass per unit, kg
1	3.006.1-2/87	Beam Б8	1	2880
2	3.006.1-2/87	Slab ПО4	2	1550
3	3.006.1-2/87	Slab П18д-8	8	600
4	DSTU Б В.2.6-108:2010	Slab ФБС 24.6.6-т	38	1960
5	DSTU Б В.2.6-108:2010	Slab ФБС 12.6.6-т	20	960
6	DSTU Б В.2.6-108:2010	Slab ФБС 9.6.6-т	27	720
7	DSTU Б В.2.6-108:2010	Slab ФБС 9.4.6-т	2	480
МД1	Sheet	Reinforced cast insitu bottom МД1	1	—
8	—	Manhole cover Т(С250)-ВК-60 ДСТУ 8943:2019	2	120
9	—	Sleeve ø 720 × 7.0; L = 600 ДСТУ 8943:2019	2	73.9
ДМ1	Sheet	Steel ladder ДМ1	2	167.3
10	—	Concrete C8/10, m^3	3	—
11	—	Corrosion-resistant coating АКВАХІМ, kg	24,5	—
12	—	Ceramic granite tiles, m^2	280	—

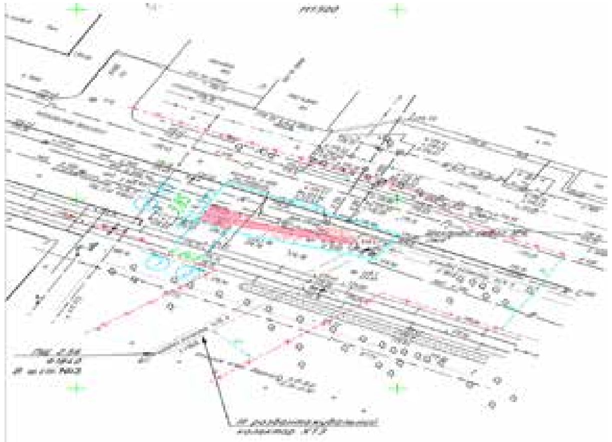


Figure 6.34. As-built drawing showing the section of the sewer collection tunnel with shaft No.1 to be rehabilitated

The actual gradient of the sewer invert is 0.025 and enrsures normal speeds in the sewer, not exceeding 3 m/s. The capacity of the invert is 1,970 l /s at a fill rate of 0.8D = 0.8 m and a speed of 1.3 m / s.

When the sewer is fully filled (2,014 l / s), the speed will not exceed 1.14 m / s. The pit shaft collects industrial and municipal effluents from small KhTZ sewers and from sewage pumping station (SPS) No. 15 [13].

Damage to reinforced concrete by gas and biological corrosion was detected in shaft No.1 and in the section of the sewer collection tunnel (tunnel shaft) in the direction of shaft No. 4 (the distance from shaft No. 1 to shaft No. 4 is 20 m); and the tunnel shaft was also affected by the dynamic effects of the flow.

Measures to ensure the stability and safety of domestic wastewater disposal in the section of the sewer tunnel on Moskovskyi Prospekt (KhTZ), which is adjacent to the 3rd subsidiary sewer KhTZ in the vicinity of stilling chamber No. 1 and pit shaft No. 4 include [13, 55, 59].

— Rehabilitating the reinforced concrete of the tunnel shaft and shaft.
— Waterproofing the shaft and the tunnel section to be rehabilitated using polymer materials.
— Arranging a pipe drop structure in shaft No. 1 (metal pipe: spheroidal graphite cast iron, 2DN = 400).
— Arranging a stilling basin in the invert part of the shaft (with a steel sheet in the bottom and cast iron plates to protect the walls) to dampen the flow velocity (the minimum permissible velocity is 1.2 m /s; the maximum permissible velocity is 3 m / s according to Ukrainian national building code DBN B.2.5-75, Para. 8.13.7).
— Providing the shaft with a staircase and platforms made of composite materials for the operating life of the shaft (by Ekipazh, Kharkiv).
— Arranging a natural draft ventilation riser of (dry filtration device).
— Carrying out work without stopping the movement of wastewater in the 3rd subsidiary sewer KhTZ (with temporarily diverting wastewater into it from shaft No.1).
— Carrying out work with no effluents in the shaft and in the tunnel for the period of work (secured by temporary cut-off devices).
— Carrying out work while maintaining the traffic of urban ground electric vehicles.

The section of the existing gravity sewer, which is to be rehabilitated (and adjacent to pit shaft No. 1), conveys industrial and domestic wastewater from the areas of Industrialnyi, Nemyshlyanskyi, sand Moskovskyi districts in Kharkiv. The pit shaft is connected with the sewer tunnel of industrial and domestic wastewater on Moskovskyi Prospekt (KhTZ) with a diameter of 1.840 mm (the main amount of wastewater coming from the basin of SPS No. 15) on the western side, and with the tunnel shaft with a diameter of 1,500 mm and shaft No. 4 of the the 3rd subsidiary sewer KhTZ with a diameter of 1,840 mm (the main amount of wastewater coming from the basin of SPS No. 21) on the eastern side [13, 49]. The difference between the elevations of the tunnel inverts is 1.07 m. The drop structure arranged in pit shaft No. 4 (of the the 3rd subsidiary sewer KhTZ) in the form of an ogee spillway. The energy is damped by counterflows. The hydraulic diagram of the tunnel sewer sections adjacent to pit shaft No.1 is shown in Fig. 6.35.

The estimated wastewater flow rate according to the data provided by Kharkivvodokanal Public Utility Company with regard to the pump operation at pumping station No. 15 during the hours of maximum wastewater disposal in the rainy season, and with regard to the development of the urban-type settlement of Kulinichi (according to the approved General Plan of the city of Kharkv and the Kharkiv Sewerage Development Scheme) makes 450 l / s. At the estimated fill rate of the tunnel shaft (after sliplining using SPIRO PE pipes with an inside diameter of D = 1.000 mm) the fill rate will be 0.45 m and velocity will be 1.35 m / s. The experience of operating tunnel sewers in Kharkiv has shown that there is wear and tear of inverts, deterioration of water intake devices and spillways in the shaft drop structures, leakage in the sewer vaults, deterioration of reinforced concrete jackets, corrosion of the

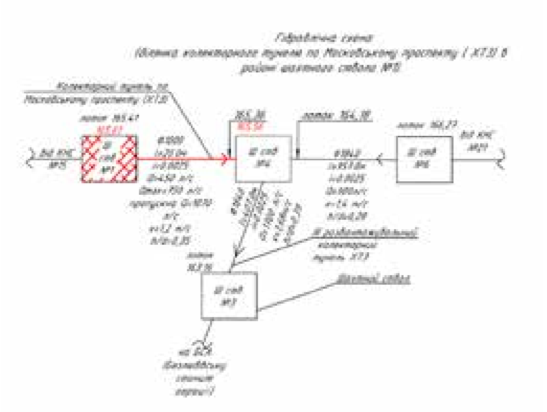


Figure 6.35. Hydraulic diagram showing the tunnel sewer sections adjacent to pit shaft No. 1

staircase, the impact of wastewater composition on the tunnel structure, the disruptive impact of gaas corrosion and so forth. At present, after prolonged exposure to gas and biological corrosion, the internal waterproofing and partially the concrete of the tunnel shaft lining and shaft No. 1 are in a state of decay. The rehabilitation measures include waterproofing the inner surfaces of the shaft and the tunnel shaft (sliplining using a SPIRO polyethylene pipe with a smaller diameter of D = 1.000 mm), reducing the initial inside diameter of the tunnel shaft (dia 1.500 mm), changing the laying depth of the invert (the absolute elevation is 164.43) and the ggradient (*i* = 0.0025). The capacity of the tunnel shaf at the standard fill rate of 0.8H will be 1,078 l /s [13]. This will ensure.

- Permissible non-silting velocities in the tunnel shaft (the velocity is over 1.2 m /s, but with regard to the approach velocity when flowing out of the spillway basin) will not exceed the permissible value of 3 m /s).
- Better values of resistance to gas corrosion, impacts of chemicals, low probability of the invert deposits.

The rehabilitation work for the tunnel shaft and the shaft includes.

- Cleaning the tunnel shaft (removing the backwater).
- Arranging the temporary partitions in the tunnel shafts for cutting off wastewater from the pit shaft and the tunnel section for the period of work.

- Arranging a pipe drop structure (riser, pipes: spheroidal graphite cast iron; H = 6.2 m; 2D = 400 mm; Q = 0.480 m^3/s; Qmax = 0.752 m^3/s) to receive sewage from SPS No. 15 and a few street sewer networks according to the design features of the existing pit shaft, the conditions of its operation in the future (acc. to DBN B.2.5, Para. 8.13.14).
- Arranging a stilling basin in the invert part of the shaft (with a steel sheet in the bottom and cast iron plates to protect the walls) to dampen the flow velocity (the minimum permissible velocity is 1.2 m /s; the maximum permissible velocity is 3 m/s according to DBN B.2.5-75, Para. 8.13.7; the parameters of the stilling basin were calculated according to the normative methods of hydraulics and scientific experience of operating tunnel sewers).
- Rehabilitating the reinforced concrete structures of the shaft using sulfate-resistant concrete with admixtures (in view of a two- to sevenfold excess of hydrogen sulfide concentrations in the pit shaft with further operation of the pipe drop structure).
- Waterproofing the shaft and the tunnel shaft to ensure protection against gas corrosion (using HDPE).
- Providing the shaft with a staircase and platforms with railings made of composite materials (by Ekipazh, Kharkiv) for the operating life of the shaft.
- Arranging a service platform with railings.
- Rehabilitating the tunnel shaft using SPIRO polyethylene pipe modules with threaded connection (L = 24.0 m; DN = 1.000 mm, SN 8) with the use of sliding supports, with concreting the annular space with sulfate-resistant concrete with admixtures.
- Carrying out beautification work (planning, fencing).

The rehabilitation work for the existing structures of the shaft includes as follows.

- Excavating a pit for carrying out work (Fig. 6.36).
- Dismantling the existing staircase and service platforms.
- Dismantling the existing floor slabs of the shaft (Fig. 6.36).
- Cleaning off the deteriorated concrete layers from the shaft walls and the balcony sink structures (Fig. 6.37, 6.38).
- Cleaning off corrosion products from the bare rebars and steel frames by sandblasting.
- Punching the service openings in the bacony plate to install a riser.

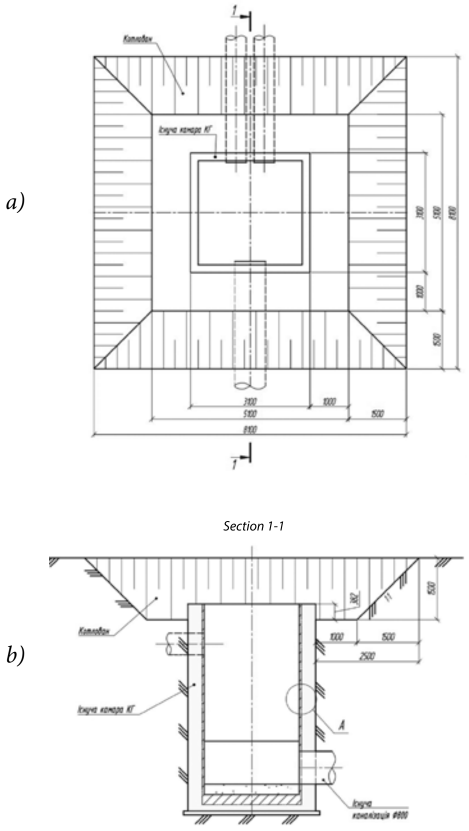


Figure 6.36. A schematic drawing showing the excavation to rehabilitate the chamber: (a) plan; (b) section 1-1

During the repair of the shaft structures the following work is to be carried out [13].

— Arranging the new reinforced concrete structures of the spillway basin with lining its inner walls with cast iron, and the bottom with steel sheets.
— Arranging the cast in situ reinforced concrete slab to secure the risers at the level of the spillway basin with waterproofing by polyethylene sheets.
— Arranging the strengthening reinforced concrete retainer for the shaft walls of sulfate-resistant concrete with waterproofing by polyethylene sheets.

