https://doi.org/10.33271/nvngu/2024-3/122

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INTEGRATED WATER RESOURCES MONITORING SYSTEM WITHIN THE STRUCTURE OF ENVIRONMENTAL SAFETY IN SOUTHERN UKRAINE

Purpose. To substantiate the components of monitoring of resource-saving regulation of the water regime of river basins in the system of environmental safety of the southern regions of Ukraine on the basis of managed restoration of water resources and elements of the disturbed aquatic environment.

Methodology. A complex of standardized methods of field, desk and laboratory research, as well as methods of statistical processing of experimental data using the method of central composite orthogonal planning was used.

Findings. The paper analyzes the trends in the water cycle in technological complexes and agricultural complexes with the subsequent use of local measures to condition the resource in order to recharge the water supply source. The modes of operation of technological equipment using process and recycled water in traditional and energy-saving modes were modeled. Schemes of recycled water purification for use in the technology park were developed to reduce the cost of the production product. A study of drought processes in the agricultural sector in the southern region was carried out to reduce the risks of water management with renewable resources. Experiments on the absorption of various types of anthropogenic mixtures through porous artificial and soil structures were performed in the field, followed by the determination of background concentrations of pollutants.

Originality. During field and laboratory studies, applied tools for regulating the nutrition of water basins were developed. For the first time, a system for identifying agronomic drought phenomena and selecting priority measures to minimize the impact of moisture deficit in the context of global warming on the regional economy was designed. Greening of recreational areas of technology parks for the separation of sediment during gray water restoration was carried out. Recommendations were developed to regulate the operation of water management areas of enterprises in conditions of fluctuation in the flow of recycled water and other auxiliary economic needs to increase the water use coefficient of cities. Methods of wastewater treatment for the formation of components of water basin recharge were systematized. To improve the aquatic environment, a number of water protection concepts and programs have been developed, such as supply management, demand management, and integrated water resources management and environmental safety measures.

Practical value. A system of combined nutrition of the water regime of the reservoir basin has been developed. Methodologies for the recovery of recycled water from municipal and industrial enterprises for reservoir nutrition were calculated and tested. Operating modes of the cavitation unit for surface water recovery were established. The directions of development of the water basin in the context of global warming and the anthropogenic load of cities have been developed.

Keywords: *ecological safety, water resources, water basin recharge, resource-saving regulation, monitoring system*

Introduction. Sources of fresh water include both renewable and depletable resources that are artificially created through desalination [1, 2]. Water is fluid, which creates additional difficulties in determining ownership rights and responsibility for preserving the quality of the resource [3]. Water is not fully utilized in the consumption process, which generates externalities associated with reverse flows. This type of resource is characterized by high variability, both in terms of supply and quality. Investment projects in the mode of water supply, on the one side, require large investments and demonstrate capacity savings, while on the other side, they often have the characteristics of a public good [4, 5].

Literature review. The study of the water basin and the state of the ecological situation of industrial regions encourages the developers of new technologies for cleaning the water space and protection of the basin to pay more attention to green technologies. The authors M. Prykhodko, A. Fedorov, O. Tuts, A. Oliynyk, P. Smyk, O. Savchuk did not consider the issue of current monitoring of water basin pollution, which postpones the direction of local pollution monitoring for a long period of time. The current identification of pollution risks is extremely relevant for the prompt resolution of issues of self-recovery of the reservoir buffer volume.

The human health condition is considered as an integrated indicator of well-being, as it depends on a combination of factors. One of the reasons for the unsatisfactory state of health of the population, on a par with economic factors, can be the pollution of the environment and the water basin. As a result of the incomplete use of the industrial component, the ecology of the regions deteriorates significantly, the biocenosis of water bodies deteriorates [5, 6], the natural processes of self-cleaning of water bodies become complicated, and the latter pass into the category of depleting resources.

Reserves of fresh groundwater suitable for drinking water supply amount to 109.3 million m^3/year (299.5 thousand m^3/day) in 12 explored deposits [7].

