Journal of Environmental Science and Engineering, 5 (2011) 1084-1091

# Prediction of the Nutrient Retention Capacity of the Rehabilitated Gemenc-Béda-Karapancsa Floodplains

Zs. Derts and L. Koncsos

*Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics (BME), Budapest H-1111, Hungary*

Received: January 25, 2011 / Accepted: March 25, 2011 / Published: August 20, 2011.

**Abstract:** The GEF-WB Nutrient Reduction project aims to reduce the phosphorus inputs of the Black Sea from the Danube by means of different interventions. Hungary takes part of this project by enhancing the nutrient trapping capacity of the Gemenc and Béda-Karapancsa wetlands (GBK) which can be found on the premises of the Danube Drava National Park along the Danube River in Southern Hungary. Due to anthropogenic influences, less of small floods reach the oxbows of the area than some decades before which has a negative effect on the ecosystem. The objective of the study is to predict the nutrient reduction capacity of the Gemenc-Béda-Karapancsa water system and to make a proposal to increase this capacity. Although the floodplain vegetation has a huge nutrient intake capacity, this is limited by the fact that the floodplain is not always covered by the water of the river Danube. For that reason, a combination of hydrodynamic modelling, flood probability calculation and an estimation of suspended solids settling constitute the base of this study. The main course taken into account is the settling of suspended solids and the ratio of total nitrogen and total phosphorus to the mass of sediment is determined by local measurement results.

**Key words:** Floodplain, hydrodynamic modelling, suspended solids, settling, nutrient retention.

## 1. Ecological Situation of the GBK Floodplain

Significant areas of the seabed had been suffering from eutrophication, and the reduction of phosphorus inputs have resulted an ecological improvement in the Western Black Sea [1]. Hungary takes part in the WB-GEF Nutrient Reduction Project (of the Danube and the Black Sea) which–in Hungary–aims to reduce Budapests discharge of nutrients into the Danube River; to enhance the nutrient trapping capacity of Gemenc and Béda-Karapancsa wetlands; and to serve as an example for similar nutrient reduction initiatives [2].

Wetlands constitute vital links between water and land, and they are among the most biologically productive ecosystems in the world, providing a wide variety of ecosystem services such as improving water quality, reducing flood damage, preventing bank and shoreline erosion, recharging ground and surface water supplies etc. [3].

The 64 km long study area is located on the premises of the Danube Drava National Park along the Danube River between 1497 and 1433 river kms (rkms) in Southern Hungary, in particular between the Sió Canal and the Serbian and Croatian state border of Hungary. The area can be divided into two parts: Gemenc (northern) and Béda-Karapancsa (southern) regions (see Fig. 1).

The study area stretches over about 14,900 ha from which 600-600 ha are covered by river branches, side branches and other water bodies (see the land cover proportions in Table 1). The study area is divided into eleven parts and the calculations and estimations are executed for these separate places.

L. Koncsos, professor, main research field: environmental modeling. E-mail: koncsos@vkkt.bme.hu.

**Corresponding author:** Zs. Derts, Ph.D., main research field: environmental modeling. E-mail: derts.zsofia@vkkt.bme.hu.