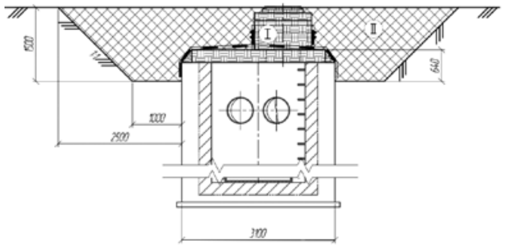


Figure 6.37. Dismantling the lining of the existing chamber

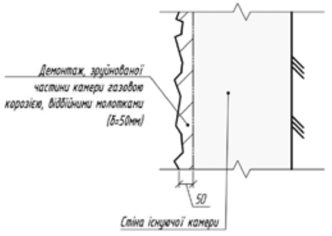


Figure 6.38. Cleaning off the deteriorated concrete layers from the shaft walls and the balcony sink structures

— Repairing the balcony structures using polymer-cement repair mixes with concreting up the balcony wall and arranging a service partition from cast in situ reinforced concrete; waterproofing the balcony surface by polyethylene and waterproofing mixes.
— Arranging the new staircase and service platform structures of fiberglass.
— Installing the tailor-made prefabricated reinforced concrete floor slabs pre-waterproofed with polyethylene sheets.

A staircase (provided by LLC Trading House Ekipazh, Kharkiv) is designed to provide descent and ascent in tank-type facilities during their repair and maintenance. The ЛВК-3О-5.0 vertical staircase with guardrails is made of composite materials [13]. The staircase is a device consisting of two cords and steps secured between them, which allow for the descent and ascent of the personnel, and an arched guardrail to reduce the falling hazard for people. The staircase and guardrails are made of fiberglass, which is chemically and corrosion resistant in aqueous solutions, and covered with enamel. The vertical staircase is permanently installed and secured to the wall and floor. To prevent slipping and overturning during operation, the staircase is equipped with metal stops for wall mounting and shoes for installation on hard floors. The supporting frame, handrailing and flooring are made of fiberglass profiles [13, 55, 59].

Prior to rehabilitation work, the project envisages the restoration of the geometry of the tunnel shaft using polymer-cement mixes and treating steel structures with corrosion-resistant materials (Figs. 6.39, 6.40). The reinforced concrete structures are lined with polyethylene sheets (Fig. 6.41). The tunnel shaft is provided to be rehabilitated using SPIRO polyethylene pipe modules modules with threaded connection (L = 24.0 m; DN = 1.000 mm, SN 8) with the use of sliding supports to ensure the required angles of inclination of the pipe and prevent it from being damaged. The annular space is filled up by injecting sulfate-resistant self-expanding grouting mortar.

Figure 6.39. Restoring the geometry of the tunnel shaft

Figure 6.40. Anti-corrosion treatment of steel structures

Figure 6.41. A pit shaft rehabilitated using PE sheets

During work, the efficient organizational and technological solutions for rehabilitating the sewer in the area of the the KhTZ plant in Kharkiv (Ukraine) were developed and implemented (Table 6.8) [13, 57, 59]. The works was performed using the open cut method by laying KORSIS polyethylene pipes of D = 1.000 mm. An efficient design for dampening the flow of wastewater in the sewer environment was proposed. During the reconstruction of the stilling chamber, a wall lining system using porcelain stoneware and grouting mortar was implemented, which is capable of counteracting biogenic corrosion.

The calculations were made and the main technical and economic indices of the project were obtained.

1. The estimated cost of construction is 4,824.314 thousand UAH, including the cost of construction and installation work (CIW) making 3,870.559 thousand UAH.
2. The duration of construction is 3.75 months, including preparatory period making 0.5 months.
3. The labor intensity of construction is 1,881.53 man-days.

Table 6.8 — Estimated cost of rehabilitation work for the sewer

Item No.	Description of costs	Estimated cost, thousand UAH		Cost distribution, thousand UAH	
		Total	CIW	Q1	Q2
1	Overhaul of the KhTZ sewer section, Inv. No. 13013	3829.767	3829.767	3000.000 3000.000	829,767 829,767
2	Customer service charges	103.404	—	80.000 —	23,404 —
3	Author's supervision	2.565	—	2.000 —	0,565 —
4	Expert examination of project documents	9.230	—	7.000 —	2,230 —
5	Estimated profit	40.792	40.792	30.000 30.000	10,792 10,792
6	Funds to cover the administrative costs incurred by construction and installation orgacontractors	18.514	—	14.000 —	4,514 —
7	VAT	820.042	—	620.000 —	200,042 —
Total:		4824,314	3870.559	3753.000 3030.000	1071.314 840.559

6.3. Developing a Model of the Section of the Sewerage Networks and Facilities on Grekivska Street and Near the KhTZ Plant

It was decided to use Autodesk Revit software for the BIM model of this section. The project documents developed in 1971 by UkrGiproKomunBud were obtained as initial data [248]. The project consisted of three A1 sheets showing as follows:

- Structural sections of shaft No.2 with detailed assembly components and specifications of structural elements;
- Structural sections of shaft No.8 with detailed assembly components and specifications of structural elements;
- Assembly drawing of the Main collection tunnel (shhft No. 2) with the existing main sewer with assembly components and specifications of the main structural elements.

The Autodesk Revit software allows for images and photos to be easily inserted as underlays and scaled using convenient scaling tools. A new project was created in the program; data and drawing scans were uploaded and scaled [244, 248].

Initially, it was decided to create an existing surface relief following the drawings. Given that these drawings were made in 1971, many objects may have changed significantly since that time. Therefore, the Google Maps satellite images of the terrain were additionally used. By comparing the images with the scans, a relief was created using the Toposurface tool. The Toposurface tool allows identifying the topographic surface by points or based on imported data. The toposurface should be created either in 3D or on the site plan. The relief measuring 500 m by 250 m was created from the territory of the Kharkiv Tool Plant to Grekivska street, alog with roads and green areas (Figs. 6.42, 6.43).

Panoramic images from Google Maps and images of the scene of the accident were used to model the buildings on Grekivska street and the area near the KhTZ plant. The main building of the Kharkiv Tool Plant, residential buildings, the main small architectural forms and fences and buildings and the area of the Shtants-Tekhnolohiya company were modeled in the LOD 200 level (Figs. 6.44, 6.45).

The main building of the KhTZ hospital, the buildings and the areas of the KhTZ plant were also modeled (Fig. 6.46) [248]. The LOD 200 level does not involve processing all architectural elements of the building facades, but is more than sufficient to consider the main overall dimensions and locations of a building [244, 248].

Figure 6.42. Creating the Toposurface showing Grekivska street

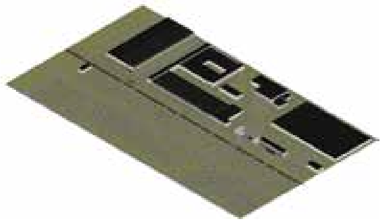


Figure 6.43. Creating the Toposurface showing the area of the KhTZ plant

Figure 6.44. Modeling the urban built-up area on Grekivska street

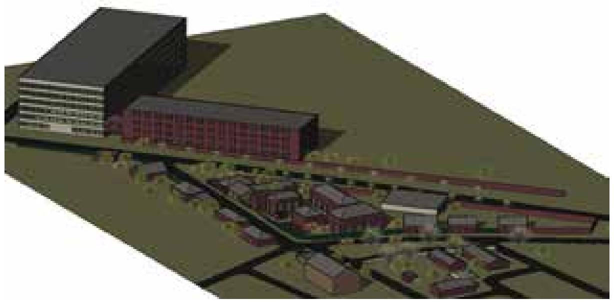


Figure 6.45. A general view of the urban built-up area on Grekivska street

Figure 6.46. Modeling the urban built-up area near the KhTZ plant

After developing the relief and the built-up environment, one can proceed directly to the development of the wastewater networks. Since the site is quite large and contains a variety of details, the model is likely to end up being very difficult to edit and view. In this case, a tool is provided that allows breaking the project into several parts and then assembling one model from several [248]. This can be achieved by creating "revit link" draft projects. Using links greatly simplifies the model and makes editing much easier. For example, in case the inspection manhole or shaft assembly is required to be moved, all the elements should be carefully selected and mistakes related to unwanted movement of adjacent elements should be avoided; moreover, the movement of the walls is complicated due to the fact that they are tied to the vertical levels. When a link is uploaded, all the elements are grouped and moved together.

In the Revit environment, all the objects that make up a model are referred to as families. Families can be system and uploaded. System families include elements such as walls, ceilings, pipes, stairs, arrays. Since modeling sewer systems requires elements such as wall rings, manhole covers, floor slabs, foundation blocks, uploaded families are required to be used. All uploaded families can be created on one's own in the family editor [244, 248].

In this project, the inspection manholes were modeled as a separate file and uploaded to the main project as a link. A number of families such as wall rings, floor slabs, manhole covers, foundation slabs, and metal ladders were created for inspection manholes (Fig. 6.47).

An important aspect of the BIM technology is the option of including information about the project objects. In the Revitsoftware, information is entered by filling in the parameters. Parameters can be both system, i.e. those that already exist in the project, and created by the user on their own, as exemplified by the family of wall rings, which included all the main parameters such as geometric dimensions, mass, brand, price, manufacturer's data. Families can be parameterized [248].

In this element, different types of wall rings were parameterized according to geometric dimensions (Fig. 6.48). The family of wall rings, for example, allows setting the information parameters such as diameter, height, wall thickness, amount of concrete and steel, mass and cost. According to the wall

Figure 6.47. Families designed to assemble inspection manholes

ring catalogs various types of rings (KC 7-3, KC 7-6, KC 10-3, etc.) may be created in one family. Next, when uploading the family to the project, the designer will be able to conveniently select the required ring based on the difference in height between the upper elevation marks of the manholes and the gradient of the sewer. Similarly to the wall rings, families of manhole floor slabs are created [248].

All parameters can also be displayed in the specification. Autodesk Revit has a quite powerful specification tool using which it is possible to conveniently sort and filter information about the model objects, and it is also possible to calculate the cost [248].

Specification

Type	Num.	Volume	Cost
KC 6-6	1	0.09 м^3	530.00
KC 8-8	1	0.18 м^3	650.00
KC 10-8	1	0.22 м^3	790.00
KC 10-9	1	0.24 м^3	870.00
KC 12-8	1	0.26 м^3	970.00
KC 12-9	1	0.29 м^3	1050.00
KC 15-9	1	0.45 м^3	1470.00
KC 20-9	1	0.59 м^3	1890.00

Figure 6.48. Standard sizes of the wall ring family and their specification

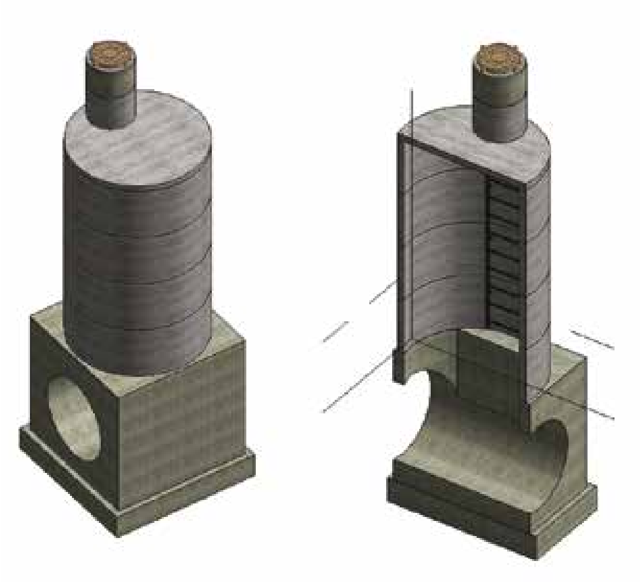


Figure 6.49. OK-1 inspection manholes

The manhole models were created and uploaded to the main project as follows.

- Key inspection manhole OK-1 with a laying depth at elevation + 95.11 m (Fig. 6.49).
- Linear inspection manhole OK-2 with a laying depth at elevation + 95.14 m (Fig. 6.50).

The models of shaft No. 8 and shaft No. 2 on Grekivska street Greek were created and uploaded to the main project (Fig. 6.51).

After uploading the files of the shafts and inspection manholes to the main project, they had to be connected by pipes. System families of different standard sizes were used as pipes. Only to create an arched tunnel on Grekivska street between the shafts an array tool had to be used according to the sketch (Fig. 6.52). It is in this tunnel where the collapse is located, which has also been modeled [248].