The balance of the Dnipro River (near Zaporizhzhia City) is, in million m^3

$$x + z_1 + w_1 + y_1 = z_2 + w_2 + y_2 \pm \Delta u,$$

where x is precipitation, for the considered time on the surface of the allocated volume; z_1 – the amount of moisture condensed in the soil and on its surface; w_1 – the amount of moisture of the underground inflow; y_1 – surface watercourses inflow (channel and slope runoff); z_2 – evaporation from the surface of water, snow, soil, land vegetation, and transpiration; w_2 – outflow of water by means of an underground runoff; y_2 – water outflow through surface watercourses (channel and slope runoff); Δu – change of water reserves in the basin during the time interval.

$$23 + 1.1 + 109 + 1{,}211 = 145 + 134 + 855 - 210.$$

The water security of Zaporizhzhia region is quite high and amounts to 29.6 thousand m^3 per year per person, mainly due to the flow of the Dnipro River, water security of underground water is only 0.061 thousand m^3 per year, water security of local surface runoff is 0.30 thousand m^3 per year [7]. However, the rapid development of society leads to a constant increase in water intake. Thus, in 2021, the total volume of water intake amounted to 1,211,900,000 m^3, which is 239,500,000 m^3 or 24.5 % more compared to 2020, and the use of water increased accordingly by 241,800,000 m^3 and amounted to 1,186.0 million m^3 [8, 9].

The dynamics of the total amount of water intake (Fig. 1), use and discharge of wastewater in the region primarily depends on the users of water resources of Zaporizhzhia TPP, PJSC DTEK Dniproenerho, which operate on direct water supply. The increase in the intake and use of fresh water of the Zaporizhzhia TPP in 2021 by 1,844,000,000 m^3 is mainly related to the technological conditions of water intake in the winter period.

In 2021, PJSC "Zaporizhstal" increased the intake and use of fresh water by 7,350,000 m^3, which was associated to a change in the assortment of rolled metal production. These processes required more intensive cooling, with the implementation of a unit for inblowing pulverized fuel into blast furnaces, with an increase in the duration of the purging of reversible cycles fresh water in the summer season and with other production needs.

Unsolved aspects of the problem. When performing a strategic analysis, they usually calculate the current needs of enterprises (Fig. 2), utility sectors and leave a reserve for maneuvering (24 % of the buffer volume). Under the influence of global warming factors, experts may not include the increased level of evaporation from the surface of reservoirs, which is extremely important today [10].

The developed water quality software block (WQ-module) is connected to the AD-module and describes the processes of chemical reactions in multicomponent systems, including decomposition of organic substances, photosynthesis and respiration of aquatic plants, nitrification and oxygen exchange with the atmosphere.

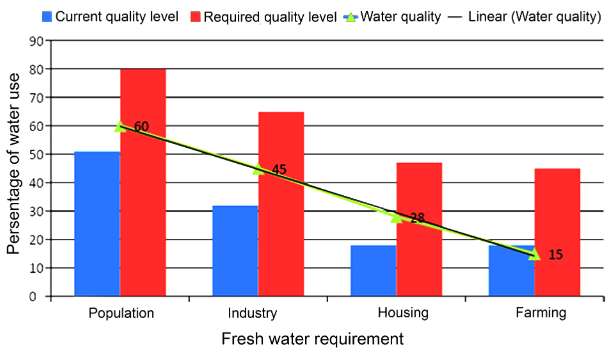

Fig. 1. Current resource quality needs, water quality imbalance

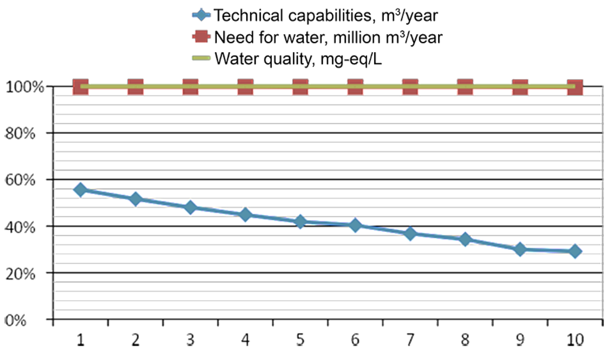

Fig. 2. The current need for water resources of indicator quality

The enterprise's water balance and water quality parameters are calculated for all indicator points by the method of rational extrapolation in an integrated two-step procedure with the AD module.

