POSSIBILITIES FOR CONTROLLING THE CONNECTION BETWEEN WASTEWATER TREATMENT PLANTS AND RECEIVING WATER BODIES

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Abstract

With increasing water supply and canalization the quality of the water playing the role of receiver often deteriorates. Among other problems, the not sufficient removal of plant nutrients by the traditional purification technology causes difficulties. Considering that the removal of fertilizers results in a significant increase in the costs of wastewater treatment, it is expedient to keep the extent of removal just at the yet acceptable level of the pollutant.

This paper deals with the removal of phosphorus as fertilizer on a transport theoretical basis.

As a result, a qualitative connection is established between water quality and water management on the one hand and the operation of the wastewater treatment plant on the other hand.

The objectives and method of the research work

With the increase in water supply and canalization the quality of the receiving water bodies often deteriorates, not only in Hungary, but all over the world. This deterioration is caused at present mainly by the introduction of the wastewater of dwellings into the receiving water bodies in spite of the increasing number of wastewater treatment plants being built. According to the literature and experience, the main reason of this problem is that — in addition to other effects as e.g. the not point-like nature of pollutants — traditional purification procedures do not remove fertilizers satisfactorily. The enrichment of these substances, in turn, may lead to the breaking of the ecological equilibrium in the receiving water body. Since the removal of fertilizers results in a rapid increase in the costs of purification, it is expedient to keep the level of pollutants at the allowed value. The necessary extent of removal can be determined from the receiving capacity for the fertilizer in question. Therefore it is justified technically and economically to analyse the ecology of the receiver and the procedure of wastewater treatment as well as the connection between them in order to make a sound foundation of design and operation.

As it became clear from earlier, mainly from biological research, the main energy source of eutrophisation processes is phosphorus, problems of the transport of phosphorus have been investigated in our study. Upon considering the economically feasible solutions here and in other countries, emphasis was given to the technical realization of results achievable by completing the purification processes utilizing activated sludge.

As a general goal, the description of the purification technology of communal wastewater by activated sludge (AS) has been set. A parametric treatment is elaborated for the third purification step with special regard to the removal of fertilizers (P), by starting from observations concerning the effect of the dynamic-kinetic change of AS on the AS base line.

The normalization of the system may increase the efficiency of the secondary clarifier when considering the macro- and submacro-arrangements and the microdynamics of differentiated sedimentation. It also improves the relation of the wastewater treatment plant and the receiving water body, since at the separation of phases the mechanism of mass transport during adsorption-storage and the kinetics of coagulation-flocculation may be brought in harmony by the consideration of the normal distributions of critical concentrations and time.

Other components of the connection between the wastewater treatment plant and the receiving water body, as well as the composite processes of technology, such as e.g. filtration, ozonization desinfection, etc. will be neglected here.

Field experiments were carried out in the wastewater treatment plant at Keszthely based on the critical evaluation of technical literature. The analysis and evaluation of the experiments occurred by the use of the ITO (Input, Transformation, Output) system. Technical literature was considered from the viewpoint of transport theory.

System approach in the removal of phosphorus

The results of field experiments carried out in 1983—84 were compared with the data found in the literature. Correlations thus obtained were classified by using transport theory.

The overall equation system of the conditions for the removal of phosphorus at macro-, micro- and submicrolevels of purification processes using activated sludge is the following:

$$C_f = F\left[e \mid i_f \mid\right] \tag{1}$$

$$K_{C_s} = C_f \mid t \mid \tag{2}$$

$$C_f \mid t \mid = F\left[Y_{X_k}\right] \tag{3}$$

$$Y_h = F\left[X_k \mid AS_{p'p} \mid\right] \tag{4}$$

Let the transformation interpreting the removal of phosphorus be

$$X_k = F \mid AS_{p,p'} \mid$$

what is a correlation between the mass of flocs and that of the wastewater in its environment (Fig. 1).

