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MEASURING, FORECASTING AND MONITORING SUSTAINABILITY OF BIOCHEMICAL WASTEWATER TREATMENT IN WAR PERIOD

The present paper provides the assessing scale of sustainability of the biochemical wastewater treatment facilities complexes in case of technogenic, natural or war catastrofes. To predict accidents in wastewater treatment facilities and contamination spread it is proposed to apply the knowledge base for the evaluation of the results of the accisent influence or damage and the possible water basin and ecosystem pollution. The determined indicators of the facilities state allows to make a grounded decision making about the biochemical process optimizing because of their possible disturbances and low quality of treated wastewater because of natural or man-made accidents. Reliable monitoring of such indicators under changing environmental conditions includes the detection of Euclidean distance increment between pairs of real observable states, determination of the probability of the transition from state to state and dynamics and evaluation its possibility and impact on the system functioning. The proposed approach allows to include not observed states in the estimated uncertainty. Analysis and interpretation of data about hypothetic results of landslide as the result of war or terrorist act should be also included into the monitoring system about the engineering objects, as they initiate damages, microcracs, decrease in quality of the biochemical treatment etc., wich can be not observed in time. It is developed the containment's evaluation procedure with the scale definition of status of the monolithic constructions of the facilities, that may be checked by their reaction on the external vibrations. Particular attention in case of the accident should be paid to the state of the active sludge, its ability to biotransformation of the pollutants of wastewater, the conducive conditions in bioreactors etc.

Key words: *biochemical wastewater treatment, sustainability, uncertainty.*

Introduction. To successfully solve the problems of minimizing pollution of the water basin, it is necessary to identify, first of all, indicators that signal the fact of pollution or the possible consequences of natural or man-made accidents or disasters, especially in war period. Such indicators include both the excess of permissible concentrations of pollutants, and the appearance (disappearance, decrease) in water of substances that are neutral in terms of changes in water quality, but contribute (prevent) the metabolism of pollutants, convert them into neutral compounds or into a state that facilitates cleaning processes. This should also include such indicators as the rate of change of observed indicators, as well as natural and technogenic factors influencing the processes of migration and metabolism of pollution.

To do this, it is necessary to create a database of facts that includes all the observed phenomena associated with the pollution of the water basin and, on its basis, to build heuristic models for the migration and metabolism of pollution characteristic of the selected water basin or ecosystem.

Particular attention should be paid to the problems of a military nature, earthquakes, tornadoes and other impacts both on the pathways of pollution distribution and on the qualitative composition of pollutants, taking into account both tectonics (for example, in points) that can unambiguously affect as the facilities with active sludge, biogas tank etc., so and the structure soils and cause visible consequences, and such that it can manifest itself after several cycles.

Measuring, forecasting and monitoring sustainability of the water basin under conditions of uncertainty. The natural water system is a classic model of the system which functions under conditions of uncertainty, because its states are determined, as a rule, not in real time, as the external disturbing factor; there is a dense but ambiguous connection between external factors (temperature of environment, atmospheric pressure, precipitation intensity, when the processes of purification are held, etc., and also with a considerable time lag between events and changes in the system state). The environmental monitoring of such system should provide:

- observation of the states and degrees of possibilities of these states;
- definition of states that are impossible in accordance with additional information (for example, the wastewater indicators may not be better or the same as indicators of natural waters);
- prediction of states those are not observed, but in principally possible, for those the given non-zero step of possibility *fM(c)* is less than the minimum degree of possibility *fM(a)* function, which is calculated for observed states [1–3].

Possibility of states' prediction that are not observed supposes the availability of external information or an informational connection between the event, the phenomenon and the system state. Such a connection really exists [4], but it is not monosemantic and allows only evaluating possible system state at quality level with a significant (up to several dozen percent) error. For exampe,

$$\mathrm{fM}(c) = 0.5 \underbrace{\min}_{\alpha} fM(\alpha)\,, \qquad (1)$$

or

$$\mathrm{D_p}[fM(c), fM(\alpha)] = \{\sum_{c\in C} [fM(c) - fM(\alpha)]^p\}^{1/p} \subseteq 0.5 \underbrace{\min}_{\alpha} fM(\alpha) \qquad (2)$$

where p – parameter of distance function D_p (for Euclidean metric p=2) [1].