The existing water quality monitoring system in the basin is imperfect and requires the development and implementation of an integrated regulation system of recharge with renewable resources [5, 8].

Today, 11 control points are located on the Dnipro River within the city of Zaporizhzhia: 0.5 km above the control outlet of the Panska creek; 0.5 km below the control outlet of Panska creek; 0.5 km above the control outlet of Markusova creek; 0.5 km below the control outlet of Markusova creek; 0.5 km above the control outlet of TSO 2; 0.5 km below the control outlet of TSO 2; 0.5 km above the confluence of the Mokra Moskovka river, above the discharge of the Kapustiana creek; 0.5 km above the confluence of the Mokra Moskovka river, below the concentrated outlet of the Kapustiana creek; 0.5 km below the confluence of the Mokra Moskovka River, above the discharge of the city's treatment facilities; 0.5 km above the outlet of TSO 1; 0.5 km below the outlet of TSO 1.

Appropriate control devices for conducting research and recording indicator values are presented in Table 1.

The aim of the study is justification of the monitoring component of the resource-saving regulation of the water regime of river basins in the system of ecological security of the southern regions of Ukraine based on the managed restoration both the water resources and elements of the disturbed aquatic environment.

Method. A complex of methods of standardized field study, desk study, laboratory and statistical study was applied in the research [11, 12]. To improve the aquatic environment, a number of concepts have been developed in the field of water resources protection and programs, such as water supply management, water demand management, and integrated water resources management and measures to ensure environmental safety [13, 14].

The problem of the impact of reclaimed water with quality indicators (total hardness – 1–5 mg-eq/dm^3; turbidity – 1–9 mg/L) on the evaporation coefficient of water in the recycling water supply system was investigated during experiments on the operating equipment of the turnover cycle of the agglomeration facility of the industrial enterprise. The results indicate the possibility of using recycled water for technological needs.

Analysis of data from installed bathymetric sensors of water supply channels has become a strategically relevant issue. The data collection process lasted from 2014 to 2019 [15]. Specialists of the research group processed climatic data on the amount of precipitation and soil moisture in the districts of Zaporizhzhia region.

The soil productivity index was calculated on the basis of annual data on the productivity of agricultural crops. The period of drought events was recorded on days with elevated temperature in the field. The depth of soil moisture was controlled with a pin rail with markings of 10, 25, 50, 100 cm. The time of checking was 3 times a day (8:00 a.m. – 4:00 p.m. – 10:00 p.m.).

Table 1

Indicator sensors of water quality

No.	Name of sensor	Range of values	Accuracy
1	pH sensor	DPS = 600, 0–14 pH	0.01 pH
2	Turbidity sensor	RS 485, 0–60 degrees	0.3 degrees
3	Salinity sensor	DSS – 600, 0–50 degrees	0.1 degrees
4	Chlorine sensor	DLS – 600, 0–20 mg/L	0.01 mg/L
5	Oxygen sensor	DOS – 600, 0–20 mg/L	0.01 mg/L
7	ORP sensor	DLS – 600, –1,999–1,999 mV	1 mV

In order to assess the profitability of measures to restore the balance of reservoirs, indices of the integral restoration of the water basin of the region have been developed. Depending on the severity of water pollution and soil moisture deficit, it is recommended to use "gray" wastewater after cavitation waste treatment.

Obtaining the results of the water imbalance of the reservoir became the starting point for the formation of scenarios of current diffuse neoplasms and the assessment of the consequences of the discharge of industrial waters. Diffuse water discharge software is under development.

When planning annual technical plans for enterprises, a useful step is to simulate the quality of wastewater of technology parks (Fig. 3).