To conveniently view the model in axonometry, one can use tools such as the boundaries of the section in 3D view and the possibility of isolation of objects, which are of some interest [248]. Thus, if during construction, when there are questions that traditional two-dimensional drawings cannot answer,

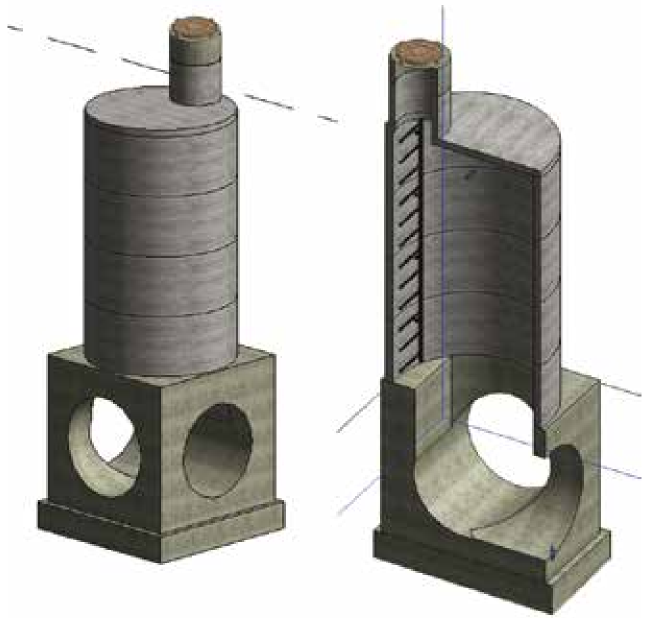


Figure 6.50. OK-2 inspection manholes

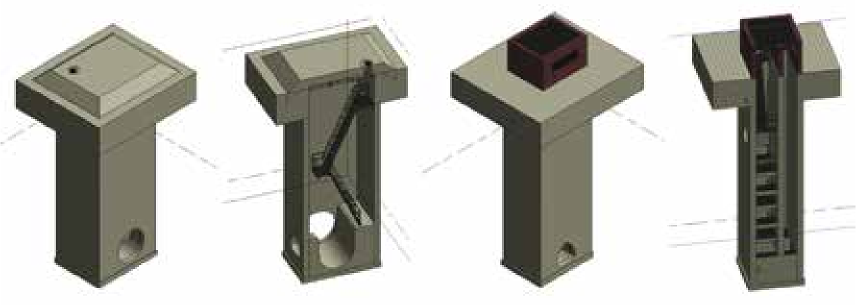


Figure 6.51. Models of shafts No. 8 and No. 2 on Grekivska street

it will be possible to find a solution in the three-dimensional model. As an example, the two-dimensional and three-dimensional models of the sewerage networks and facilities on Grekivska street and near the KhTZ plant are shown in Fig. 6.53 and Fig. 6.54 respectively.

After modeling the site, the next step is to design the views with extensive graphics visibility settings. The graphics visibility tools allow modifying the material of objects, the color of their fill and contours, transparency and thickness of lines (Fig. 6.55) [248].

An important point for the monitoring of the existing sewers is the option of implementing the parameter of the “condition of structure” variable [248]. For example, when using the model, the user can, based on the original data, set the degree of wear and tear of the structure in percentage terms. Further in the model space, based on this parameter, you can assign filters that will highlight in different colors and sort out structures depending on their condition (Figs. 6.56, 6.57).

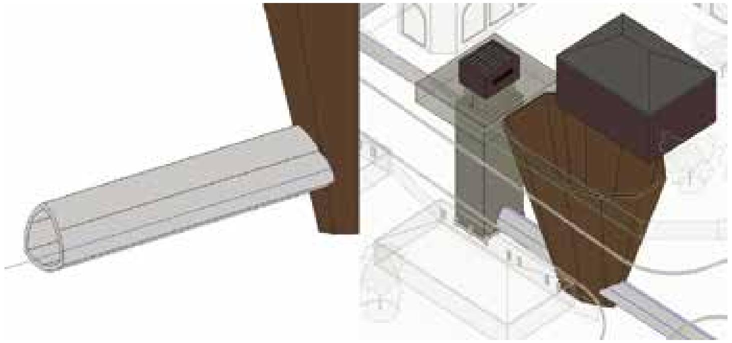


Figure 6.52. An arched tunnel and the location of the collapse

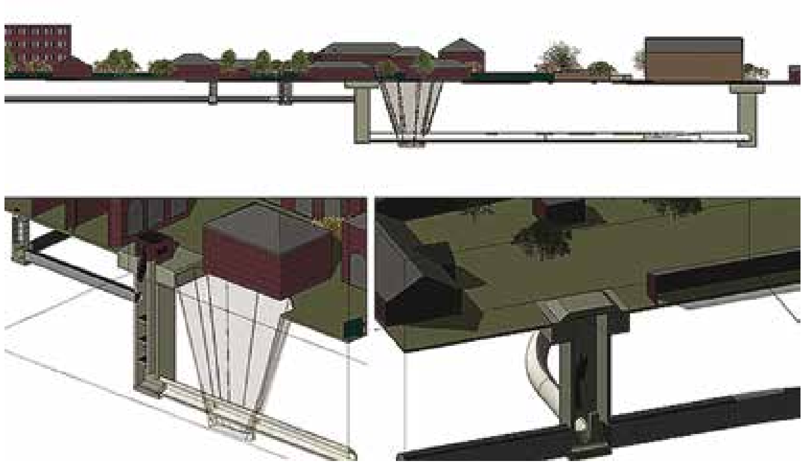


Figure 6.53. 3D sections of the modeled site on Grekivska street

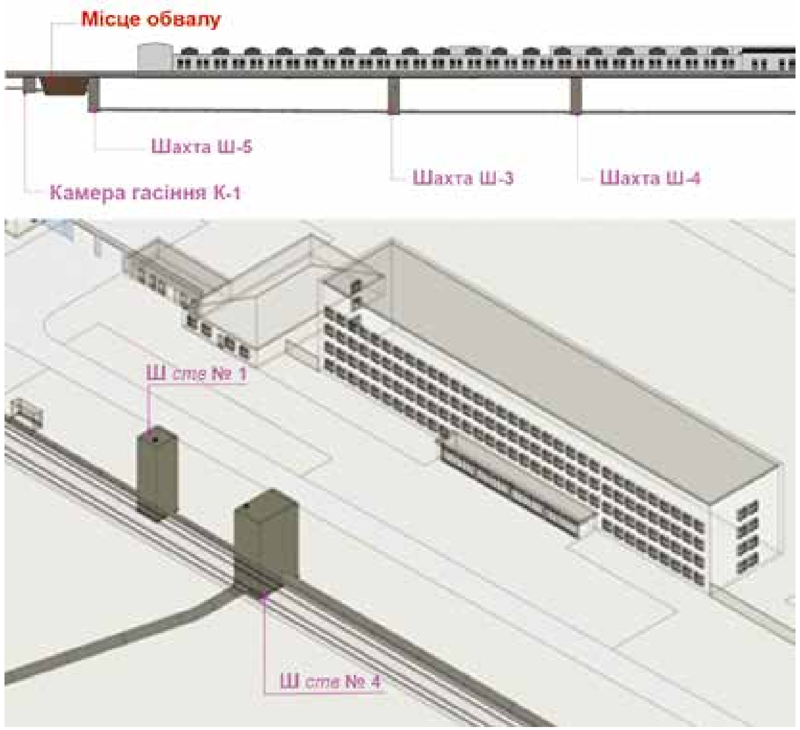


Figure 6.54. 3D sections of the modeled site near the KhTZ plant

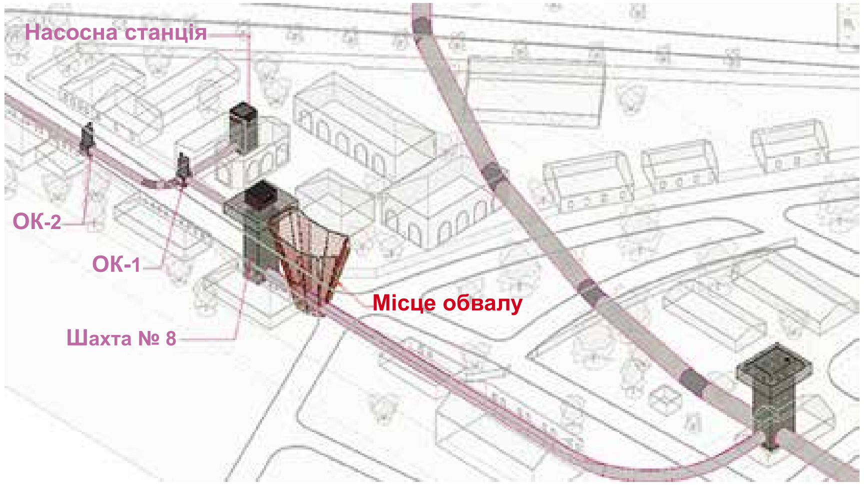


Figure 6.55. General axonometric view of the modeled site

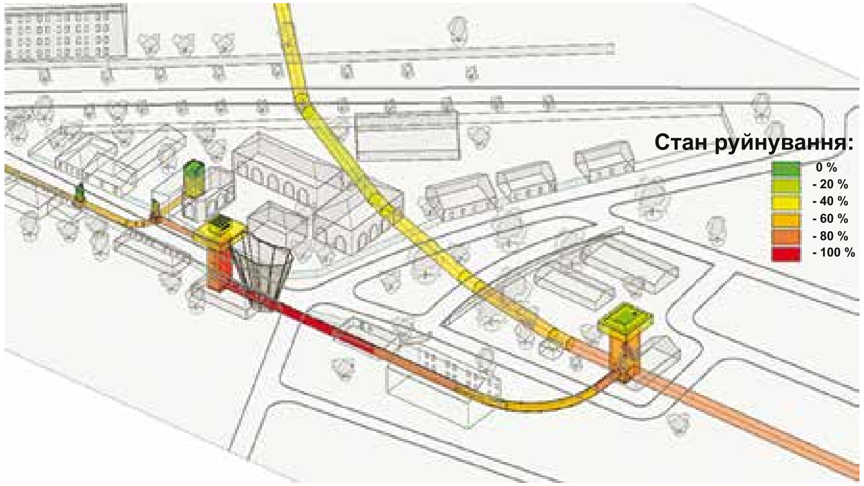


Figure 6.56. The condition of the structures of the modeled site on Grekivska street

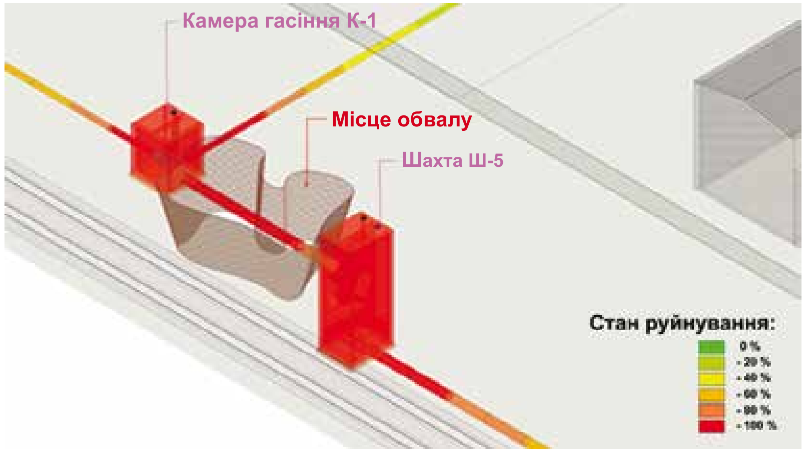


Figure 6.57. The condition of the structures of the modeled site near the KhTZ plant

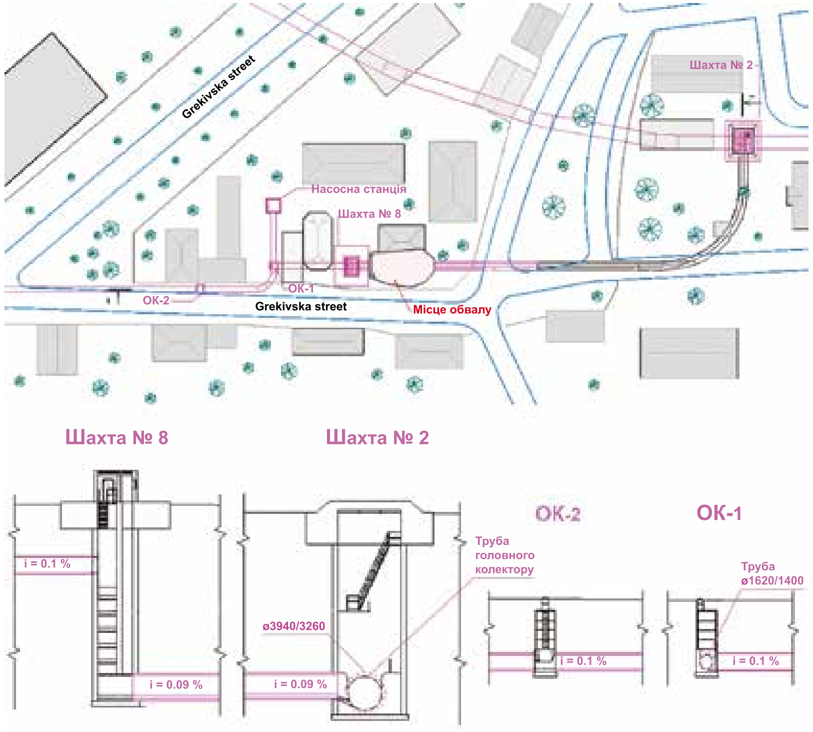


Figure 6.58. Elaborated drawings

Specification of structural elements OK-1

Element	Brand	Volume	Quantity	Cost
Драбина металева	Драбина	0.01 $м^3$	1	2100.00
Люк металевий	Люк	0.01 $м^3$	1	1450.00
Плита перекриття	ПП-200	0.35 $м^3$	1	1690.00
Стінове кільце	КС 6-6	0.09 $м^3$	1	530.00
Стінове кільце	КС 20-9	0.59 $м^3$	4	7560.00

Tray fragment OK-1

Name	Comments	Volume	Cost
Бетон М200	Tray fragment	9.00 $м^3$	8400.00

Figure 6.59. Specifications of the OK-1 elements

Using the graphics visibility settings and by creating new annotation families (such as height marks, marks, sizes), all the necessary drawings were made from the original data. If it is required to elaborate several types and drawings of the same type, it is not necessary to design each drawing separately, the program provides a function of creating templates [248]. The template stores all graphics visibility settings, scales and filters. In the future, the template can be assigned to all the same types of drawing. For this site, similarly to the drawings based on the original data, the drawings were prepared as follows: site plan, sections of shafts No. 2 and No. 8 (Fig. 6.58).