If the results base (obtained on the basis of multi-year studies of treatment facilities) is compiled and includes executions (the limits within which the characteristics of the basin water can be observed, with corresponding indicators of the probability of observation); a set of states that have an opportunity of zero-measure observations (the limits for which observed variable never overreaches); calculated possible states (which are not really observed) and the corresponding opportunity degrees of their realization and the probable consequences of this realization, then it is possible to create conditions for management processes on the heuristic basis. All these need the reliable control of information, which is impossible without system reliability engineering and its predicting with reliability monitoring scheme under changing environmental conditions [5–10].

The detection of Euclidean distance increment between pairs of real observable states is proposed. These states are situated side by side under the same time interval. The probability and opportunity of the transition from state to state and dynamics (outward and interior) should be also defined. At last the detection of states feasible in principle (which are not locked on-line but may have an influence on system and its performance in global sense) and evaluation its possibility and impact are proposed. At the first step it is necessary to define situation on base of the data which are at the disposal (data of observation the current process on some observation interval). Further on different levels of specification there are identified the best hypothesises relatively realization of some generic system states, the conceive about how these hypothesises influence on real features of concerned variables. These conceives are composed on base of suitable experimental behaviour and specific functions. At last specified generalized restriction is supplemented or replaced by restrictions which are renewed by the best hypothesizes. With every of these ones it is the some degree of confidence is tied together. When using only the information contained in the data, this approach allows to include in the estimated uncertainty (generalized constraint) certain characteristics that cannot be determined by the real data that is observed, i.e. it is possible to predict or recover with a certain degree of certainty the states of variables not included in the forecast or recovery at the time of observation. To conclude, taking into account the "bottlenecks" in introducing the latest technologies of management of drainage systems helps to avoid their creation during the development of new systems, as well as in case of modernization of existing ones [12–13].

If we presents the degree of confidence increasing MB of hypothesis ***h*** on base of output ***e*** supervision in the form of

$$\mathrm{MB[h,e] = \{P(h|e)\text{-}P(h)\}/(1\text{-}P(h)}\,, \qquad (3)$$

where P(h|e) – conditional probability ***h*** under known ***e***, and P(h) – expert evaluation of probability for the specified time interval, than degree of confidence increasing MD relatively ***h*** may be presented as

$$MD[h, e] = \{P(h)\text{-}P(h|e)/P(h), \quad (4)$$

and the factor uncertainty CF may be presented as

$$CF[h, e] = MB[h, e]\text{-}MD\{h, e]. \quad (5)$$

The values MB, MD and CF, obtained for the every specific event are placed in base also. The base may be used for formation of system control heuristics for operation under uncertainty conditions. These heuristics make it possible to improve the quality of water basin management under conditions of uncertainty and action under factors which are poor evaluated.

Decision about control action should be made on the base of selection (by Monte-Carlo approach) some contamination strates (bounds of existence, which in linguistic form may be presented as “Great value” (G), “Medium value” (M), “Low value” (L) and ”Natural value” (N) when no control actions are required) with accounting the possibility of probability its realization. The spectrum of virtual contaminants thus obtained allows for appropriate regulatory action to be taken to minimize these contaminants.

The system’s model of the water basin status management should be based on the cumulative data, the knowledge base, set of rules of production, logical deduction gear and conclusion building gear by means of uncertain and incomplete input data. In other words such model would be an Expert System (ES). Cumulative data or Data base (DB) as a rule is formed as the some quintets: context – parameter – value – attendant factors – comments. The context may be presented as the point with fixed spatial coordinates and attendant data (number of point, the date of measurement, the measurement procedure); parameter – defines the general activity of specimen and radionuclides’ spectrum; value – defines α– β– and γ-activity of each spectrum component (absolute or comparative); attendant factors define the routine monitoring results or the results caused by force-majeure (earthquake, flood, man-caused and so on); comments define the presence and nature of changes in comparison with the previous measurements, other peculiarities.

Knowledge base (KB) should save the behaviour’s alternative models of all system components and the system as a whole under the various conditions of functioning, various external factors and conditions, various forms and processes of effluents transference.

The rules of production (RP) or heuristics are formed per next sample:

IF (precondition), THEN (action) [index of distinctness ID]. (6)

As the preconditions the quintets conjunctions and action which includes the quintet’s parameters value definition may be used. For the action’s quintet ID computation there are used the rule’s ID together with the ID of those quintets that are related to rule in question.

The rules may be used on the base of relative precondition for action quintet’s parameters values awarding (the direct sequence of deduction guided by data) or proceed from action’s quintet for ascertainment those precondition quintets which should be defined (inverse sequence of deduction guided by the goal).