Suitability of wastewater quality provides additional opportunities for reserving industrial resources for further treatment. The research was conducted on the turnover cycles of the industrial plant. The overall dimensions of industrial aggregates were measured with a tape measure, and the temperature regimes of the inlet and outlet of wastewater were measured with a pyrometer. The speed of the water flow was measured with Zhestovsky's turntable in open channels.

The initial data was the quality of the input resource (hardness, alkalinity, recharge, oxygen concentration, heat capacity of sediments on the equipment tube) and the number of self-cleaning speeds, the required amount of water, depending on the technology, were mathematically calculated. An additional tab of the program calculates the water-chemical balance of each area and device (water losses for purging, drip loss, evaporation, required percentage of power).

The mathematical apparatus automatically calculates the appropriate evaporation coefficient and the thickness of possible deposits in the system. During the experiments, 1,223 items of equipment in 23 shops of metallurgical plants were calculated. The error of the experiment does not exceed 4 %, which confirms the relevance of the research.

Research conducted on metallurgical equipment (stages 1–4) indicates the possibility of saving water resources when re-using up to 12 % per hour at standard water quality (water hardness 4.8 mg-eq/L; alkalinity 3.3 mg-eq/L, salinity 680 mg/L (Table 2)).

Implementing the automation of the power supply system will provide an opportunity to replenish the reservoir in remote operational mode.

Research results. A mathematical model of cavitation water purification performance was developed

$$y = 46.062 - 7.172x_1^2 - 16.745x_1^3 - 25.898x_2^2 + \\ + 2.738x_2^3 + 14.137x_1 \cdot x_2,$$

where x_1 is hardness of water, mg-eq/L; x_2 – productivity of the process, %; y – the number of cycles – 15–74 cycles.

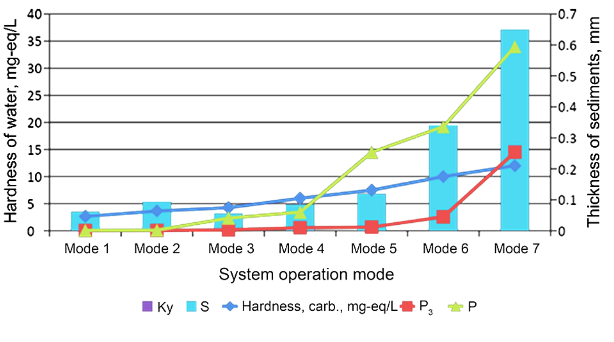

Fig. 3. The influence of water mode quality indicators on the evaporation coefficient and sediment thickness in the water supply system:

Ky – evaporation coefficient; S – thickness of sediments, mm; P_3 – alkalinity, mg-eq/L; P – carbonate accumulation, mm

Table 2

Technical possibilities of conditioning the first aqueous solution according to recovery scenarios

The first aqueous solution	Cavitation treatment (1 stage)	Infiltration processing (2 stage)	Modeling of industrial wastes (3 stage)	Reverse filtration (4 stage)
Turbidity 120	60	48	28	5
pH = 8.4	7.4	7.2	6.1	5.3
Hardness 12.8	7.8	7.1	4.8	0.5
Alkalinity 7.31	6.1	5.4	3.3	0.01
$C_{O_2} = 28$	44	32	12	18
$C_{CO_2} = 15$	23	17	24	21
Salinity 1,200	680	420	235	181
ORP = –1,408	–284	108	54	273

Studies of wastewater treatment with alternative adsorbents to reduce pollutant concentration were conducted. For the experiments, a filter column and a mixer were used to grind adsorbent fractions. Samples with a volume of 5 liters of technogenic mixtures were used in the experiments (Fig. 4). The duration of the process varied from 10 to 2,880 minutes (Fig. 5).

The results of the process were reflected by express tests of hardness, alkalinity, ORR reaction, TDS meter.

Mathematical model of performance of water system recharge

$$y = 446.4863 + 48.65x_1 + 145.9x_2 - 6.59x_1^2 - \\ - 6.54x_2^2 + 16.225x_1 \cdot x_2,$$

where x_1 is air temperature, %; x_2 – carbonate hardness of recharge water, mg-eq/L; y – the amount of required recharge of water system, m^3/h.