A significant advantage of using BIM models is the option of promptly obtaining specifications. For example, for the OK-1 inspection manhole, the specification of the number of structural elements and the amount of concrete for the invert part is obtained (Fig. 6.59) [248].

In the future, this BIM model of the wastewater disposal network can serve as a template and example for creating other models of all networks in Kharkiv.

6.4. Measures for Safety and Environmental Protection to Be Taken During Rehabilitation Work for the Sewerage Networks and Facilities

When performing construction and installation work and during operation, the main requirements of the documents should be complied with as follows [205–218].

- — Ukrainian national building code DBN B.1.2-7-2008 Basic requirements for buildings and structures. Fire Security.
- —Ukrainian national building code DBN B.2.5-74:2013 Water supply. External networks and structures.
- —Fire safety regulatory act NAPB Б.03.002-2007 Standards for determining the categories of premises, buildings and outdoor installations for explosion and fire hazard.
- —Ukrainian national building code DBN B.2.5-13-98* Engineering equipment of buildings and facilities. Fire automation of buildings and facilities.
- —Ukrainian national building code DBN B.1.1-7-2002 Fire safety of construction sites.
- —Rules for arrangement of electrical installations.
- —Fire safety regulatory act NAPB 01.001-2004 Fire safety regulations in Ukraine.
- —State regulations on occupational safety and health DNAOP 0.00-1.21-95 Rules for safe operation of consumers' electrical installations.

External and internal fire extinguishing is not required for a tunnel sewer [205-218].

When performing construction and installation work one should provide for continuous ventilation of the tunnel and the fire safety measures as follows.

- —The general contractor together with the customer and subcontractors develop and approve in the prescribed manner fire safety measures, occupational health and safety measures and include the main provisions in the project;
- —The areas for fire-resistant sites are provided to be placed with passages between them with a width of at least 5.0 m according to Para. 2 of the Fire safety regulations in Ukraine.
- —The places for smoking, arrangement of fire point stands with the

placement of appropriate signs is provided in the Work order project; the complete set of primary fire extinguishing means is to be accepted according to the appendix to the Fire safety regulations.

According to Paras. 2 and 3 of Annex 2 to the Resolution No. 1010 of the Cabinet of Ministers of Ukraine from December 13, 2017 (criteria for determining extensions and changes in activities and facilities that are not subject to environmental impact assessment) the facility of the sewerage networks and facilities on Grekivska street and on Moskovskyi Prospekt (KhTZ) is not subject to environmental impact assessment, as the reconstruction is planned with no redevelopment, with no changes in the external geometric dimensions, purpose and intended use of the facilities, and without increasing the generated and the generation of new hazardous wastes, with no increase and emergence of new emissions into the atmosphere air and discharge of pollutants into water bodies, with no noise, vibration, light, heat and radiation pollution, or radiation action [205–218].

To ensure the integrity of the structures and safety of wastewater disposal, the reconstruction of the section (tunnel shaft 20 m long) of the KhTZ tunnel sewer (on Moskovskyi Prospekt) and shaft No.1 adjacent to the above sewer [205–218].

According to the Law of Ukraine "On Planning and Building Development" and the provisions on public participation in decision-making in the field of environmental protection, the position of the interested public was taken into consideration when developing rehabilitation measures. The population was warned about the planned rehabilitation activities. Similar measures were taken on Grekivska street.

The sewerage networks and facilities near the KhTZ plant is located in the area of roads with heavy traffic and urban ground electric vehicles transport (the tram transportation system within the industrial area of the city).

Further, measures will be considered to rehabilitate the sewerage networks and facilities near the KhTZ plant and on Grekivska street according to the similar pattern. The area of the sites to be rehabilitated within the protected zone is 0.03 ha. According to DBN B.2.5-75:2013, the protected zone of the collection tunnel section to be rehabilitated is 10 m in each direction from its side wall [205–218].

The rehabilitation measures provide for a slight reduction in the diameter of the networks, which will ensure.

—Reserve capacity.
—Non-silting velocities.

— Carrying out rehabilitation work for the sewer and the tunnel in the future.
—Retaining the conditions of adjacency to the pit shaft.

On completion of rehabilitation work, the sewerage networks and facilities will not affect the environment, except for the allowable limits of emissions of substances into the air when operating the stilling chambers and inspection chambers. Adverse effects on soils, groundwater and vegetation can occur in non-compliance with technological regulations and the occurrence of an emergency situation [205–218].

Rehabilitating the utility networks and facilities will have a positive effect on the social and man-made environment, as the wastewater disposal system in the city districts of Kharkiv is optimized.

Rehabilitation construction work will be accompanied by environmental impacts including a number of components.

During rehabilitation work there is an impact on the air environment: emissions into the air of combustion products from the engines of earthmoving machinery and cargo trucks, emissions from processing equipment.

Emergency situations during construction can occur in the event of a natural disaster or fire. The developed recommendations provide measures to prevent ignition, fires and other emergencies.

Measures to rehabilitate the sewerage networks and facilities include a set of technological, design, and construction solutions aimed at minimizing the risk of man-made emergencies. In compliance with technological regulations, negative residual phenomena in the natural environment are not to be expected [205–218].

The whole work package for the sewerage networks and facilities should be carried out with the safe work permits according to the process work flowcharts and the work order project (WOP).

With the onset of darkness, in case of carrying out work during the hours of darkness, the work areas should be lit. The work site is to be fenced. It is forbidden to park vehicles for unloading closer than 10 m from the edge of the slope.

Before starting work, drivers must make sure that there are no people or machines in the work area. Before starting the movement after the next stop, the driver must give a warning signal.

When dumping the soil with a bulldozer, it is forbidden to move the blade outside the edge of the slope, and the distance from the edge of the caterpillar to the edge of the embankment should be at least 1.5 m. Fire safety measures should be developed and implemented at the construction site [205–218].

A responsible person is appointed to perform daily work on the supervision of primary fire extinguishing means and the organization of fire extinguishing.

It is prohibited to smoke and light fire at the construction site. Smoking is allowed only in specially designated areas equipped with fire extinguishers. Control over compliance with the technology of work at the construction site is carried out by the foreperson. It is forbidden to start work without overalls, footwear and personal protective equipment. Before performing work in sewer shafts, they must be ventilated; ventilation should be carried out for the entire stay of workers in the shaft and tunnel [205–218].

It is forbidden to touch moving and current-carrying parts of machinery, electric wires. Work is allowed to be carried out by the personnel who have passed a medical examination, training, instruction and assessment of knowledge on occupational health.

The emergency response plan should include organizational measures aimed at rescuing people, eliminating the emergency situation and preventing its development. The plan should take into consideration the cases of emergencies. Owing to the design and technical solutions taken, their strict observance, along with the observance of operational regulations, carrying out all necessary production operations during the construction and operation of the facility, the probability of occurrence and scope of emergency situations at the sewer site are assessed as minimum.

Conclusions to Chapter 6:

1. A new method of cleaning sewers from various degrees of blockage was developed. Factors influencing the efficiency of work using the expert evaluation method were investigated; the most important of which are as follows: the degree of blockage (the percentage of blockage of the sewer's capacity); the nature of blockage (sludge, construction debris and so forth); the profile of the section to be rehabilitated (existing angles of curvature, length, etc.). The proposed method has advantages over analogues in terms of technical and economic performance;
2. Organizational and technological recommendations for the repair of the sewer tunnel by pushing and introducing secondary treatment from reinforced concrete rings lined with ribbed polyethylene have been developed. When comparing recovery options by different methods, it should be noted that the proposed technology using reinforced concrete rings lined with ribbed polyethylene is more cost-effective than the relining method using polyethylene or fiberglass pipes due to their high cost. The duration of the proposed method of pushing with the introduction of secondary treatment of reinforced concrete rings with anti-corrosion properties will be reduced by 30% compared to other methods.
3. Organizational and technological recommendations for the rehabilitation of the sewerage networks and facilities near the KhTZ plant were developed, particularly the technology of rehabilitation for stilling chambers using granite slabs and polymer lining were presented. The economic effect of the implementation is more than 30 % compared to analogues, and the service life of the stilling chamber structures will be more than 30 years;
4. The issue of the electronic database of the sewerage networks and facilities of the city of Kharkiv was studied; as an example, the models of the sections of the networks on Grekivska street and near the KhTZ plant were developed.

CHAPTER 7

THE SYSTEM OF ORGANIZATIONAL AND TECHNOLOGICAL MONITORING OF THE STABLE OPERATION OF THE SEWERAGE NETWORKS AND FACILITIES

7.1. Justifying the Use of Fuzzy Logic of the stable operation of the Sewerage Networks and Facilities

Based on the organizational and economic foundations for the development of indicative assessments of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities described in Paragraph 4.2, it is necessary to determine the indices of stability for each group of indices (Tables 4.5 to 4.12) of the stability of the sewerage networks and facilities. It should be noted that to date, there is no single methodology for determining a summarizing index of the stability of the sewerage networks and facilities. At present, there are a number of methods for determining the stability of operation; however, they have their own specifics for determining and selecting appropriate indices that require specific skills in such areas of knowledge as the operation of wastewater disposal structures, modern information technologies, mathematical modeling, graph theory and so on.

Therefore, it is relevant to create a software toolkit, an expert system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities, where the user can set the input parameters in a verbally understandable natural language, without resorting to complex mathematical and computer tools. The implementation of the proposed system is possible using the apparatus of fuzzy logic, which is quite effective in solving technical problems, where there is a large amount of input data. The use of this approach is described in solving the problems of choosing methods for restoring water supply and wastewater disposal pipelines, determining the categorization of network sections [20, 27, 173–181, 309, 310], and a reasonable choice of the composition of the compound based on the qualitative characteristics of the objects in operation.

In order to determine the stability of the operation for sewerage networks and facilities, a model for determining a summarizing stability index based on seven groups of indices described in Paragraph 4.2 [11].

To determine the summarizing stability index for the sewerage networks and facilities, its fluctuations should be considered as one of the optimization criteria.

When solving the problem of determining the stability of the operation for sewerage networks and facilities, the input data cannot be compared quantitatively, and they are often determined by qualitative characteristics such as “many”, “considerably” and so on. Input data also depend on the experts’ subjective assessments and include uncertainty and ambiguity, which are important to consider in the decision-making process. It is now recognized that the fuzzy set theory is useful in solving problems when the data are presented in the form of linguistic expressions (verbally) and depend on the experts’ subjective assessments [11].

Considering the summarizing operation stability index, it can be determined through the example of using a fuzzy set [108, 146, 147, 172, 174, 178, 183, 194, 200–202]. In terms of sewerage networks, stability depends on the seven identified groups of indicative indices (input data). The multifactor input data classifier converts their multidimensional space into a particular set of categories. In addition, since there is no clearly established way to determine the stability of the operation for sewerage networks and facilities, the knowledge that experienced engineers can provide should be effectively used.