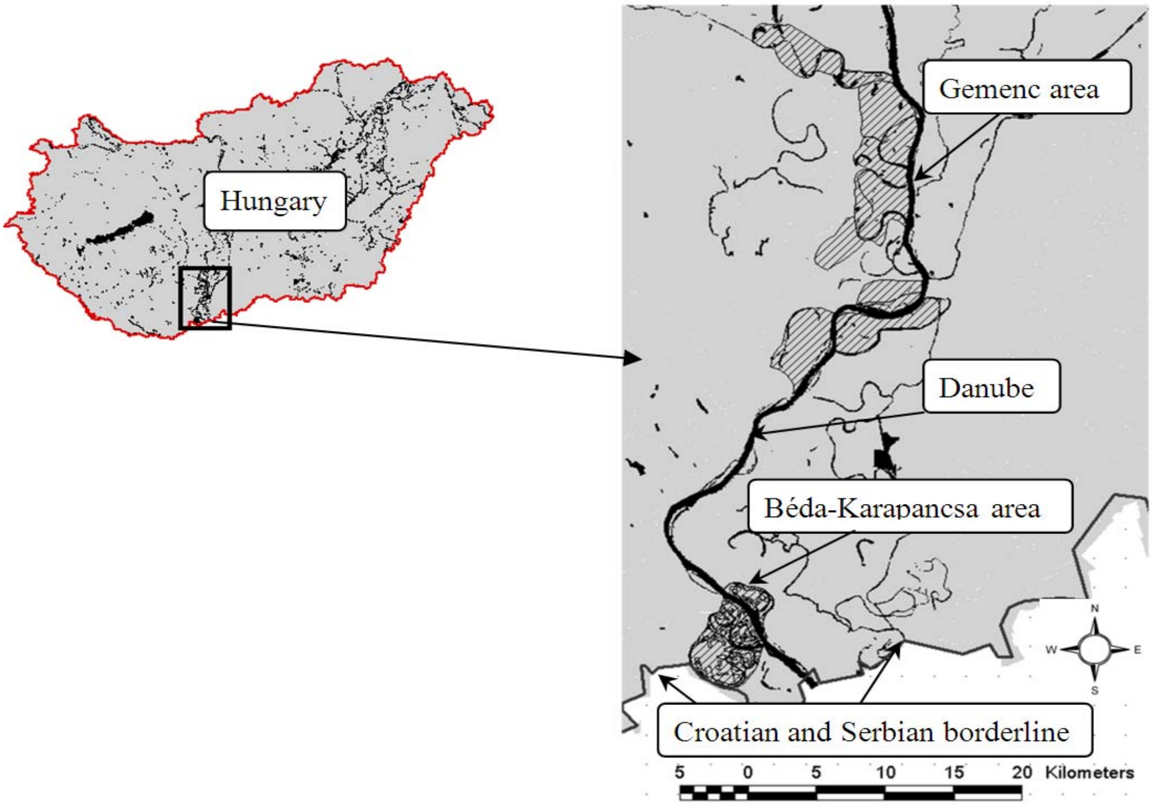


**Fig. 1 The Gemenc-Béda-Karapancsa study areas along the river Danube.**

**Table 1 Land use patterns in the GBK area.**

| Land cover type | Area [ha] | Proportion [%] |
|---|---|---|
| Artificial surfaces | 44 | 0.3 |
| Agriculture areas | 800 | 5.4 |
| Forests and semi natural areas | 12,473 | 83.8 |
| Wetlands | 360 | 2.4 |
| Waters from which | 1,212 | 8.1 |
| Rivers | 630 | 4.2 |
| Natural water bodies with continuous water supply | 582 | 3.9 |
| Total | 14,890 | 100.0 |

## 2. Identification of the Problem and Objectives

In case of the floodplains of the Danube River in Hungary, the main disadvantageous anthropogenic activities have resulted a great reduction of these areas, their progressive filling up during flood events, and a consequent decrease of the Danube river bed height due to dredging [3]. The latter one is proved by trend analyzes of the water level series: a definite negative tendency can be identified on Fig. 2 which resulted a decrease of the frequency of lower floods. As less of fresh water gets in the side branches and oxbows, the water exchange between the main river bed and the elements of the floodplain became weak, which has a negative influence on the whole ecosystem.

The main objectives of the GEF project in the GBK include involvement of the nutrient reduction capacity of the floodplains and ameliorating the ecological state of the study area by the improvement of the gravitational communication between the Danube and the water system.

As a result of the main problem, the objective of the

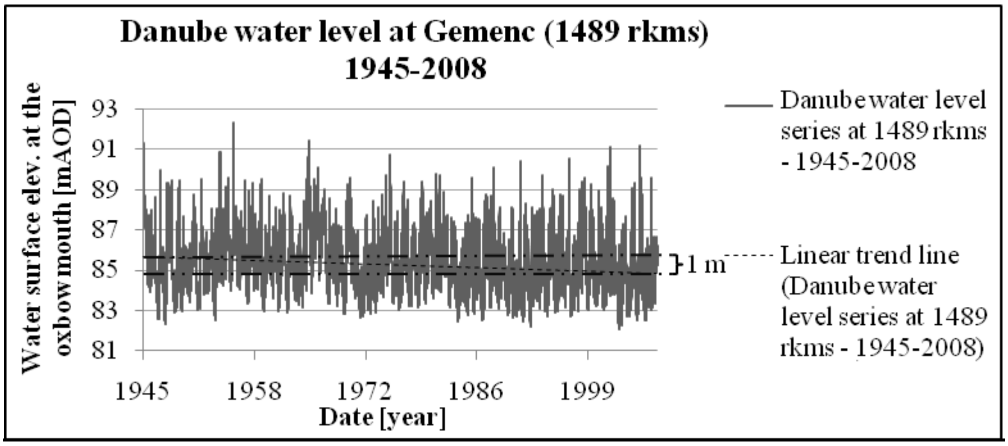


**Fig. 2 Decrease of the water level of the Danube due to the sinkage of the riverbed.**

study is to predict the nutrient reduction capacity of the Gemenc-Béda-Karapancsa water system and to make a proposal to increase this capacity.