Assessment of water pollution is extremely relevant, especially in the vicinity of technology parks, for possible modelling of reducing the risks of intoxication of water bodies and the state of aquatic biodiversity [16, 17].

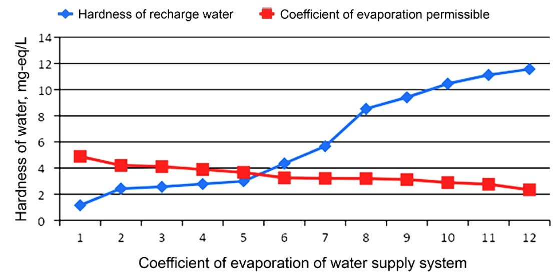

Fig. 4. The influence of the hardness of the recharge water on the permissible evaporation coefficient of water supply systems

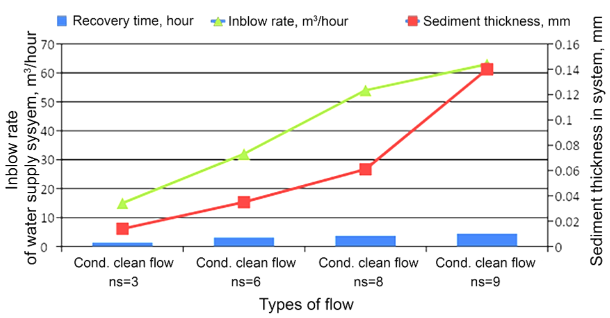

Fig. 5. The duration of conditionally clean wastewater recovery and operational parameters of the water system

The natural excess of infiltration rates and the rate of dilution of wastewater pollutant concentrations in many water body cross-sections are different. The need to estimate infiltration parameters over large areas of a catchment increases the need for distributed catchment modelling. The accuracy of the water pollution risk results may vary depending on the type of soils that make up the water body, hydrological maps and the control of the operation of the company's infiltration sites. The soil infiltration parameters represented in the distributed model and its configuration affect the accuracy of the results for the river body's nutrition. Productive infiltration of artificial soil plots is useful for increasing the specific productivity of the reference area of recreational areas.

The research and results obtained formed the basis for the development of the reservoir recharge system. The aquatic environment recharge system comprehensively analyses the environmental conditions online and the withdrawn volumes of process water from industrial reservoirs, cavitation recovery sites, infiltration control sites, membrane treatment plants and determines the time of their entry into the water supply source (in case of reservoir imbalance).

The remote quality control sensors are located in the pilot sections of the reservoir and at the outlet of the water recovery sites and provide quantitative information to the main server of the enterprise.

The system includes both quantitative and qualitative analysis sensors:

- recreational reservoirs (in each district of the city, up to 25,000 m^3 of water);
- cavitation unit (conditionally dirty water cycles, capacity up to 150 m^3/h);
- membrane plant (conditionally clean water cycles, capacity up to 100 m^3/h);
- infiltration site (area up to 120 m^2, with a specific capacity of 15 m^3/hour;
- communications;
- pumping stations;
- an integral center for processing information on flows.

The use of the reservoir recharge system within one city allows: with mechanical wastewater treatment, to obtain up to 1,200,000 m^3/year of additional resource, or 37 % of water consumption (Fig. 6); with chemical water treatment, to obtain up to 1,578,034 m^3/year, or 18 % of water consumption. The size of the reserve depends on the type of natural resource use and the industry profile of the region [17, 18]; when using bioengineering methods, up to 1,276,845 m^3/year, or 11 % of water consumption, is released (Fig. 7).

The volume should be planned based on local drinking water consumption; infiltration water recovery with artificial soils releases up to 37,145 m^3 /year.