A fuzzy set is a set of ordered pairs or tuples $A = \{ < x \mid \mu A(x) > \}$, where x is an element of a universal set or universe X, and $\mu A(x)$ is a membership function, which associates each $x \in X$ with a real number from the closed interval [0, 1], i. e. this function is defined as below:

$$\mu_A(x): \quad X \to [0,1] .$$

A fuzzy variable is defined as a tuple:

$<\alpha, X, A>$, where α is the name of the fuzzy variable;
X — is the domain of its definition (universe);
$A = \{ < x \mid \mu A(x) > \}$ — is a fuzzy set on X, which describes the possible values that can be taken by the fuzzy variable α [174, 178, 183, 194, 200–202].

A linguistic variable is defined as a tuple: $<\beta, T, X, G, M>$, where

β —is the name of the linguistic variable;
T — is the basic term set of a linguistic variable or the set of its val-

ues (terms), each of which represents the name of a separate fuzzy variable α;
X — is the domain (universe) of fuzzy variables that are included in the definition of the linguistic variable β;
G — is a syntactic procedure that describes the process of forming new values meaningful in the context under consideration from the set *T* for a given linguistic variable (for example, using logical connections "and", "or" and modifiers such as "very", "slightly", etc.);
M — is a semantic procedure that allows associating each new value of a given linguistic variable obtained by the procedure *G*, with some meaningful content by forming a corresponding fuzzy set [108, 146, 147, 172].

An elementary fuzzy statement is, in the general case, a narrative sentence that expresses a complete opinion, which can be judged on its truth or falsehood only with some degree of certainty [146].

Fuzzy linguistic statements are referred to as statements of the following types:

1. Statement "β is α", where β is the name of a linguistic variable, α is its value from *T*.
2. Statement "β is ∇ α", where ∇ is the modifier corresponding to the words such as "very", "more or less", "much more" and others that can be obtained using the procedures *M* and *G* of this linguistic variable.
3. Components of the statements, which are derived from statements of types 1 and 2 and fuzzy logical operations in the form of connections "and", "or", "if — then" [172, 200].

To assess the degree of truth of an arbitrary fuzzy statement, we introduce the mapping $T : U \to [0, 1]$, a mapping of the truth of fuzzy statements, where *U* — is the set of fuzzy statements [172, 200].

The main logical operations with fuzzy statements are presented as follows.

Logical negation [172]. The negation of the logical statement A is a unary logical operation, the result of which is a fuzzy statement, the truth of which by definition takes on the value:

$$T(A) = 1 - T(A). \tag{7.1}$$

Logical conjunction [200]. The conjunction of the fuzzy statements *A* and *B* is referred to as a binary logical operation, the result of which is a fuzzy statement, the truth of which is determined by the equation:

$$T(A \wedge B) = min\{T(A), T(B)\} \text{ — } min\text{-conjunction.} \tag{7.2}$$

The following alternative equations can be used to determine the degree of truth of the conjunction of the fuzzy statements:

algebraic product: $T(A \wedge B) = T(A) \times T(B)$,
limit product: $T(A \wedge B) = max\{T(A) + T(B) - 1, 0\}$,

drastic product: $T(A \wedge B) = \begin{cases} T(B), & якщо\ T(A) = 1 \\ T(A), & якщо\ T(B) = 1 \\ 0, & в\ інших\ випадках. \end{cases}$

Logical disjunction [108, 146, 147, 172, 174, 178, 183, 194, 200–202]. The disjunction of the fuzzy statements *A* and *B* — is a binary logical operation, the result of which is a fuzzy statement, the truth of which by definition takes on the value:

$$T(A \vee B) = max\{T(A), T(B)\} \text{ — } max\text{-disjunction.} \tag{7.3}$$

The following alternative equations can be used to determine the degree of truth of the disjunction of the fuzzy statements:

algebraic sum: $T(A \vee B) = T(A) + T(B) - T(A) \times T(B)$,
limit sum: $T(A \vee B) = min\{T(A) + T(B), 1\}$,

drastic sum: $T(A \vee B) = \begin{cases} T(B), & якщо\ T(A) = 0 \\ T(A), & якщо\ T(B) = 0 \\ 1, & в\ інших\ випадках. \end{cases}$

The rule of the fuzzy product or simply fuzzy product is understood the expression of the form (*i*):

Q; P; A $\Rightarrow$ *B; S; F; N*, where (i) is the name of the fuzzy product,
Q — is the scope of the fuzzy product (description of the subject area of knowledge);
P — is the condition of applicability of the fuzzy product kernel (logical expression, the truth of which allows activating the kernel),
A $\Rightarrow$ B — is the kernel of the fuzzy product;
A — is the condition of the kernel, and B is the conclusion, which is fuzzy linguistic statements, $\Rightarrow$ is a sign of the logical sequence;

S — is the method of quantifying the degree of truth of the conclusion (activation method);
F — is the coefficient of certainty or confidence of the fuzzy product;
N — is the postconditions of the product, which describes the actions that are performed in the case of implementing the kernel of the product [200].

The simplest version of the rule of the fuzzy product can be written in the form:

RULE <No.>: IF “β_1 is α”’, “β_2 is α”.

7.2. Fuzzy Set Theory as the Basis of Fuzzy Logic

The main definitions given in Paragraph 7.1 are implemented to solve multi-criteria problems, which include determining the stability of the operation for sewerage networks and facilities. The data provided for its definition does not have a clear unit of measurement and is usually given in the form of fuzzy rules. The main stages of the fuzzy inference are presented in the sequence as follows: beginning; formation of a rule base; fuzzification of input variables; aggregation of subtexts in the fuzzy rules of the product; activation of subconclusions in the fuzzy rules of the product; defuzzification; end.

1. The formation of a rule base for the fuzzy inference systems is a presentation of empirical knowledge or expert knowledge in the form of a finite set of rules of the fuzzy products. In this case, each of the fuzzy statements should define the membership functions of the values of the term set for each linguistic variable [200–202].

2. The fuzzification is a procedure of finding the values of the membership function of fuzzy sets (terms) on the basis of ordinary (not fuzzy) input data [200–202].

Prior to fuzzification, it is assumed that the specific values of all input variables of the fuzzy inference system are known, i. e. the set of values is $V = \{a1, a2, \ldots, am\}$, where each $a_i \in X_i$ (X_i — is the universe of the linguistic variable β_i). These values can be obtained, for example, through visual inspections or telediagnostics of the health of the sewer network. Next, each of the subconditions of the form “β_1 is α'” of the rules of the fuzzy inference system is considered, where α' is a term with the known membership function $\mu'(x)$. The result of the fuzzification of the subcondition of the form “β_1 is α'” is the value of $b_i' = \mu'(a_i)$. The phase of fuzzification is considered to be completed when all values of b_i' for each of the subconditions of all the rules included in the given rule base of the fuzzy inference system will be found. This set of values is denoted as $B = \{b_i'\}$.

3. The aggregation is a procedure of determining the degree of truth of the conditions according to each of the rules of the fuzzy inference system [166, 169].

Prior to this stage, the values of the truth of all the subconditions of the fuzzy inference system are provided to be known, i. e. the set is $B = \{b_i'\}$. Next, each of the conditions of the rules of the fuzzy inference system is considered. If the condition is a fuzzy statement of the form 1 or 2, then the degree of its truth is equal to the corresponding value of b_i'. If the condition consists of several subconditions, and the linguistic variables in the subconditions are not equal in pairs, then the degree of truth of a complex statement is determined on the basis of the known values of the truth of the subcondition. Hence, the quantitative values of the truth of all the onditions of the rules of the fuzzy inference system are found [201].

The aggregation stage is completed when all the quantitative values b_k''' for each rule Rk being part of the fuzzy inference system are found. This set is denoted as $B'' = \{b_1'', b_2'', \ldots, b_n''\}$.

4. The activation is a procedure of finding the degree of truth for each of the subconclusions of the rules of the fuzzy product [202].

Prior to this stage, the values of the truth of all the conditions of the fuzzy inference system are provided to be known, i. e. the set is $B'' = \{b_1'', b_2'', \ldots, b_n''\}$ and the values of the weighting factors F_i for each rule. Next, each of the conclusions of the rules of the fuzzy inference system is considered. If the conclusion is a fuzzy statement of the form 1 or 2, then the degree of its truth is equal to the algebraic product of the corresponding value b_i'' by the weighting factor F_i. If the conclusion consists of several subconclusions, and the linguistic variables in the subconclusions are not equal in pairs, then the degree of truth of a complex subconclusion is equal to the algebraic product of the corresponding value b_i'' by the weighting factor F_i. Thus, all the values of ck of the degrees of truth of the subconclusions for each of the rules R_k, included in the rule base of the fuzzy inference system, are found. This set of values is denoted as $C = \{c_1, c_2, \ldots, c_q\}$, where q — is the total number of subconclusions in the rule base [200–202].

Next, the membership functions of each of the subconclusions for the considered output linguistic variables are determined. For this purpose, one of the methods that are a modification of a fuzzy composition method may be used:

min-activation: $\mu'(y) = min\ \{c_i, \mu\ (y)\}$;
prod-activation: $\mu'(y) = ci \times \mu\ (y)$;
average-activation: $\mu'(y) = 0,5 \times (c_i + \mu\ (y))$, (7.4)

where:
$\mu\ (y)$ — is the membership function of the term, which is the value of a variable ω_j given on the universe Y [200].

The activation stage is considered to be completed when for each of the input linguistic variables included in the separate subconclusions of the rules of the fuzzy products the membership functions of the fuzzy sets are determined from the values, i. e. the set of the fuzzy sets: $C_1, C_2, \ldots, C_q$.

5. The accumulation is a procedure of finding the membership function for each of the output linguistic variables [200–202].

Prior to this stage, the values of the truth of all the subconclusions for each of the rules R_k included in the rule base of the fuzzy inference system are provided to be known, in the form of a set of the fuzzy sets: $C_1, C_2, \ldots, C_q$, where q — is the total number of the subconclusions in the rule base. Next, each of the output linguistic variables $\omega_j \in W$ and the related fuzzy sets $C_{j1}, C_{j2}, \ldots, C_{jq}$ are sequentially considered. The accumulation result for the output linguistic variable ω_j is defined as the union of the fuzzy sets $C_{j1}, C_{j2}, \ldots, C_{jq}$ according to one of the following equations:

$$\mu_D(x) = max\{\mu_A(x), \mu_B(x)\},\ \forall x \in X;$$

$$\mu_D(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x),\ \forall x \in X;$$

$$\mu_D(x) = min\{\mu_A(x) + \mu_B(x), 1\},\ \forall x \in X;$$

$$\mu_D(x) = \begin{cases} \mu_A(x), & \text{якщо } \mu_B(x) = 0, \\ \mu_B(x) & \text{якщо } \mu_A(x) = 0,\ \forall x \in X; \\ 1, & \text{в інших випадках.} \end{cases}$$

$$\mu_D(x) = \lambda \cdot \mu_A(x) + (1 - \lambda) \cdot \mu_B(x),\quad \lambda \in [0, 1],\ \forall x \in X. \qquad (7.5)$$

The accumulation stage is considered to be completed when for each of the output linguistic variables the final membership functions are defined, i.e. the set of the fuzzy sets C1', C2', …, Cs', where s is the total number of the output linguistic variables in the rule base of the fuzzy inference system.

6. The defuzzification is a procedure of finding the ordinary (not fuzzy) value for each of the output linguistic variables [200–202].

Prior to the beginning of this stage, the membership functions of all the output linguistic variables in the form of the fuzzy sets $C_1', C_2', \ldots, C_s'$ are provided to be known. Next, each of the output linguistic variables $\omega_j \in W$ and the related fuzzy set C_j' are sequentially considered. The result of the defuzzification for the output linguistic variable ω_j is determined in the form of the quantitative value of $y_j \in$ R obtained according to one of the equations below [123]. The defuzzification stage is considered to be completed when for each of the output linguistic variables the final quantitative values are determined in the form of a real number, i. e. in the form of $y_1, y_2, \ldots, y_s$, where s — is the total number of the output linguistic variables in the rule base of the fuzzy inference system.

To determine the quantitative values of the output linguistic variables, one can use one of the following methods [7]:

1) The center of gravity method or the centroid of the area is calculated according to the formula:

$$y = \frac{\int_{min}^{max} x \times \mu(x)dx}{\int_{min}^{max} \mu(x)dx} \qquad \mathbf{(7.6)}$$

where:
y — is the result of defuzzification;
x — is a variable corresponding to the output linguistic variable ω;
$\mu(x)$ — is the membership function of the fuzzy set, which corre sponds to the output variable ω after the accumulation stage;
min and *max* are the left and right points of the interval of the carrier of the fuzzy set of the considered output variable ω.