The main goal is the accumulation of possible preconditions and possible actions. Index of distinctness may be computed by ID precondition, ID rule and output quintet’s ID.

ID precondition is determined by the least of the ID statements which are compose the precondition.

Obtained values are multiplied by rule’s ID (for the part which meets for action) and then the resulting index (RI) is arrived. If the quintet is not shaped for this moment, RI may play the role of quintet’s ID. If the last exists with the output index (OI) the values of ID are found by next procedure:

$$ID = OI + RI(1 - OI), \quad RI, OI > 0$$
$$ID = -(|RI|(1 - |OI|)), \quad RI, OI < 0 \quad (7)$$
$$ID = \frac{|OI| + |RI|}{1 - \min\{|OI|, |RI|\}}, \quad RI, OI < 0.$$

In case of an accident in water basin with pollution spread dynamics let’s consider several heuristics:

IF ([the water basin pollution WBP spot dynamics is within the 2σ limits (SPOTSTAB)] AND [natural and/or man-made accidents during the previous measurements’ cycles are absent (NMMA=0)]), THEN [monitoring procedure is routine (MONROUT)].

IF [SPOTSTAB] AND [NMMA=1], THEN [together with MONROUT the causal monitoring MONCAUS for the points which are laid on the direction from accident epicenter (AEC) should be provided, i.e. MONROUT + MONCAUS AEC].

IF [SPOTSTAB] AND [it is a tendency to increase of average monotonous displacement of WBP spot in the same direction within 2σ limits (TMD2σ), THEN [MONROUT + MONCAUS MD] (MONCAUS MD – extra causal monitoring in monotonous RAW spot displacement’s direction).

IF [SPOTSTAB] AND [NMMA=0] AND [NONSTABSPOTNOCR], THEN [check the RAW expansion model conformity CHECKEXPMODCONF] (NONSTABSPOTNOCR – RAW spot dynamics is not critical).

Checking the model may be realized by definition of its sensitivity to parameters’ deviations and adjustment of certain parameters for the purpose of accordance the predicted on the time of extrapolation and real measured at that time values of WBP. After this adjustment the WBP spot dynamics modeling is realized along the all period of functioning of depository. There is also another permissible step (if there are several models of WBP spot dynamics): implementation of concurrent modeling by several models and using the model which has the minimal metrics of predicted distribution of WBP spot relative to the real distribution.

IF ([SPOTNSTABn-1] AND [SPOTNSTABn] AND [NMMA=0] AND [NONSTABSPOTNOCR] AND [the vectors of WBP spot shifts are situated in different quadrants – VECTSPOTSHIFTDIFQUAD]), THEN [CHECKEXPMODCONF]. The [SPOTNSTABn-1] and [SPOTNSTABn] correspond to the WBP spot dynamics detection in (n-1)-th and n-th measurement cycles.

IF ([SPOTNSTABn-1] AND [SPOTNSTABn] AND [NONSTABSPOTNOCR] AND [NMMA=0] AND [the vectors of WBP spot shifts are situated in the same quadrant – VECTSPOTSHIFTSAMQUAD]), THEN [CHECKEXPMODCONF] AND [check the density of separate blocks or containment as a whole – CHECKCONTDENS].

IF ([NONSTABSPOTCRIT] AND [NMMA=1] AND [VECTSPOTSHIFTDIFQUAD], THEN ([it is necessary to change MONROUT at the critical procedures of monitoring MONCRITIC] AND [use the WBP expansion critical models WBPEXPCRITMOD]. MONCRITIC assumes the changing of range, changing of parameters' measuring frequency in the all points around WBP spot with the selective measurements in the points in which the parameters have the largest values. WBPEXPCRITMOD – the models concerned with formation of the channels along which the WBP expansion is realized more strongly.

IF ([NONSTABSPOTCRIT] AND [NMMA=1] AND [VECTSPOTSHIFTSAMQUAD], THAN [MONCRITIC] AND [WBPEXPCRITMOD] AND [man-made protective barrier establishing across the WBP spot movement path PROTBAR if the movement is directed to the settlements, the water supply points and so on].

Reliable assessment of the state of wastewater biochemical treatment facilities. One of the main problem of WBP dynamics is the seismic resistance which is realized by design monitoring (with the aid of direct and mediate methods) for the exposure and elimination the danger of wastewater treatment facilities destruction, the great landslides data collection, knowledge level increasing about deviations in the main direction of subterranean waters redistribution, drawing up the seismic dangerous maps connected with the treatment facilities influence zone. Mentioned monitoring in routine process periodically analyzes the facilities conditions but in the cases of natural or man-made, war accidents which may influent on the facilities conditions the code of causal monitoring is activated.