The removal of phosphorus may occur by either biological assimilation or by the combination of this and chemical precipitation, the time course of which may be characterized by distribution factor K_{C_z} together with equations

$$e \mid i' p \mid = \left[\gamma \frac{KOI}{P}\,;\; \beta \frac{BOI}{P}\right] \rightarrow \max \tag{5}$$

$$i'' = \left[\alpha \frac{KOI}{P}\,;\; \delta \frac{BOI}{P}\right] \rightarrow \max \tag{6}$$

where each

$$i''_p = [i_j \,\text{Poly-}P \leq i_k \, A\,T\,P] \tag{7}$$

$$i'''_p = [\text{pH}: i_{\text{cat}}\,;\, i_{\text{inh}}], \text{ in which} \tag{8}$$

i_{cat} is the intensive of cations and

$$i_{\text{cat}} = i\,[\text{Ca, Fe, Al}] \rightarrow \max \tag{9}$$

i_{inh} = the intensive of inhibitors

$$i_{\text{inh}} = i\,[Mg^{2+}, \text{bicarbonate, Poly-P}] \rightarrow \min \tag{10}$$

The storage of Poly-P is a precondition for choosing arrangement X_k with respect to l/T which ensures the variation of the anaerobic—aerobic states of the sludge.

The effect of this change in X_k appears as a variation in intensive i_p at the submicro level according to

$$X_k = F\,(AS_{p,p'})$$

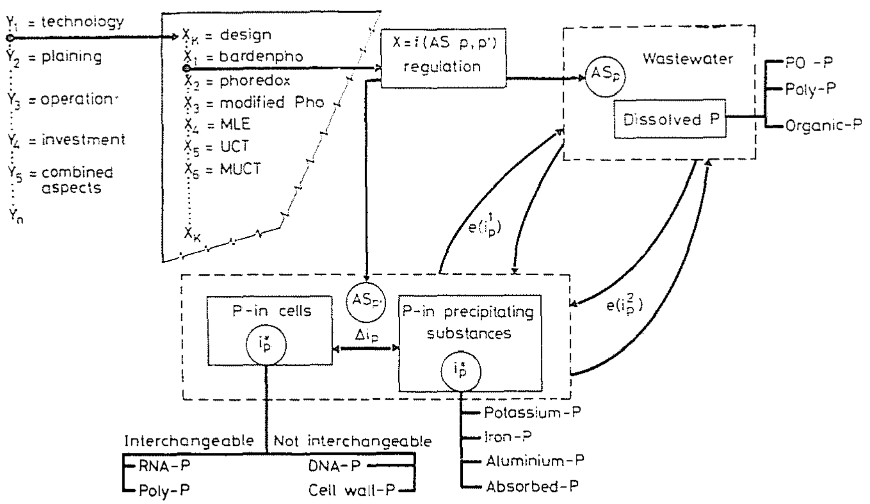

Fig. 1. System approach in the removal of phosphorus

The acceleration or deceleration of

$$i_p = | i_p^1 ; i_p^2 |$$

shows the effect of the introduction of arrangement X_k in the distribution of $K_{C_x} P$ (Fig. 2). From this it can be concluded that in aerobic systems where the transport of energy and matter occurs according to the equation

$$AS_p[e | i_p^2 |], AS_{p'} [e | i_p^1 |] \rightarrow K_{C_x} \tag{11}$$

phosphorus is also precipitated (Figs 1, 2). Thus K_{C_x} could be measured experimentally what makes the solution of equation system (1)—(4) possible.

Thus from the viewpoint of the transport of energy and matter, five mechanisms can be set as the most probable ways of the biologically assisted chemical removal of phosphorus:

1. The basic mechanism is the normal assimilation of phosphorus which is always operating and the efficiency of which depends on i_p (it results 1—2,5% in an $e | i_p^1 |$).

2. The storage of Poly-P which is ensured by changing the anaerobic and aerobic environments of the activated sludge, in dependence of i_p (A storage of P as high as 5—8% may be achieved).

3. Ordinary precipitation in the wastewater occurring due to the change in the aerobic-anoxic-aerobic states as a function of i_p'''.