2) The center of gravity method for one-point sets:

$$y = \frac{\sum_{i=1}^{n} x_i \times \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \qquad \mathbf{(7.7)}$$

where:
n — is the number of one-point (one-element) fuzzy sets, each of which characterizes a single value of the output linguistic variable under consideration.

3) The center of area method. The center of the area is equal to $y = u$, where the value of u is determined by the equation:

$$\int_{min}^{u} \mu(x)\, dx = \int_{u}^{max} \mu(x)\, dx \tag{7.8}$$

Thus, the proposed approach allows obtaining a quantitative assessment of the characteristics of the object, if the source data is fuzzily defined.

7.3. Calculating the Indicative Estimates for the System of Organizational and Technological Monitoring of the stable operation of the Sewerage Networks and Facilities on the Example of the City of Kharkiv

With reference to the system of indices given in Chapter 4, calculations were performed for three zones, the sewerage networks and facilities near the KhTZ plant (SNF1), on Grekivska stret (SNF2), and near Bezlyudivski treatment plants (SNF3). To compare the obtained values, the indices of the sewerage networks and facilities in Kharkiv (SNFK) were calculated. Calculations were made on the basis of information and summary data, statistical analysis and experience of operation of these facilities during 2019–2020 [11]. The sequence numbers in the first columns in Tables 7.1 to 7.7 correspond to the numbers in Tables 4.5 to 4.11.

Table 7.1 — Availability of the sewerage networks and facilities to the city

Item No.	**Parameter**	**Index value by facility**			
		SNF1	SNF2	SNF3	SNFK
1.1	Level of availability of sewer networks to the city (km/km^2)	2.752522	3.229842	0	3.996234
1.2	Level of availability of sewers to the city (km/km^2)	2.43142	2.48134	2.039933	5.78377
1.3	Level of availability of sewer tunnels to the city (km/km^2)	0.099558	1.87308	1.246256	1.95486
1.4	Level of availability of sewer shafts to the city (units/km^2)	1.039823	0.68555	0.159734	1.542857
1.5	Level of availability of stilling chambers to the city (units/km^2)	0.553097	1.05051	1.665557	3.85714

Table 7.2 — Indices of funding from various sources

Item No.	Parameter	**Index value by facility, %**			
		SNF1	**SNF2**	**SNF3**	**SNFK**
2.1	Share of funding from the municipal budget	75 %	20 %	80 %	20 %
2.2	Share of funding from the budget of the operating company	25 %	2 %	20 %	7 %
2.3	Share of funding from the European Bank for Reconstruction and Development	0 %	75 %	0 %	65 %
2.4	Share of funding from the partial contribution of construction companies	0 %	0 %	0 %	8 %

Table 7.3 — Indices of the effectiveness of rehabilitation work for the sewerage networks and facilities

Item No.	**Parameter**	**Index value by facility, %**			
		SNF1	**SNF2**	**SNF3**	**SNFK**
3.1	Index of the effectiveness of rehabilitation work for sewer networks	61 %	0 %	58 %	65 %
3.2	Index of the effectiveness of rehabilitation work for sewers	8 %	11%	36 %	12 %
3.3	Index of the effectiveness of rehabilitation work for sewer tunnels	0 %	0 %	0 %	0 %
3.4	Index of the effectiveness of rehabilitation work for sewer shafts	15 %	19 %	18 %	25 %
3.5	Index of the effectiveness of rehabilitation work for stilling chambers	5 %	1 %	25 %	25 %

Table 7.4 — Indices of the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities

Item No.	**Parameter**	**Index value by facility, %**			
		SNF1	**SNF2**	**SNF3**	**SNFK**
4.1	Index of the effectiveness of eliminating accident-caused damage to sewer networks	89 %	92 %	88 %	90 %
4.2	Index of the effectiveness of eliminating accident-caused damage to sewers	85 %	82 %	79 %	85 %
4.3	Index of the effectiveness of eliminating accident-caused damage to sewer tunnels	82 %	81 %	77 %	82 %
4.4	Index of the effectiveness of eliminating accident-caused damage to sewer shafts	67 %	68 %	74 %	79 %
4.5	Index of the effectiveness of eliminating accident-caused damage to stilling chambers	62 %	59 %	68 %	68 %

Table 7.5 — Indices of the environmental safety of operating the sewerage networks and facilities

Item No.	Parameter	Index value by facility, %			
		SNF1	SNF2	SNF3	SNFK
5.1	Index of the environmental safety of operating sewer networks	31 %	28 %	33 %	48 %
5.2	Index of the environmental safety of operating sewers	41 %	25 %	39 %	52 %
5.3	Index of the environmental safety of operating sewer tunnels	34 %	19 %	28 %	36 %
5.4	Index of the environmental safety of operating sewer shafts	34 %	18 %	19 %	37 %
5.5	Index of the environmental safety of operating stilling chambers	27 %	18 %	25 %	32 %

Table 7.6 — Indices of the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities

Item No.	Parameter	Index value by facility, %			
		SNF1	SNF2	SNF3	SNFK
6.1	Coefficient of efficiency for application of funds allocated for the stable operation of sewer networks	78 %	82 %	89 %	74 %
6.2	Coefficient of efficiency for application of funds allocated for the stable operation of sewers	73 %	72 %	65 %	65 %
6.3	Coefficient of efficiency for application of funds allocated for the stable operation of sewer tunnels	88 %	89 %	90 %	84 %
6.4	Coefficient of efficiency for application of funds allocated for the stable operation of sewer shafts	69 %	70 %	71 %	77 %
6.5	Coefficient of efficiency for application of funds allocated for the stable operation of stilling chambers	65 %	63 %	70 %	74 %

According to the results of the calculations, it is extremely difficult to draw an unambiguous conclusion regarding the stability of the studied sewer systems, because the indices have different units of measurement; moreover, the number of these indices is significant. Thus, it is relevant to develop an automated system that would simplify the process of determining the stability of the sewerage networks and facilities [11, 174].

Table 7.7 — Indices of the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities

Item No.	Parameter	Index value by facility, %			
		SNF1	SNF2	SNF3	SNFK
7.1	Index of the efficiency of implementing the system	27 %	8 %	28 %	27 %
7.2	Index of the innovative implementation of the system	36 %	4 %	2 %	6 %
7.3	Index of the utilization of domestic technology	27 %	17 %	27 %	26 %

7.4. Developing Methodological and Software Tools for the System of Organizational and Technological Monitoring of the stable operation of the Sewerage Networks and Facilities

The computer model of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities comprises seven subsystems, the description of which is given in Table 7.8.

The fuzzy inference system is implemented using the Fuzzy Logic Toolbox trial version of the MATLAB system, which contains a set of GUI modules that provide the structural identification stage in the interactive mode [11].

The general view of the window of the FIS-editor of the MATLAB system of the subsystem of stability for the availability of the sewerage networks and facilities to the city is shown in Fig. 7.1. The descriptions of one of the input variables and the output variable are given in Fig. 7.2.

The input and output variables are connected out using the knowledge base (Fig. 7.3). It contains more than 120 rules that take into account all combinations of input variables and the impact of these combinations on the stability for the availability of the sewerage networks and facilities to the city. All subsystems, the description of which is presented in Table 7.8, were designed according to the similar principle. The developed subsystems were tested to determine the stability by various indices for the sewerage networks and facilities near the KhTZ plant (SNF1), on Grekivska stret (SNF2), and near Bezlyudivski treatment plants (SNF3), and for the sewerage networks and facilities in Kharkiv (SNFK) (Table 7.9) [11].

The result of the subsystem operation is output in graphic form (Fig. 7.4).

Table 7.8 — Variables, term sets, and terms of the computer model of the system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities

Variable	Term set (indices, unit of meas.)	Terms	Definition
1	2	3	4
Subsystem of stability for the availability of the sewerage networks and facilities to the city			
Input variables			
1.1	Level of availability of sewer networks to the city (km/km^2)	[0;2] [2;3] [3;10]	Unsatisfactory Satisfactory Sufficient
1.2	Level of availability of sewers to the city (km/km^2)	[0;2] [2;3] [3;10]	Unsatisfactory Satisfactory Sufficient
1.3	Level of availability of sewer tunnels to the city (km/km^2)	[0;2] [2;3] [3;10]	Unsatisfactory Satisfactory Sufficient
1.4	Level of availability of sewer shafts to the city (units/km^2)	[0;2] [2;3] [3;10]	Unsatisfactory Satisfactory Sufficient
1.5	Level of availability of stilling chambers to the city (units/km^2)	[0;2] [2;3] [3;10]	Unsatisfactory Satisfactory Sufficient
Output variable			
Stability1	Stability for the availability of the sewerage networks and facilities to the city	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the funding from various sources			
Input variables			
2.1	Share of funding from the municipal budget (%)	[0;20] [20;80] [80;100]	Insufficient Moderate Sufficient
2.2	Share of funding from the budget of the operating company (%)	[0;20] [20;80] [80;100]	Insufficient Moderate Sufficient
2.3	Share of funding from the European Bank for Reconstruction and Development (%)	[0;20] [20;80] [80;100]	Insufficient Moderate Sufficient
2.4	Share of funding from the partial contribution of construction companies (%)	[0;20] [20;80] [80;100]	Insufficient Moderate Sufficient

Table 7.8 (continued)

1	2	3	4
Output variable			
Stability2	Stability for the funding from various sources	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the effectiveness of rehabilitation work for the sewerage networks and facilities			
Input variables			
3.1	Index of the effectiveness of rehabilitation work for sewer networks (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
3.2	Index of the effectiveness of rehabilitation work for sewers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
3.3	Index of the effectiveness of rehabilitation work for sewer tunnels (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
3.4	Index of the effectiveness of rehabilitation work for sewer shafts (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
3.5	Index of the effectiveness of rehabilitation work for stilling chambers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
Output variable			
Stability3	Stability for the effectiveness of rehabilitation work for the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities			
Input variables			
4.1	Index of the effectiveness of eliminating accident-caused damage to sewer networks (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
4.2	Index of the effectiveness of eliminating accident-caused damage to sewers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
4.3	Index of the effectiveness of eliminating accident-caused damage to sewer tunnels (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
4.4	Index of the effectiveness of eliminating accident-caused damage to sewer shafts (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate

Table 7.8 (continued)

1	2	3	4
4.5	Index of the effectiveness of eliminating accident-caused damage to stilling chambers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
Output variable			
Stability4	Stability for the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the environmental safety of operating the sewerage networks and facilities			
Input variables			
5.1	Index of the environmental safety of operating sewer networks (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
5.2	Index of the environmental safety of operating sewers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
5.3	Index of the environmental safety of operating sewer tunnels (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
5.4	Index of the environmental safety of operating sewer shafts (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
5.5	Index of the environmental safety of operating stilling chambers (%)	[0;20] [20;80] [80;100]	Critical Satisfactory Moderate
Output variable			
Stability5	Stability for the environmental safety of operating the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities			
Input variables			
6.1	Coefficient of efficiency for application of funds allocated for the stable operation of sewer networks (%)	[0;20] [20;70] [80;100]	Unsatisfactory Satisfactory Sufficient
6.2	Coefficient of efficiency for application of funds allocated for the stable operation of sewers (%)	[0;20] [20;70] [80;100]	Unsatisfactory Satisfactory Sufficient

Table 7.8 (continued)

1	2	3	4
6.3	Coefficient of efficiency for application of funds allocated for the stable operation of sewer tunnels (%)	[0;20] [20;70] [80;100]	Unsatisfactory Satisfactory Sufficient
6.4	Coefficient of efficiency for application of funds allocated for the stable operation of sewer shafts (%)	[0;20] [20;70] [80;100]	Unsatisfactory Satisfactory Sufficient
6.5	Coefficient of efficiency for application of funds allocated for the stable operation of stilling chambers (%)	[0;20] [20;70] [80;100]	Unsatisfactory Satisfactory Sufficient
Output variable			
Stability6	Stability for the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Subsystem of stability for the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities			
Input variables			
7.1	Index of the efficiency of implementing the system (%)	[0;20] [20;80] [80;100]	Unsatisfactory Satisfactory Sufficient
7.2	Index of the innovative implementation of the system (%)	[0;20] [20;80] [80;100]	Unsatisfactory Satisfactory Sufficient
7.3	Index of the utilization of domestic technology (%)	[0;20] [20;80] [80;100]	Unsatisfactory Satisfactory Sufficient
Output variable			
Stability7	Stability for the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient

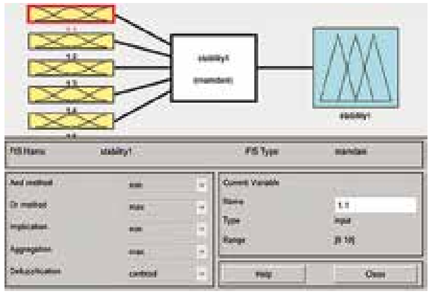


Figure 7.1. A general view of the window of the FIS-editor of the MATLAB system of the subsystem of stability for the availability of the sewerage networks and facilities to the city

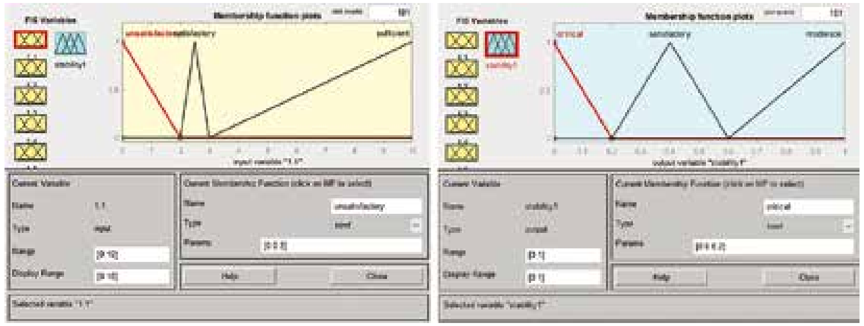


Figure 7.2. Input and output variable description windows

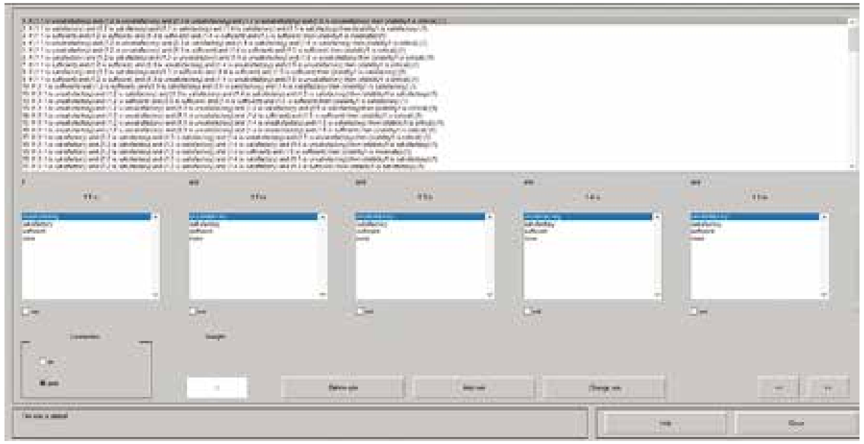


Figure 7.3. A fragment of the knowledge base for determining the stability for the availability of the sewerage networks and facilities to the city

Figure 7.4. A fragment of the knowledge base for determining the stability for the availability of the sewerage networks and facilities to the city

Table 7.9 — The results of the stabilities determined by different indices for the sewerage networks and facilities

Item No.	Parameter	Value by facility, %			
		SNF1	SNF2	SNF3	SNFK
1	Stability for the availability of the sewerage networks and facilities to the city	0.5	0.5	0.5	0.09
2	Stability for the funding from various sources	0.4	0.5	0.5	0.5
3	Stability for the effectiveness of rehabilitation work for the sewerage networks and facilities	0.3	0.1	0.5	0.5
4	Stability for the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities	0.6	0.6	0.6	0.6
5	Stability for the environmental safety of operating the sewerage networks and facilities	0.3	0.2	0.3	0.4
6	Stability for the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities	0.7	0.7	0.7	0.7
7	Stability for the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities	0.4	0.2	0.3	0.3

To determine the overall stability of the sewerage networks and facilities, a separate system has been developed, consisting of the following input and output variables (Table 7.10) [11].

Table 7.10 — Variables, term sets, and terms of the system of determination of the overall stability of the sewerage networks and facilities

Variable	Trem set	Trms	Definition
Input variables			
Stability1	Stability for the availability of sewerage networks and facilities to the city	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability2	Stability for the funding from various sources	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability3	Stability for the effectiveness of rehabilitation work for the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability4	Stability for the effectiveness of eliminating accident-caused damage to the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability5	Stability for the environmental safety of operating the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability6	Stability for the efficiency of the application of funds allocated for rehabilitation and elimination of accident-caused damage to the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Stability7	Stability for the efficiency of implementing the system of the organizational and technological monitoring to ensure the stable operation of the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient
Output variable			
Stability	Overall stability of the sewerage networks and facilities	[0;0,2] [0,2;0,6] [0,6;1]	Critical Satisfactory Sufficient

This system was developed according to the previously described principles using the Fuzzy Logic Toolbox tools of the trial version of the MATLAB system. The result of the developed system is given in Table 7.11.

The presented methodology can be developed to provide recommendations for improving the level of stability of the sewerage networks and facilities based on a determined overall stability value [11].

Table 7.11 — The results of the overall stability determined for the sewerage networks and facilities

Item No.	Parameter	Value by facility, %			
		SNF1	SNF2	SNF3	SNFK
1	Overall stability	0,5	0,3	0,5	0,2

Conclusions to Chapter 7:

1. It was found that to date, there is no single methodology for determining summarizing index of the stability of the sewerage networks and facilities. There are a number of methods for determining the stability of operation, but they do not cover the full life cycle of the sewerage networks and facilities. It should be noted that some indices are quite difficult to be assessed quantitatively or qualitatively as input variables, so it is relevant to use the fuzzy logic apparatus, which is quite effective in solving technical problems.
2. The fuzzy inference algorithm as a fundamental tool for determining the stability index of the operation of the sewerage networks and facilities was investigated.
3. A system of organizational and technological monitoring of the stable operation of the sewerage networks and facilities based on indicative estimates was developed. Using the fuzzy logic apparatus based on the MATLAB program, a software toolkit was created to determine a summarizing stability index for the operation of the sewerage networks and facilities, by means of which it is possible to make decisions on the implementation of certain measures to adjust operational characteristics. The presented methodology can be developed to provide recommendations for improving the level of stability of the sewerage networks and facilities based on a determined overall stability value.

CHAPTER 8

CALCULATING THE ECONOMIC EFFICIENCY OF IMPLEMENTING THE MONITORING OF SEWERAGE NETWORKS AND FACILITIES

The economic effect is a useful effect of economic activity, which is measured as the difference between the monetary income from this activity and the monetary cost of its implementation.

The economic effect is a quantitative and qualitative characteristic of the impact of the elements of the economic system on the effectiveness of its functioning. Unlike technical, technological and other non-economic effects, the economic effect exists mainly in monetary terms and is monetary income. Therefore, in a sense, the concepts of "economic effect" and "monetary income" are identical. Depending on the nature of the impact of individual elements on the effectiveness of the economic system there are positive, plus (with a sign "+", "plus-effect"), negative, minus (with a sign "–", "minus-effect", or as it is often called a defect) and zero effect [17, 86, 127, 129, 134, 169].

In order to calculate the economic effect of monitoring, it is necessary to identify the number of accidents, or the probability of an accident. At a given amount, an average of 12 accidents occur per year. Since accidents cannot be predicted, they can be calculated using the probability theory through the random number method in the Excel environment, i.e. the random distribution of 12 accidents [17, 86, 127, 129, 134, 169]. Tables 8.1, 8.2 and 8.3 show the calculations of accidents in three scenarios.

Given the distribution of random numbers, according to the first scenario, we obtain savings in the amount of 22,826.46 thousand UAH. Given the distribution of random numbers, according to the second scenario, we obtain savings in the amount of 20,006.47 thousand UAH. Given the distribution of random numbers, according to the third scenario, we obtain savings in the amount of 22,834.44 thousand UAH.

According to the initial data, there are on average 12 accidents per year occurring in the investigated sewer shafts. The cost of eliminating accidents may be 4,824.314 thousand UAH; 4,784.4528 thousand UAH; and 18,924.3156 thousand UAH. In order to use these data in further research, we calculate their average value.

(4,824.314 + 4,784.4528 + 18,924.3156) / 3 = 9,511,027.47 (UAH).

Table 8.1 — The first scenario of the occurrence of accidents

Amount for repair	**Random value (probability of the occurrence of an accident)**	**Probability 1 Random distribution of accidents**			
4,824.314	0.768381	4,824.314	18,924.316	4,784.453	4,824.314
4,784.4528	0.424326	18,924.316	4,824.314	18,924.316	4,784.453
18,924.3156	0.689677	4,784.453	4,824.314	4,784.453	18,924.316
Monitoring savings					22,826.46

Table 8.2 — The second scenario of the occurrence of accidents

Amount for repair	**Random value (probability of the occurrence of an accident)**	**Probability 2 Random distribution of accidents**			
4,824.314	0.483544	4,824.314	4,824.314	18,924.316	18,924.316
4,784.4528	0.761694	4,824.314	18,924.316	18,924.316	4,784.453
18,924.3156	0.062515	4,784.453	4,784.453	4,824.314	18,924.316
Monitoring savings					20,006.47

Table 8.3 — The third scenario of the occurrence of accidents

Amount for repair	**Random value (probability of the occurrence of an accident)**	**Probability 3 Random distribution of accidents**			
4,824.314	0.209136	4,824.314	4,824.314	4,784.453	18,924.316
4,784.4528	0.377952	18,924.316	4,784.453	4,784.453	4,784.453
18,924.3156	0.701777	4,784.453	4,824.314	4,824.314	18,924.316
Monitoring savings					22,834.44

We calculate the amount for eliminating the accidents per year, in the event of accidents, in the number of 12 cases as follows.

9,511,027.47 × 12 = 114,132,329.5 (UAH)

It can be concluded from the above calculation that in the event of 12 accidents per year, the rectification of their consequences will be 114,132,329.5 UAH.

The author of the dissertation research proposes to introduce a system for monitoring the stable operation of sewerage networks and facilities (investigated in the research work), the cost of which is 580,000.00 UAH. We calculate the payback period of the above investments as follows.

The payback period is the minimum time interval (measured in months or years) from the beginning of the project (the implementation of the monitoring system in this case) during which investment costs (capital investments) are covered by the net cash flow [11]. The payback period is calculated according to the formula:

$$PP = IC / PRT, \tag{8.1}$$

where:

IC — are the investment costs;

PRT — is the total net profit.

In our calculation, as the total net profit, we use the amount for eliminating the accidents, because according to the conditions of their prevention, cost savings will occur.

$PP = 580{,}000 / 114{,}132{,}329.5 = 0.0051$ (years)

$PP = 0.0051 \times 12 = 0.061$ (months)

As we can see from the performed calculation, the payback period of this implementation project will be about three months.

In addition, it should be noted that the implemented monitoring system will prevent emergencies, but the routine repair of sewer networks is still necessary. We believe that the cost of this repair is 20 % of the amount for eliminating accidents.

$114{,}132{,}329.5 \times 20\,\% = 22{,}826{,}465.8$ (UAH)

In order to calculate the economic effect, we use the *NPV* indicator. The *NPV* (Net Present Value) is referred to as the net discounted income. With a positive value of *NPV*, it is considered that this investment is effective. The concept of *NPV* is widely used in investment analysis to assess various types of investments.

$$NPV = \sum_{i=1}^{n} \frac{CF}{1+d^{i}}, , \tag{8.2}$$

where:

CF (Cash Flow) — is the cash flow of the i-th period;

d — is the discount (the rate: the coefficient that discounts flows). The discount rate is usually set in accordance with the interest rate in the banks of the country in which the project is implemented, which is the object of investment;

n — is the number of cash flows of capital investments (in this case, we believe that the investment for the implementation of the monitoring system is divided into five equal parts).

$$NPV = \frac{116000}{(1+0{,}14)^1} + \frac{116000}{(1+0{,}14)^2} + \frac{116000}{(1+0{,}14)^3} + \frac{116000}{(1+0{,}14)^4} + \\ + \frac{116000}{(1+0{,}14)^5} = 392{,}284.85 \text{ (UAH)}$$

As a result, we obtain an economic effect in the amount of UAH 392,284.85.

In order to make more rational decisions about investments and because of the need for monitoring, it is necessary to forecast possible future costs for accident elimination and repair.

A number of researchers consider forecasting to be an integral part of the management process that precedes the development of any measures. In essence, forecasting is a process of scientifically sound prediction of the future, characterized by a certain degree of probability and uncertainty and forms the information basis for management decisions [17, 86, 127, 129, 134, 169]. Since forecasting is part of the management process, it includes the object and the subject (Fig. 8.1).