For the easing of mentioned types of monitoring procedures there are recommended the accelerometers setting in separate assemblies of facilities structure for the recording of vibrations caused by possible landslide sources. Similar action promotes the analysis and interpretation of appeared situation. Seismic landslides and landslips, which challenge the soil vibration, generate the destructive waves in the reservoirs and rivers, dangerous for the installations and soil structure. On the maps characterized the prospective surface movements (for example, natural frequency and intensity of earthquakes) facilities in-situ it is necessary to insert the instructions related to possible damages, local geological structure, probability of steady landslides, landslips and soil rarefactions inside of every seismic zone and immediately in zone of wastewater treatment facilities location.

Analysis and interpretation of information about hypothetic results of each landslide or earthquake are very difficult because of lack the precise and single meaning data. Therefore these facts should be taken into account in process of decision making. After the significant burst or earthquake the installations may be damaged but as a rule the results of these injuries are difficultly observed – there may be microcracks, changes in internal facilities bearing structures and so on. The results may be observed later, for example by increasing of BWP components concentration in subsoil waters in wells drilling around of facilities. Index of BWP components leakage may be represented as "summary area of microcracks – to summary area of facilities" relation (or "summary area of microcracks – to area of facilities bottom" relation). As a facilities damage scale it may be used the next categories of status:

A – Damages are absent or immaterial;

B – The slight or medium damages;

C – The significant damages;

D – Entire damage of facilities when its functioning is not possible.

The monolithic constructions of the facilities theoretically may be checked by their reaction on the external vibrations. Their natural frequency and

Table 1

Class	WBP limits (max)	Facilities condition evaluation	Overall performance of technical condition
0	< 2σ	Good	Damages are absent. The all processes are flow under license
1	≤ 2σ	Satisfactory	Damages are absent or immaterial
2	> 2σ	Non satisfactory	Approximately uniform expansion of WBP spot evidence of overall marginal damage of compaction which may be compensated by drainage
3	>> 2σ	Breakdown	Monotonous growth of WBP spot along the direction on the accident's epicentre evidence of essential damage of facilities. It is necessary to build the artificial barrier between facilities and important zones near them which are on the way of WBP spot movement. If the WBP spot movement stopping is impossible it should be considered the question of these zones evacuation or alternation of their activity

external source vibration's absorption factor may be used for evaluation. As the several authors claims [11]: the more damages – the less (droningly) natural frequency but external source vibration's absorption factor from the beginning arises and then – decreases. Hence the alternations in constructions' inflexibility and especially vibrations may be used as indexes of structural damages. Such investigations should be carry out after each earthquake which is fixed in-situ of facilities. It is necessary also to fulfill some analytical inspection which supposes the careful study of initial constructive calculations, designed specifications, and implementation of extra structural analysis combined with field observations and test data.

The first step in containment's evaluation procedure (CEP) consists of status scale definition (for example – four):

"0" – the absence of whatever problem (during the several previous years there were no natural or man-made accidents which may influence on soil, subsoil waters and facilities' installations structures; the monitoring results witness that level of WBP components pollution in the points being periodically controlled is not characterized by monotonous changes and registered deviations out of natural background in limits of doubled error of measuring methods or measuring instruments.

"1" – presence of negligible problems (during the previous routine monitoring cycle it was a certain accident epicenter of which was remote from facilities but in controlled zone the some small shocks were observed; during the previous and current routine monitoring cycles the monotonous changes of WBP components pollution distribution were not revealed but the marginal coming out of 2σ limits in one or several controlled points were observed).

"2" – presence of increased filtration of WBP components (during the previous and current routine monitoring cycles and causal parameter measurement in points which are positioned along over direction to the meaningful accident epicenter – although this epicenter is substantial remote from the facilities influence zone – the monotonous movement of WBP components spot is found out and it oversteps the limits 2σ in every direction).

"3" – presence of essentially damaging of facilities (during the previous and especially current routine monitoring cycles and causal parameter measurements the important parameter changes (>> 2σ) are found out first of all in the points joined along the considerable accident't epicenter direction and this epicenter is relatively close to facilities.

The wastewater treatment facilities containment status scale definition may be presented as in the Table 1.