4. Accelerated precipitation in the wastewater when function i_p'' is near to its maximum value or even reaches it.

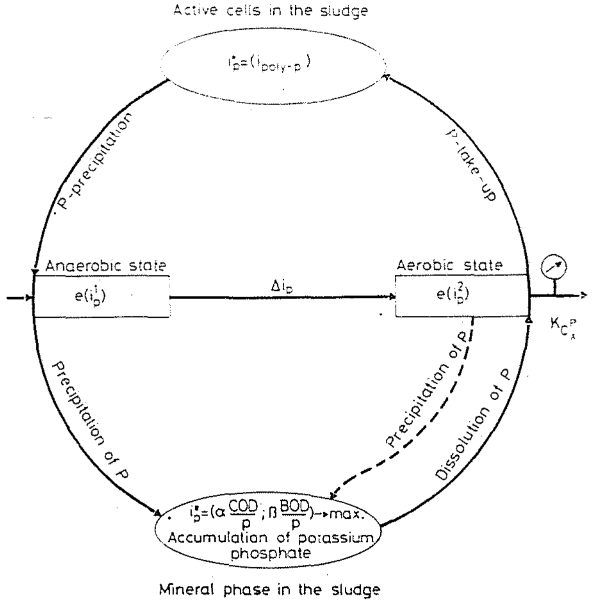

Fig. 2. **Scheme of the system intensitively induced for P**

Biofilm precipitation occurring in the case of bacterial denitrification if the wastewater environment of the biofilm is favourable, in dependence of i''_p.

The bonity of the optimization of functions and the aspects of the given system depend strongly on the correctness and consistence of qualitative and quantitative data required in the application of the different mechanisms.

The role of the differentiated settling in the transport of nutrients

Since the main energy source of eutrophisation is phosphorus, problems concerning the transport of phosphorus were studied.

The connection between the wastewater treatment plant and the receiving water body is discussed on the basis of the ecology of the above mentioned nutrient-transport and the system of the purification system with activated sludge which was examined from the viewpoint of the phosphorus removal (ITO/AS_C). The scheme of the system is illustrated in Fig. 3.

The most sensitive unit of the system is subsystem 3. This is partly due to the strongly stochastic characteristics of the input intensives, T_p and T_C in transport T_{23}. The intensives of the AS base line are partly also quasi-stochastic.

In the general case, the output of subsystem 3 is the output of the secondary clarifier.

The observation of this change in the transition section of the settling curve (Fig. 4) and its mathematical modelling makes possible the observation