Using the methods of economic forecasting, an optimum equation of trends of average costs for repairing sewer shafts was found (Table 8.4).

To better illustrate, Fig. 8.2 shows the evolution of the costs for repairing sewer shafts.

Table 8.4 — Forecast trends of the costs for repairing sewer shafts

Type of repair	**Repair costs (of three types of repair) by years, thousand UAH**				
	2016	**2017**	**2018**	**2019**	**2020**
Type 1 repair	4,051.28	4,344.28	4,438.37	4,592.746	4,824.314
Type 2 repair	4,141.56	4,193.99	4,241.5	4,435.19	4,784.453
Type 3 repair	16,500.92	17,213.56	17,465.73	18,233.58	18,924.32
Average value	8,231.253	8,583.943	8,715.2	9,087.172	9,511.027
Forecast equation	$y = 27.395x^2 - 141.96x + 9098.6$				
Coefficient of determination (R^2)	$R^2 = 0.9856$				

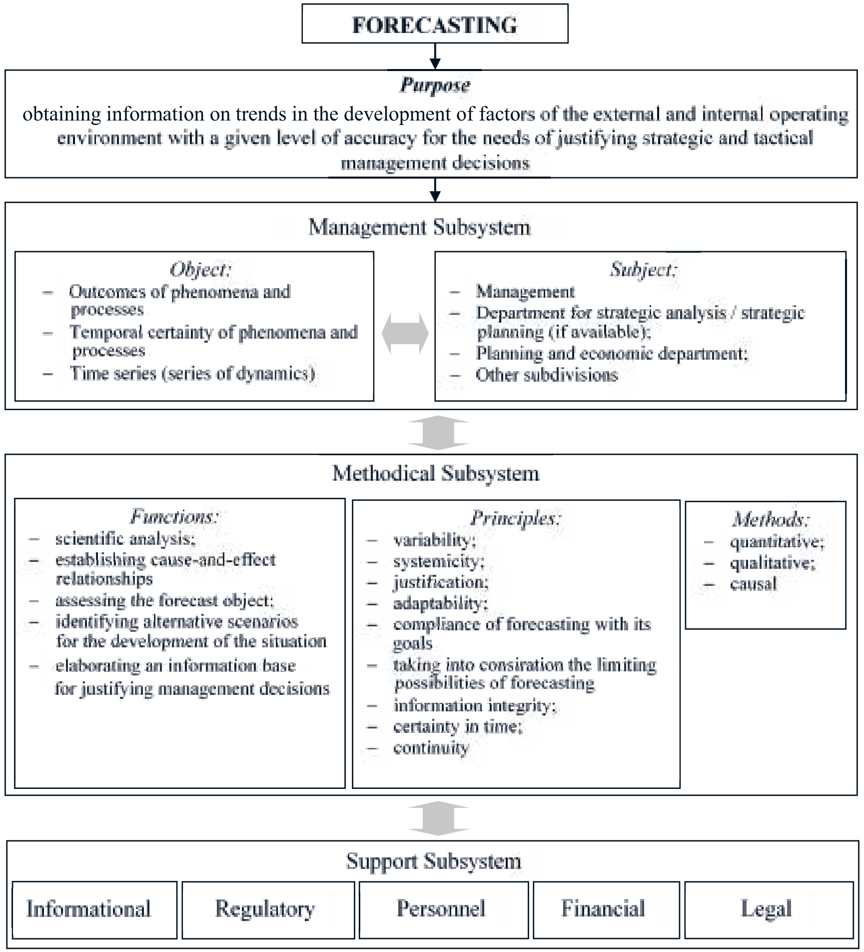


Figure 8.1. The main components of the forecasting methodology [3]

By comparing the forecast equation by different functions, the function, the coefficient of determination of which approximates the value with the highest degree of probability, was selected. In this case, it is a polynomial function of the second order ($R^2 = 0.9856$).

To compare the forecasted values with previous years, their chain rate of increment should be calculated [17, 86, 127, 129, 134, 169]. The calculations that are given in Table 8.5, 8.6 indicate the constant, rapid growth of costs for repairing sewer shafts from year to year, which confirms yet again

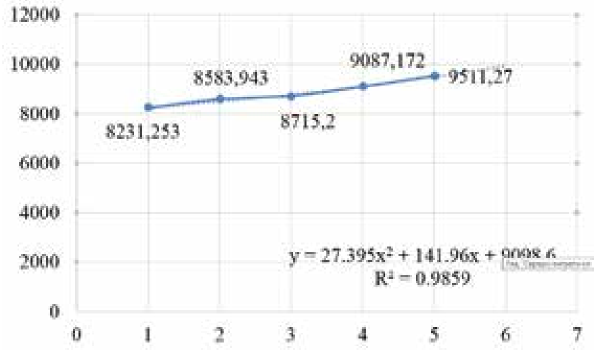


Figure 8.2. The evolution of the costs for repairing sewer shafts

the relevance and timeliness of the research, because all these costs may be reduced through the implementation of a monitoring system.

To ensure the proper functioning of the investigated sewer shafts, constant monitoring measures should be required. The monitoring system includes several stages for different types of monitoring.

The author proposes conducting two types of monitoring, periodic, which is performed four times a year and large-scale, which is performed once a year (in the summer period). Both types of monitoring are to be performed by a monitoring group, which includes five people (the head of the monitoring group, a supervision engineer and three technicians).

The responsibilities of the head of the monitoring group include planning the monitoring, carrying out the general coordination and producing a monitoring report. The supervision engineer conducts an analysis on the compliance of the operation of the investigated sewer shaft with the standards established by the legislation. Technicians check pipelines for contamination and easy passage; evaluate the tightness and ease of opening of the sewer manhole covers; thoroughly inspect the walls, floors and inverts, and the mouths of the pipelines [30, 65, 83].

Table 8.5 — The forecasted values of the costs for repairing sewer shafts

Value	Forecast Year 1 (2021)	Forecast Year 2 (2022)	Forecast Year 3 (2023)
Repair costs, thousand UAH	9,936.58	10,434.67	10,987.56

Note: calculated by the author based on Table. 4.4.

Table 8.6 — Chain rates of increment of repair costs for sewer shafts (developed and calculated by the author)

Years	Repair costs (average values)
2016	8231.253
2017	8583.943
Chain rates of increment (+), decrement (–), %	4.28
2018	8715.2
Chain rates of increment (+), decrement (–), %	1.53
2019	9087.172
Chain rates of increment (+), decrement (–), %	4.27
2020	9511.027
Chain rates of increment (+), decrement (–), %	4.67
2021*	9936.58
Chain rates of increment (+), decrement (–), %	4.47
2022*	10434.67
Chain rates of increment (+), decrement (–), %	5.01
2023*	10987.56
Chain rates of increment (+), decrement (–), %	5.3

**Note*: calculated by the author

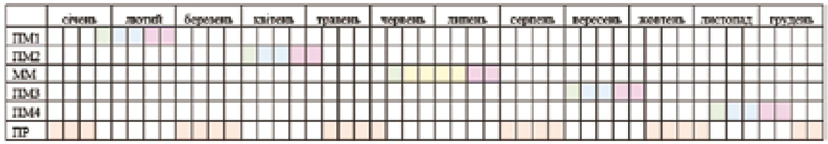
Periodic monitoring includes the following types of work: detection and timely prevention of disruption of the proper operation of the wastewater disposal network; identification of the reasons that may threaten its structural integrity.

Large-scale monitoring, in turn, includes the following: identification of faults in the technical condition and hydraulic operating conditions of the sewerage network; thorough inspection inside all shafts, of the mouths of the pipelines and through channels; inspection of the proper functioning of the equipment and fittings; and elimination of minor malfunctions by the group itself.

Table 8.7 presents the calendar schedule of monitoring activities throughout the year in terms of their types and stages.

As can be seen from the calendar schedule, the monitoring process is evenly distributed over time to make the supervisory and control measures systematic, which will ensure the maximum level of accident prevention and the implementation of preventive measures against emerging threats according to the type of monitoring.

Table 8.7 — Calendar schedule of monitoring activities for threats of sewer shaft accidents



	січень				лютий				березень				квітень				травень				червень				липень				серпень				вересень				жовтень				листопад				грудень			
ПМ1				🟩	🟦	🟦	🟥	🟥																																								
ПМ2													🟩	🟦	🟦	🟥	🟥																															
ММ																						🟩	🟨	🟨	🟨	🟨	🟥	🟥																				
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ПМ4																																										🟩	🟦	🟦	🟥	🟥		
ПР	🟧	🟧	🟧						🟧	🟧	🟧	🟧						🟧	🟧	🟧	🟧								🟧	🟧	🟧	🟧						🟧	🟧	🟧	🟧						🟧	🟧

Note: drafted by the author

Legend:

PS	Planning a monitoring route, preparatory stage
PM 1-4	Periodic monitoring
LSM	Large-scale monitoring
E	Eliminating identified threats of accidents
OR	Ongoing repair as needed

A need arises to calculate the amount of ongoing costs associated with monitoring activities.

The calculation of costs will be performed according to the elements of economic costs, which include tangible costs, salary costs, social security-related costs, depreciation costs and other operating costs [17, 86, 127, 129, 134, 169].

Tangible costs include the cost of raw materials and direct materials; fuel and energy; spare parts; auxiliary and other materials used up during monitoring[17, 86, 127, 129, 134, 169].

Salary costs include the salaries of the monitoring group, which is calculated based on the piece-rate system, where the employee's salary is contingent on the number of units produced (or amount of work performed) of appropriate quality with regard to qualifications and working conditions.

Social security-related costs include pension plan contributions, social insurance contributions, unemployment insurance contributions, and other safety net contributions. This element includes all contributions to the pension fund and other social funds, which are charged on the employee's pay in accordance with the current legislation. Deductions from the employee's pay to the pension and other social funds are not included in this element, as they are included in the element of salary costs [17, 86, 127, 129, 134, 169].

Depreciation includes the amount of accrued depreciation of fixed assets, intangible assets and other non-current tangible assets, which is reflected in accounting records.

The item “Other operating expenses” includes communication service costs, risk insurance costs, rent costs, and so forth.

Table 8.8 provides the calculation of ongoing costs under different types of monitoring for threats of sewer shaft accidents.

Table 8.8 — Costs under different types of monitoring for threats of sewer shaft accidents, UAH

Item No.	Costs	Periodic monitoring	Large-scale monitoring
1	Tangible costs	16800	50400
2	Salary costs	46500	139500
3	Social security-related costs	10230	30690
4	Depreciation costs	11390	34170
5	Other operating costs	12150	36450
Total actual cost		**97070**	**291210**

Note: calculated by the author

Table 8.9 — Calculation of the accident elimination cost reduction owing to the use of the monitoring system

Parameter	Parameter value
Average cost of eliminating one accident, thousand UAH	9,511.03
Average cost of eliminating 12 accidents per year, thousand UAH	114,132.33
Costs of ongoing repair, including the elimination of the threat of major accidents, thousand UAH	22,826.47
Ongoing costs for the implementation of the entire monitoring system, thousand UAH	679.49
Total amount of ongoing costs of the monitoring system, thousand UAH	23,502.96
Savings (ongoing cost reduction), including the use of the monitoring system, thousand UAH per year	**90,629.37**

Note: calculated by the author

Table 8.8 clearly states that one periodic monitoring process will cost 97,070.00 UAH, and it should be conducted four times a year according to the calendar schedule. Periodic monitoring should thus amount to 388,280.00 UAH. Large-scale monitoring, which should be conducted once a year, amounts to 291,210.00 UAH. In this case, the total amount of ongoing costs for the implementation of the entire monitoring system is 679,490.00 UAH. Furthermore, the costs per year compared with the previous period with no monitoring system in place and with the existing costs of eliminating accidents will be reduced by an average of 80 % (the calculation is given in Table 8.9).

Therefore, we can safely say that the system proposed by the author for monitoring threats of sewer shaft accidents demonstrates its economic efficiency both in terms of return on investment and savings in ongoing costs.

It should also be noted that the effect of the prevention of accidents is not only economic, but also social, in terms of reducing emissions of harmful substances into the environment and as a result reducing the morbidity rate.

Conclusions to Chapter 8:

Using probability theory by the method of random numbers, the probability of the occurrence of accidents has been calculated, based on which the effectiveness of the system for monitoring the stable operation of sewerage networks and facilities has been found, which amounts to 392,284.85 UAH. The effect of the prevention of accidents is not only economic, but also social in terms of reducing emissions of harmful substances into the environment and as a result reducing the morbidity rate.

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