The containment status scale evaluation has some uncertainty and that fact may have influence upon the decision-making procedure. If the wastewater facilities containment status is represented in digital form as a belonging function μd then for the above-mentioned stated cases the next table may be arranged (Table 2). Here [0] – absolute non true, [0,1–0,3] – the poor level of truth, [0,4–0,5] – essentially level of truth, [0,6–0,7] – the high level of verity, [0,8–0,9] – almost the verity, [1,0] – well-defined truth.

Table 2

Class	Membership function	d = 0	d = 1	d = 2	d = 3
"0"	μ_d	0,9	0,8	0,4	0,1
"1"	μ_d	0,8	0,9	0,6	0,2
"2"	μ_d	0,2	0,9	0,9	0,8
"3"	μ_d	0	0,5	0,8	0,9

The belonging to status which corresponds to classes "0", "1", "2" or "3" is derived from equation

$$\mu = max\{\mu 0, \mu 1, \mu 2, \mu 3\}. \quad (8)$$

The real facilities status may be found out by taking into account the accumulated effect of seismic stresses (landslides, fractures, shocks) influence. For that it is necessary to:

– Determine the frequency and strength of shocks in-situ of facilities over the all observations period and on the base of these data formulate the forecast in advance.

– Simulate the influence of accumulated landslides, fractures and shocks on the facilities constructions from point of view the probability of structure changes in facilities walls and bottom which may stipulate the formation of microcracks net, summary area of which promote the WBP components departure (migration).

– Determine the threshold pollution exceeding of which guarantees the more than 50% probability of microcracks net rise.

After listed steps it is necessary to equip the stations for the facilities status monitoring by accelerometers connected with automated monitoring system (AMS). The accelerometers data should be accumulated in the next format: [date, shocks amount, integrated value of shocks strain, the maximal acceleration in succession, series duration].

It is necessary to bring in heuristics the data listed in the format and at the same time transmit them to the Facts Base, where possible – with the comments (if it is connected with subsequent WBP spot dynamics detection, which is correlate with the fact).

At the same time the heuristics 1–8, presented above, may be formulated as following:

1-a. IF ([SPOTSTAB] AND [NMMA=0] AND [TLS=0]), THEN [MONROUT] (here TLS=0 means that tectonic landslides [TLS] are absent or ATLS ≤ THR1 where ATLS – the accumulated TLS, THR1 – threshold for the case when the maximal shock value is within limits of average minimal shock during the all time of observations).

2-a. IF ([SPOTSTAB] AND [NMMA=1] AND [TLS=1], THEN ([MONROUT + MONCAUS AEC]) (here TLS=1 means that tectonic landslides occurres but their values are small, although exceed the TRH1).

3-a. IF ([SPOTSTAB] AND [TMD2σ] AND [TLS=2]), THEN ([MONROUT] AND [MONCAUS MD]) (here TLS=2 means that tectonic landslides are noticeable and accumulated landslides ALS are within limits THR1 < ALS < 0,2 THR).

4-a. IF ([SPOTSTAB] AND [NMMA=0] AND [NONSTABSPOTNOCR] AND [TLS=2]), THEN [CHECKEXPMODCONF].

5-a. IF ([SPOTNSTABn-1] AND [SPOTNSTABn] AND [NMMA=0] AND [NONSTABSPOTNOCR] AND [VECTSPOTSHIFTDIFQUAD] AND [TLS=2]), THEN [CHECKEXPMODCONF].

6-a. IF ([SPOTNSTABn-1] AND [SPOTNSTABn] AND [NMMA=0] AND [NONSTABSPOTNOCR] AND [VECTSPOTSHIFTSAMQUAD] AND [TLS=3]), THEN [CHECKCONTDENS]. (here TLS=3 means that tectonic landslides are noticeable and accumulated landslides ALS are within limits 0,2 THR < ALS ≤ 0,4 THR).

7-a. IF([NONSTABSPOTCRIT]AND[NMMA=1] AND[TLS=3]AND[VECTSPOTSHIFTDIFQUAD], THEN [MONCRITIC].

8-a. IF ([NONSTABSPOTCRIT] AND [NMMA=1] AND [TLS=4] AND [VECTSPOTSHIFTSAMQUAD], THEN ([MONCRITIC] AND [RAWEXPCRITMOD] AND [PROTBAR]. (here TLS=4 – tectonic landslides within ALS limits 0,4THR ≤ ALS ≤ 0,7 THR).