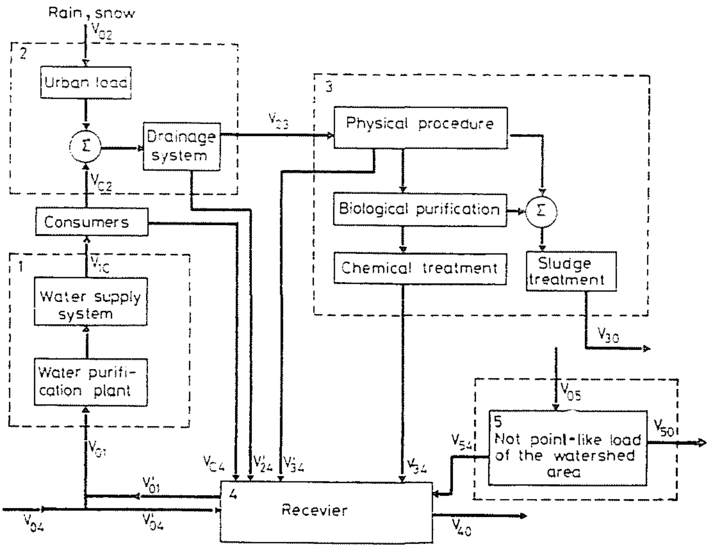

Fig. 3. Connection between the wastewater treatment plant and the receiver

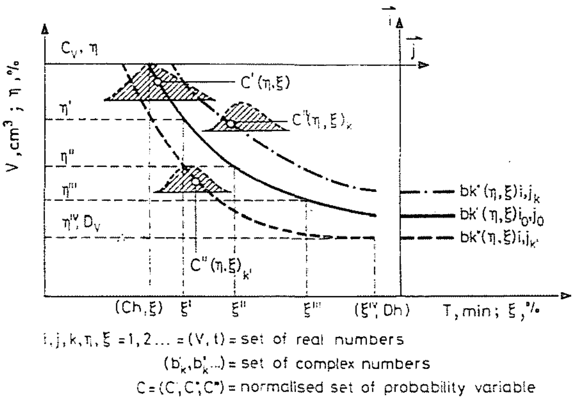

Fig. 4. Mathematical modelling of the transition reaction

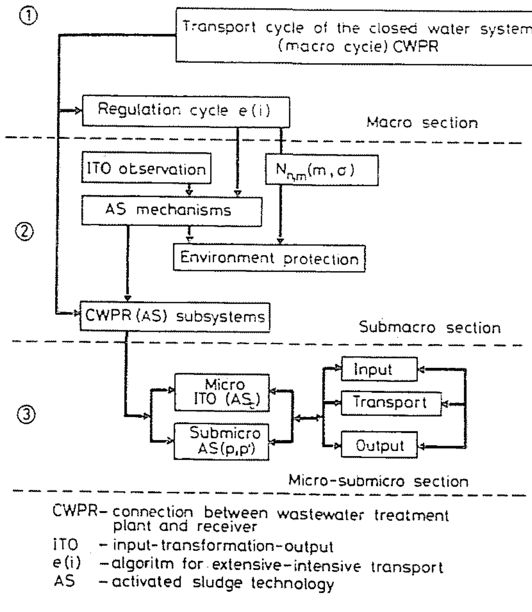

Fig. 5

of AS_C from the viewpoint of phase separation. In turn, this provides a possibility for the regulation of the connection between the wastewater treatment plant and the receiving water body by means of intensive k_c.

Disregarding the effect of intensive V_{30} on the environment, this study is aimed at investigating the changing process of changing of matter-energy intensive V_{34}.

The incorporation of the mathematical model of settling process into the connection system wastewater treatment plant — receiving water body oc-

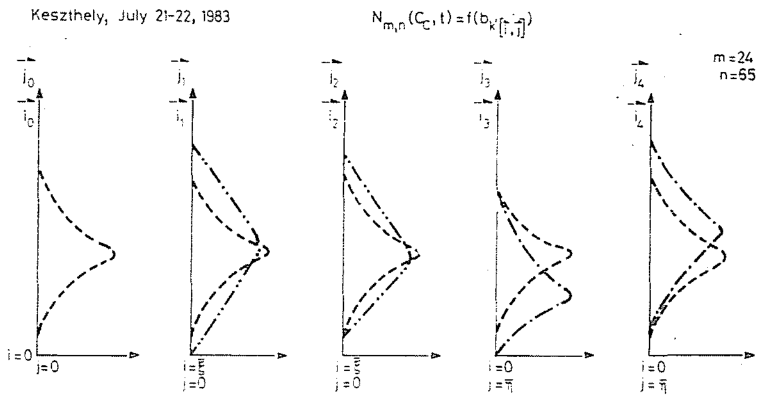

Fig. 6. Effect of (i, j) system on (system)

curred by the utilization of the current biochemical results from the study of purification processes with activated sludge. This was the basis for designing our system. This system applies the submicro, micro, submacro and macro sections for describing the operation of ITO/AS_c (Fig. 5).

One of the possible approaches for characterizing ITO/AS_C is the construction of the interactions of the (i, j), (ξ, η) and $N(C_c, t_c)$ systems. System (i, j) forms space, (ξ, η) represents the description of the stochastic flow of matter and energy in time, and regulating system $N(C_c, t_c)$ ensures the possibility of standardization of the whole ITO/AS system.

The result of this interaction is the distribution k_c (Fig. 6) which shows that differentiated settling manifests itself in different effect-differences in the directions of the two axes. The existence construction and utilization of this distribution occurs in inductive and deductive ways based on experience from experiments and data from the literature. By using this distribution

$$(\varrho_{ke} - \varrho_{kc}) \text{ and } (V_{p\,\min} - A_{p\,\max})$$

can be given for the separation of phases, whereas the resultant differentiated settling rate may be written as

$$v_p = K_c \sqrt{\frac{2g}{k_c\, C_D}}\ (\text{m/s}) \tag{12}$$

where

$$C_D = \frac{1}{C_D\, p' ; p}\ (\text{cm}^2/\text{g}), \text{ as } C_D \text{ is an}$$

inverse function of mass flow from the viewpoint of differentiated settling.