Fig. 8 shows four scenarios of smart city development. According to the political scenario developed (by experts from the municipality and industrial technoparks), the city of Zaporizhzhia is expected to increase its CO_2 emissions to 220 Gt, which will lead to an increase in the average temperature by

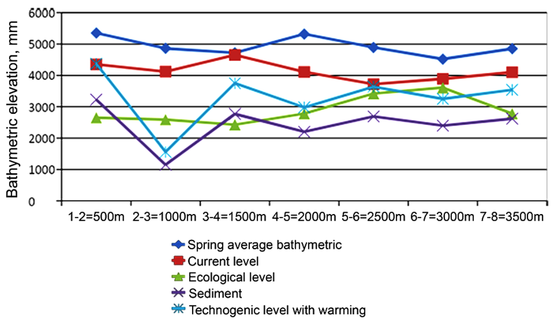

Fig. 6. Amount of pollutant at Dnipro river crossings by scenarios (industrial segment)

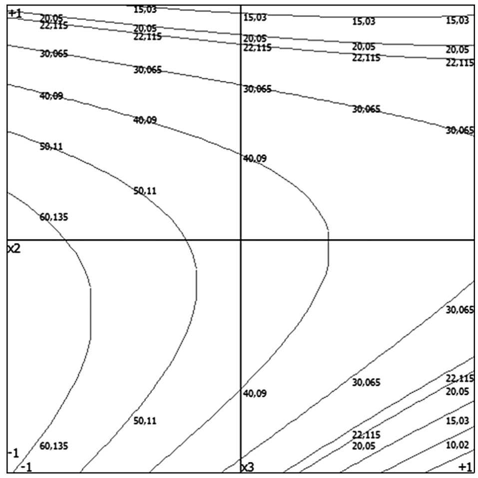

Fig. 7. Diagram of the number of cycles of the cavitation generator

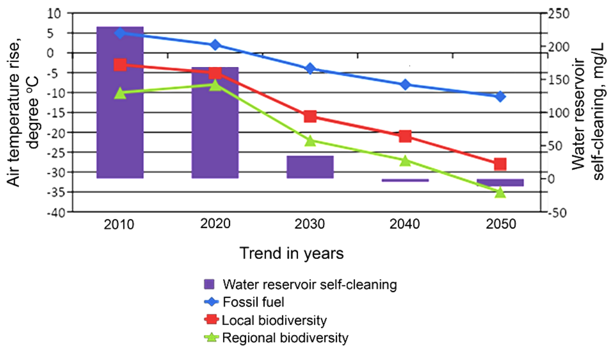

Fig. 8. Graph of the decrease in the intensity of self-cleaning of a reservoir with the loss of biodiversity due to increase in air temperature (deterioration of the environment)

6 degrees Celsius each month annually, which will become a driving force for biodiversity degradation, destruction of water bodies and destruction of socio-economic relations in the city (Dnipro city – 187 Gt, Kherson city – 42 Gt).

In the current scenario, hourly data is required to flexibly regulate the amount of reclaimed water fed into the reservoir. At the same time, the municipality develops a production program for the required amount of recycled water to ensure the functioning of the city's recreational areas. Under the industrial scenario (Fig. 8), industrial emissions increase from 150 to 227 Gt, causing an 8-degree Celsius temperature increase, energy demand.

Development of an early warning system for the condition of the aquatic environment. The system should be designed to perform the following functions:

1. Maintenance of basic data sources. Includes basic data and all types of warning standards for sudden water pollution accidents, water quality standards in functional areas, threshold standards for early warning indices and early warning level standards.

2. Calculation and analysis of complex assessment indices, necessary assessment of the impact of the pollutant.

The calculation of the indices is divided into two parts.

Qualitative analysis: the indicators include the type of accidents, the scale of the affected water body areas, the categories of affected water body areas, and the degree of environmental damage, which can be selected optionally in the interface early warning system according to the actual water pollution situation to assess the consequences of accidents.

Quantification: including selection of pollutant indicators, downstream monitoring catchment areas and calculation of the area of impact, time impact and scale of impact.

The system operates in an industrial metallurgical city, where municipal wastewater, industrial sludge water, and industrial conditionally clean water are present. The municipal wastewater segment includes wastewater from municipalities, the private sector, and local agricultural enterprises.