## 3. The Concept of the Study

The huge nutrient intake capacity of the floodplain vegetation has already been proved in Ref. [4], but this retention is limited by the fact that the floodplain is not always covered by the water of the river Danube. For that reason, a combination of hydrodynamic modelling of advective transport, probability calculation and an estimation of suspended solid settling constitute the base of this study.

It was assumed that the water quality on the floodplain is the same as in the Danube river bed. The main course taken into account is the settling of suspended solids and the ratio of total nitrogen (TN) and total phosphorus (TP) to the mass of sediment is determined by local measurement results of BME.

These statements are explained in details in the following chapters.

## 4. Phosphorus and Nitrogen Retention in the Branches

As water surfaces represent about eight percent of the whole floodplain in which four percent is occupied by side branches and oxbows, the main part of the nutrient retention occurs on the floodplain. The maximal nutrient retention capacity of the side branches and oxbows is the entire nutrient flow from the Danube to the branches, which is obviously a theoretical maximum.

As the water level increases in the Danube, it attains a level when the flow reaches the side branches and oxbows. In the interval $z_{D,max}$–$z_{br,}$ (see Fig. 3) there is connection only between the main river and its branches. When the Danube water level exceeds the top of the side branch river bed, the water starts to flow to the floodplain.

The maximum value of the nutrient reduction of the side branch–oxbow system is the total quantity of nutrients getting into the branches: it would result 100% efficiency in the branches, which is an upper estimation of the reality. It means that the calculation of the annual nutrient retention potential of the branches is based on the next relation:

$$M_{max,br} = n \cdot C_0 \cdot V_{br} \tag{1}$$

Where,

$M_{max,br}$ is the maximal nutrient mass retention of the branch system [tonnes/year];

n is the annual average number of small floods: the periods when Danube water level reaches $z_{D,max}$ but doesn't exceed $z_{br}$ (see Fig. 4);

$C_0$ is the background concentration of the studied components [g/m$^3$];

$V_{br}$ is the maximal volume capacity of the side branch and oxbow system [106 m$^3$].