$C_{Dp';p}$ = roughness factor in which the characteristics of submacro system $DS_{ke} - CF_{ke}$ are reflected,

DS = adaptive-learning mechanism

CF = coagulation-flocculation mechanism
k_e = effect of the above mechanism on airing
k_c = effect of the above mechanism on secondary clarifier

$$C_{D_{p'};p} = \begin{bmatrix} f \mid DS_{ke} ; CF_{kc} \mid \\ f \mid DS_{ke} ; CF_{ke} \mid \end{bmatrix}$$

Thus the equilibrium conditions of the initial state can be written in the following new form:

$$F_D = f\, v_p\,(C_D) \, ; A_{p\min} \, / \, v_{p\max} \, / \, ; A\; S(/ke/) \tag{13}$$

The unknown C_D cannot be determined for individual flocculating particles, at least not in a deterministic way as the general curves (C_D, Re) are unknown for the third step of the AS technology. Hence if we consider that during the phase-separation process in the microsection the transport mechanism primarily characteristic for AS (the so-called adsorption-storage cycle) does not play a secondary role with respect to the coagulation-flocculation kinetic mechanism in the separation of phases as it is proved by photomicrographs, but it appears as a harmonic equilibrium alternative being the most sensitive indicator of the equilibrium state, then in the secondary clarifying process C_D would be

$$C_D = f(DS_{ke}, CF_{kc}) \tag{14}$$

and at simultaneous precipitation

$$C_D = f(DS_{ke}, CF_{ke}) \tag{15}$$

This is advantageous from the viewpoint of theoretical treatment, since intensive AS/k_c may be determined in an empirical way by direct measurements.

Regulation possibilities of the connection between wastewater treatment plants and receiving water bodies

In addition to intensives ($\varrho_{ke} - \varrho_{kc}$); ($V_{p\ \min} - A_{p\ \max}$) appearing in phase separation, the normalising effect of ITO'AS$_c$/$N(C_c, t_c)$ in (ξ, η) may be interpreted as a smoothing effect on the surface of flocculae due to the effect of different coagulating agents.

This "smoothing", erosion, and fraction, percussion and aggregation of the surface can be characterized by probabilities $\vec{m}(\xi, \eta)$. The resultant probability, $\vec{M}(\xi, \eta)$ may be obtained by aggregating the probabilities of individual processes:

$$\vec{M}(\xi, \eta) = \lambda\, \vec{F}_R\,(\xi, \eta) = \Sigma\, F_R(\xi, \eta) \text{ and} \tag{16}$$

$$\vec{M}(\xi, \eta) = \Sigma \vec{m}(\xi, \eta) \tag{17}$$

In transport, $V(23, 34)$, vector M provides the total amount of work used for purification. The direction and numerical value of vector $\vec{M}$ may be utilized in the synchronization of airing and secondary clarifier in subsystem 3 (Fig. 3), what means a possibility for improving the efficiency of the plant.

With vectors $\vec{M}$ determined for plants operating with activated sludge, in larger regions a vector polygon can be constructed which provides information on the resultant movement of the AS systems in the region and makes the setting of regional ecological balance possible for the determination of the extent and direction of regulation required.

One of the means for regulating the connection between the wastewater treatment plant and the receiving water body is the distribution of load $N_v(\eta, \sigma)$.

In Figure 7 the distribution of the optimum intensive k_0 for phase separation is shown in %. From this, the difference in loads can be forecasted for the mass transport $V(OC, 2; 34)$. The pointing out of mechanisms ensuring the dynamic equilibrium of the system became necessary for establishing just this.

1. We introduce the concept of delayed transport process T_d (Fig. 8). Then

$$V_{34}(t) = f(V_{02}(t - T_d); V_{C2}(t - T_d)) \tag{18}$$

where function f is defined in coordination system (i, j), i.e. it is of extensive nature, correspondingly to Fig. 8A.