In the event of an incompliance of the wastewater quality, the controller rejects the defective volume of contaminated water and sends it for re-treatment at the regional conditioning stations. Uncontrolled discharges are not allowed as the water supply system is controlled by the Regional Water Inspectorate, environmental inspections, and representatives of the municipality. The entire water supply and wastewater disposal system is equipped with remote sensors for monitoring hardness, alkalinity, pH, salt content, oxygen, carbon dioxide, phosphates, and nitrates.

During the trial operation of the water system, a program for assessing the state of regional water development was tested. It consists of five modules:

1. General situation management module. Presentation of the urban basin risk, including the overall regional situation, river water balance and water buffer zone, which helps experts learn more about the geographical location, hydrology and meteorology, status and location of water functional zones, etc.

2. Aquatic environment assessment module. Changes in water quality in each basin cross-section over time, study of water distribution, generation of a distribution diagram of the main water flows, according to the main pollution indicators in selected river cross-sections, calculates indicator coefficients and excessive arrays.

3. Waste management module. Accounting for the volume of wastewater, buffer volume of urban rivers and enterprises, calculating the excess capacity of the aquatic environment and the amount of pollutants. The module calculates the concentration of pollutants at the water intake site downstream after their degradation, diffusion and the length of the marginal impact of pollutants on the biocenosis.

4. Step-by-step progression of the aquatic environment risk prevention module. Based on the analysis of precipitation and water demand, the module combines data on water quantity and water quality; it determines the risk status of local water resources by runoff.

5. Early warning module for aquatic environments. Evaluates the situation by calculating the impact scale and the time of impact of volleyed discharges on the aquatic environment. Based on the defined benchmark quality indicators, it predicts scenario trends and provides early warnings to the appropriate experts.

The algorithm of the power supply system.

In the current mode, each element of the system operates in an autonomous remote mode and has its own technological cycle (duration from 3 to 720 minutes). The final product is recycled water with quality indicators (water hardness 3.2 mg-eq/L; water alkalinity 1.8 mg-eq/L; pH = 7.5; salt content = 250 mg/L). When this level is reached, the sensor sends a signal to the main server, including the site number, the amount of water recovered, and the shift number.

The effect of using this system is to control the quantity and quality of the allocated resources, the duration of water quality degradation, control of the treatment technology, and restoration of surface water quality by four measures. Preservation of the reservoir's biocenosis, development of surface stream intersections and agricultural plots constitute a future natural resource and enhance the city's image. The economic impact of the implementation is estimated at over UAH 30 million per industrial technopark.

The planned research focuses on modelling the aesthetics of the floodplain lake landscape, for the public, in the context of ecological river restoration. The choice of visual factors is related to several operational factors:

- modelling the pool in various aspects;
- regression analysis: the dependent variable is the average aesthetic factor provided by the people surveyed; the independent variables are the visual characteristics of the water basin.

Finally, the modelling is based on six visual and physical variables: 1) green dominance; 2) brown dominance; 3) presence of warm currents; 4) presence of poorly structured aquatic vegetation; 5) presence of sediments; 6) muddy water.

In addition to aerial photography, ground photographs of structural elements of landscapes can also be used for operational purposes [19]. Assessing perceptions is a truly challenging problem for hydrologists. By providing quantitative information on various aspects of social perception, questionnaires combine social and environmental data to provide management scenarios and identify patterns of most valuable environmental and hydraulic achievements.

For the management of river objectives and especially river restoration, the landscape is a secondary consideration. There is a strong discrepancy between the perception of nature by different experts [20].

The landscape is a secondary consideration for the management of river objectives and especially river restoration. There is a strong inconsistency of the nature perception by different experts [20]. Integral and sustainable management of river flows for hydrological restoration, flood protection or human recreation – the importance of priorities varies depending on the river stretches. The multifunctionality of a water basin does not mean that all water uses should be maintained everywhere [21].

To maintain the image, the municipality can involve the public in setting key priorities when assessing the prospects for the river environment and the benefits for the specific features of the river basin.