In case of breach of the treatment process, each operating rule for choosing the method of regulating the wastewater biochemical treatment [14-15] can be presented in the form of the heuristics as follows:

IF [{(VWS_A) AND (WPC_A) AND (ASC_A) AND (ASI_A)},

OR {(VWS_S) AND (WPC_B) AND (ASC_B) AND (ASI_B)}], THEN {NIT_B},

IF {(VWS_A) AND (WPC_A) AND (ASC_B) AND (ASI_A)}, THEN { NIT_A},

IF {(VWS_B) AND (WPC_A) AND (ASC_A) AND (ASI_B)}, THEN { NIT_B},

where VWS – velocity of the wastewater stream, WPC – pollutants concentration in wastewater, ASC – active sludge concentration, ASI – active sludge index (reflects its properties), NIT – necessity for intensification of treatment process, and A, G, S, – relevant estimates (average, big and small) [14–15].

In addition to the procedures given above after reconstruction of the damaged biotechnological wastewater treatment facilities for the successfull functioning of the bioreactor it should be paid attention to:

1. The content of wastewater:

– it should be acceptable for the microorganisms activity: pH, temperature, loading by COD, toxic elements availability etc.

The results of the standard analisyses made may be unsufficiant, because wastewater may content heavy metals, oils, acids, Caprolactam, Formaldehyde, HMD etc.

2. The properties of the active sludge immobilizing material:

– the influence of the material on treated water and microorganisms: it may be extraction of toxic elements (HMD, acids etc.) into water;

– exclusion of fibres getting into water from immobilizing material; providing the strenth of the filter for exclusion of getting into water the materals of filter.

3. The type of microorganisms: will it be clean culture (or 2–3 cultures), or active sludge, which may be adopted to such type of water. Work with clean culture is always more difficult, because some, even little changes in wastewater can kill all the culture, but active sludge is able to adopt to the new conditions.

4. Possibility of the immobilizing material regeneration: the culture should growth and it should be the regime for the optimal young, not old cells of microorganisms. Some pollutants, such as heavy metals etc., will be aglomerated at the elements of the biofilter, so there should be a system for cleaning filters.

For the aim of environmental safety ensuring utilisation of the worked out immobilizing material and old cells of microorganisms. The desinfection of treated water from microorganisms is also required.

Conclusions. The organization of monitoring these and other indicators (permanent or selective, including those organized on the basis of risk models) helps to monitor the dynamics of the state of the water basin and provide a forecast of its possible state at a given point in time. And this optimizes both the quality of water and the processes of its biochemical treatment.

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ВИМІРЮВАННЯ, ПРОГНОЗУВАННЯ ТА МОНІТОРИНГ СТІЙКОСТІ БІОХІМІЧНОГО ОЧИЩЕННЯ СТІЧНИХ ВОД У ВОЄННИЙ ПЕРІОД

У дослідженні представлена шкала оцінки стійкості комплексів біохімічних очисних споруд у разі техногенних, природних або воєнних катастроф. Для прогнозування аварій на очисних спорудах та поширення забруднення пропонується застосовувати базу знань з метою оцінки результатів впливу або наслідків аварії та врахування можливого забруднення водного басейну та екосистеми. Встановлені індикатори стану об'єктів дозволяють прийняти обґрунтоване рішення про оптимізацію біохімічних процесів через їх можливі порушення та низьку якість очищених стічних вод внаслідок природних або техногенних аварій. Достовірний моніторинг таких показників за змінних умов навколишнього *середовища включає виявлення приросту евклідової відстані між парами реально спостережуваних станів, визначення ймовірності переходу від стану до стану та динаміки, та оцінку його ймовірності та впливу на функціонування системи. Запропонований підхід дозволяє включити неспостережувані стани в оцінену невизначеність. Аналіз та інтерпретація даних про гіпотетичні наслідки зсувів внаслідок війни чи терористичного акту також мають бути включені до системи моніторингу інженерних об'єктів, оскільки такі зсуви ініціюють пошкодження, мікротріщини, зниження якості біохімічного очищення тощо, які можуть не спостерігатись вчасно. Розроблено методику оцінки захисної оболонки з масштабним визначенням стану монолітних конструкцій об'єктів, що можна перевірити за їх реакцією на зовнішню вібрацію. Особливу увагу при аварії необхідно звернути на стан активного мулу, його здатність до біотрансформації забруднюючих речовин стічних вод, сприятливі умови в біореакторах тощо.*

Ключові слова: *біохімічне очищення стічних вод, стійкість, невизначеність.*