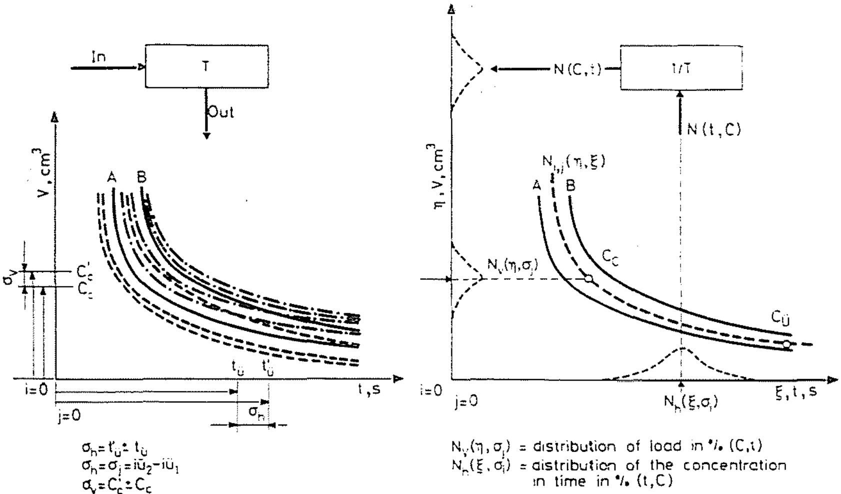

Fig. 7

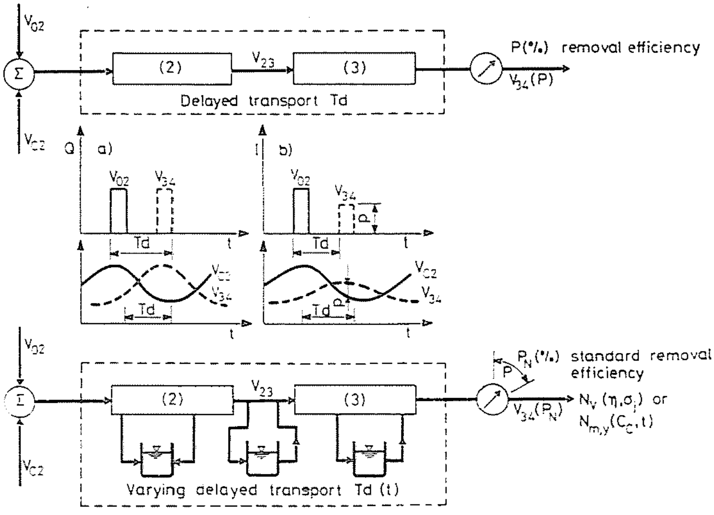

Fig. 8. Regulation of subsystems 2 and 3

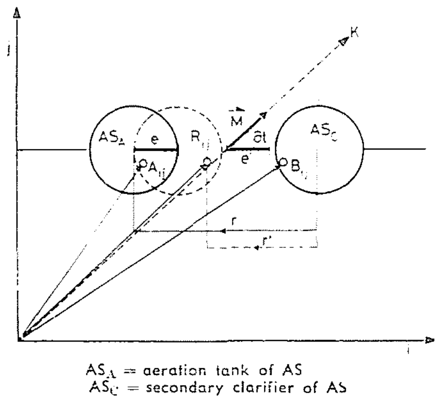

Fig. 9. Subsystem of e = operation shift and r = f(e) recirculation in the macrosection of system (i, j)

2. In the macrosection of subsystem 3 the peaks in load different from standards can be smoothed by recirculation and simultaneous temporary storage as is shown in Fig. 9 This requires the adjustment of T_d according to the function of the intensive p (Fig. 8B), where p is the probability of the removal of loading pollutants. Optimum removal efficiency can be established obviously only when knowing the load $V_{23}(p)$.

In the first case the time of transport is invariant, since the distribution of output $V_{34}(p)$ is similar to that of input $V_{23}(p)$. This is not consistent with the other parameters of the connection system of wastewater treatment plants and receiving water body. Hence, considering that $T_d(p)$ is not time-invariant, the load intensive of $0 < p(\xi, \eta) < 100\%$ is given by distribution $N_{m,n}(C_c, t)$ (Fig. 7), as the optimum efficiency of the plant in system (i, j) (Fig. 8).

The $V_{23}(p) > N_{m,n}(C_c, t)$ means a state load which requires modification of $T_d(p)$ by temporary storage or recirculation. The role of recirculation is illustrated in Fig. 9. Storage may be realized similarly to a facultative pool before subsystem 3 by $T_d(t)_5$ and after it by $T_d(t)_4$. It may also be realized inside the subsystem on the basis of the standard removal efficiency $P_N(\%)$ (Fig. 8).