Including public participation in river management and planning can reduce the number of protesters in decision-making. However, if improving public acceptance and support is the goal, it should be noted that the public is not a homogeneous group, but encompasses people with different interests. Public participation is also aimed at identifying imperfect perceptions and expanding knowledge about the full functioning of the ecosystem [5, 22].

Conclusions. To improve the aquatic environment, a number of water protection concepts and programs have been developed, such as supply management, demand management, and integrated water resources management and environmental safety measures.

1. The levels and volumes of environmental and water crises, which are aggravated by climate change, on the scale of the technology park, leading to an increase in the cost of energy resources in the region, a decrease in freshwater resources by 44 %, and the need to address regional problems of resource efficiency of the water basin, are determined.

2. Scientific and methodological approaches to improving the productivity of wastewater treatment (infiltration, water regime regulation, sedimentation in thin-layer blocks, mechanical treatment) to increase the water content of the basin are substantiated based on the developed systematic methodology.

3. Based on the improved principles of automation of the water treatment system and the water-chemical regime of the reservoir, their joint operation in different modes, the parameters of the reservoir power supply system modes are substantiated.

4. The implementation of the developed river power supply system reduces water and electricity consumption by up to 47 % and reduces the discounted payback period of investments to 4 years per region.

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Інтегрована система моніторингу водних ресурсів у структурі екологічної безпеки півдня України

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Мета. Обґрунтування складових моніторингу ресурсоощадного регулювання водного режиму басейнів річок у системі екологічної безпеки південних регіонів України на основі керованого відновлення водних ресурсів й елементів порушеного водного середовища.

Методика. Використано комплекс стандартизованих методів польових, камеральних і лабораторних досліджень, а також методів статистичної обробки експериментальних даних із використанням методу центрального композиційного ортогонального планування.

Результати. У роботі проаналізовані тенденції здійснення кругообігу води в технологічних комплексах і агрокомплексах із подальшим використанням локальних заходів із кондиціювання ресурсу з метою живлення джерела водопостачання. Виконане моделювання режимів роботи технологічного обладнання на технічній і повторній воді в традиційному та енергоощадному режимах. Розроблені схеми доочищення повторної води для використання в технопарку з метою зниження цехової собівартості товарного продукту виробництва. Виконані дослідження процесів засухи в аграрному комплексі в південному регіоні з метою зниження ризиків водного господарства відновленими ресурсами. У польових умовах виконані досліди всмоктування різних типів техногенних сумішей через пористу штучну та ґрунтову структуру з подальшим визначенням фонових концентрацій забруднювачів.

Наукова новизна. У ході польових і лабораторних досліджень розроблено прикладний інструментарій для регулювання живлення водних басейнів. Уперше здійснене проєктування системи ідентифікації агрономічних посушливих явищ і вибір пріоритетних заходів із мінімізації впливу дефіциту вологи в умовах глобального потепління для регіональної економіки. Виконана екологізація роботи рекреаційних ділянок технопарків для виділення осаду при відновленні сірих вод. Розроблені рекомендації щодо регулювання режимів роботи водогосподарських ділянок підприємств в умовах коливання стоку повторних вод та інших допоміжних господарських потреб для підвищення коефіцієнту водовикористання міст. Систематизовані методи обробки стічних вод для формування складових живлення водного басейну. Для поліпшення водного середовища розроблена низка концепцій у галузі охорони водних ресурсів і програм, таких як управління поставками, управління попитом та інтегроване управління водними ресурсами і заходи щодо забезпечення екологічної безпеки.

Практична значимість. Розроблена система комбінованого живлення водного режиму басейну водоймища. Розрахована та апробована методологія відновлення повторних вод комунальних і промислових підприємств для живлення водоймища. Налагоджені режими експлуатації кавітаційної установки для відновлення поверхневих вод. Розроблені напрями розвитку водного басейну в умовах глобального потепління й техногенного навантаження міст.

Ключові слова: *екологічна безпека, водні ресурси, живлення водних басейнів, ресурсоощадне регулювання, система моніторингу*

The manuscript was submitted 29.01.24.