Considering all this and based on earlier experience the connection between the wastewater treatment plant and the receiving water body, the analysis of the flow of matter $m(V_{34}, V_{40})$ is written with the transport approximation

$$m[(i, e)_{34}; (i, e)_{40}] \tag{19}$$

Interaction of water management and water quality in the connection of wastewater treatment plant and receiving water body

The description of the above connection has been attempted on the basis of the law of the conservation of matter by using the intensive parameters of mass transport. It is supposed that the yearly normal distribution of the intensive characterising the receiver water body can be given and let it be

$$N_m(i_{40}; e).$$

If the ratio of extensive is nearly constant in flow (V_{34}, V_{40}), the distribution of the intensives of the transport from the side of the plant is characterised by $N_{m,n}(C_c, t) = N_m(i_{34}, e)$.

Thus

$$N_m(\sigma_{i,e}) = N_m(i_{40}; e) - N_{m,n}(C_c, t) \tag{20}$$

In this case information can be obtained concerning the necessary intervention for synchronising the plant and the receiving water bedy in order to protect water quality.

The general form of Eq. (20) is:

$$N_m\,[i_{34}, e; i_{43}, e] \text{ where } e \approx k \tag{21}$$

If this is solved so that the extensives are considered state variants, then information can be obtained for water management. The general form of the equation may be given as:

$$N_m[e_{34}, i; e_{40}, i] \text{ where } i \approx k \tag{22}$$

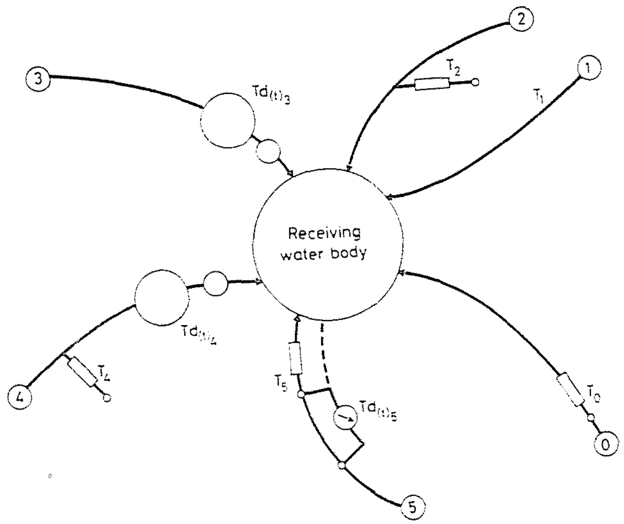

Fig. 10. Connection to the receiving system

From this it follows that the total solution of the connection provides the complete exploration of the interaction between water quality and water management Fig. 10. The most general form of this interaction can be written as

$$N_m[e \mid i \mid_{34} ; e \mid i \mid_{40}] \text{ where } e, i \neq k \tag{23}$$

The detailed elaboration of the practical applicability of this latter correlation is the most important task of future research.

Denotations

c = change of the intensive
c_p = intensive change of phosphorus
AS_p = effect of the technological subsystem of AS macrosection on the liquid around the organic mass
$AS_{p'}$ = effect of the technological subsystem of AS macrosection on the organic mass
e = amount of matter or energy
$e(ip)$ = amount of matter or energy in function of the intensive of phosphorus
k = kinetic change in the transport of matter,- energy
k_c = time distribution of the kinetic change in intensive c
Y_n = AS macrosection, vector of its subsystem
Y_1 = technology

Y_2 = planned
Y_3 = operational
X_k = arrangement of k in the subsytem of Y
$Y_1(x_1)$ = bardenpho
$Y_1(x_2)$ = Phoredox
$Y_1(x_3)$ = UCT, etc.
$C_p(t)$ = kinetic acceleration or deceleration of the P-intensive
$K_{C_x}^{p}$ = acceleration or deceleration of the intensive as a result of introducing arrangement x
$Y(x)$ = introduction of arrangement X carried out in the subsystem of macrosection AS
X = effect of change in arrangement X of subsystem AS on organic material or sewage at submicro level (AS_p, p')
a_{ij} = technological coefficient matrix
T_p = nutrient load (transport)
T_c = phosphorus load (transport)
AS_c = dynamic effect of activated sludge technology in the settling pool.

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