The number of small floods was determined for the

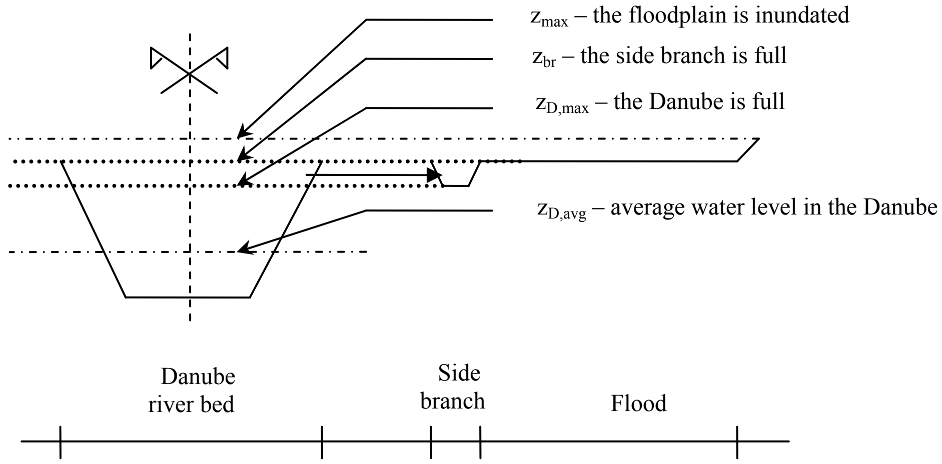


**Fig. 3 Communication between the main river bed and the water system in function of the water level in the Danube.**

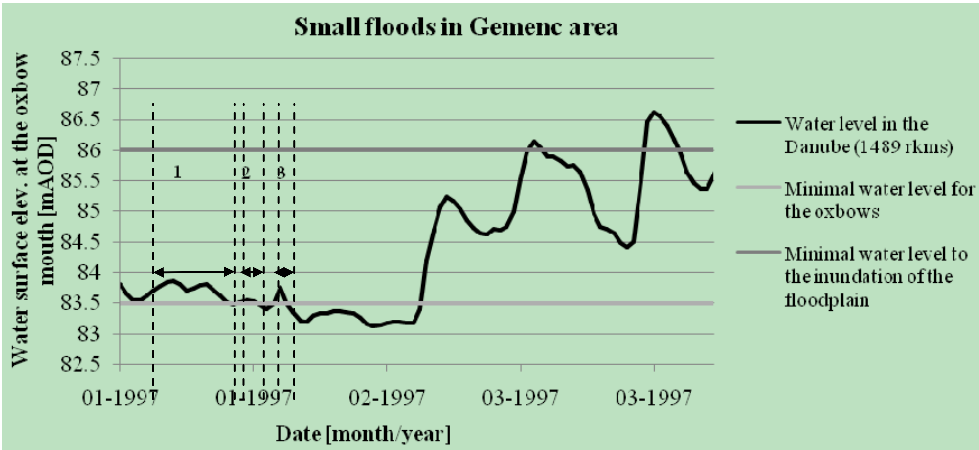


**Fig. 4 Definition of small floods that reach only the side branches and oxbows.**

different parts of the study area: it resulted an average of six periods per year (it varied between one and nine small floods per year).

To calculate the background concentration resulting from the Danube flow, it was assumed that the composition of water is the same as that in the main river bed. Hence, the concentrations were determined in function of the flow of the Danube by means of basic water quality monitoring data. The applied equation was:

$$C_{SS} = 0.2948 \cdot Q_{Danube}\,[m^3/s]^{0.5837}\ [mg/L] \quad (2)$$

The concentration of total phosphorus was determined in function of the suspended solid concentration and an equation between the total nitrogen and total phosphorus concentrations was applied:

$$C_{0,TP} = 0.000604 \cdot C_{0,SS} + 0.17146\ [mg/L] \quad (3)$$

and

$$C_{0,TN} = 3.75 \cdot C_{0,TP}\ [mg/L] \quad (4)$$

This last one was proved by measures taken in the flood sediments on the area: a proportion of 1 : 3.75 was detected between the concentration of total phosphorus and of total nitrogen.

The total volume of the branch system was estimated by means of the cross-sections of the side branches and oxbows, of the information concerning the length of the branches and of the CORINE Land Cover data base which contains the size of different water surfaces in the study areas.

This estimation resulted that the total surface of the side branches and oxbows is approx. 500 ha which equals 4% of the total surface of the study area; the volume of the branch system occupies about 9 million $m^3$s which equals 3% of the total water volume that can cover the floodplain. Hence, after summarizing the nutrient retention of the side branches and oxbows, $M_{br,TSS}$ is 1300 t/yr, $M_{br,TP}$ is 7.3 t/yr and $M_{br,TN}$ is 27 t/yr.

It has to be underlined that these values give an upper estimation of the realistic nutrient retention in the branches.

## 5. Nutrient Retention Estimation for the Floodplains

### *5.1 Two Dimensional Floodplain Modelling*

By means of a hydro-dynamic model developed specifically for this problem [5], flood events were simulated for each part of the whole study area.

Our input data were:

(1) 3D surface elevation model for the whole study area;

(2) selected Danube water levels at given sections of the river-chosen after the study of the floodplain surface;

(3) Danube flow-calculated by an empirical Q-H curve.

Our simulation results were (for each chosen Danube water level in each area):

- flood volume;
- flooded area;
- average water depth;
- floodplain flow and;
- residence time.

These output data were applied in the further calculations.

### *5.2 Annual Frequency of the Danube Water Levels*

However highest floods are the most effective in suspended solid sedimentation, these events happen rarely. To take this into account, the nutrient reductions and the annual durations (probabilities) will be multiplied at the end to get a weighted sum.

As the average water level has been in a continuous decrease during the past decades, to determine the average annual duration of the selected Danube water levels, only the data of the last thirteen years were used. The probability (in %) and the average annual duration (in d/yr) were calculated with an empirical water level distribution function set up from the available water level data interpolations to the selected Danube river sections.

### *5.3 Calculation Methodology of the Nutrient Retention Capacity*

The further calculations are based on the reactor principle, which handles the study areas as boxes where the trapped nutrients are calculated from the difference of the incoming and outgoing nutrient mass flow for each analyzed component.

For the floodplains, the same assumption was taken into consideration as in case of the branches: the water quality on the floodplain is the same as in the main river bed.

### *5.4 Background Loading of the Floodplain from the Danube Main River Bed*

When examining the removal of the suspended solids (SS), the assumed determinative process was sedimentation. Based on empirical relationships concerning the Danube [6] for three suspended sediment fractions, a function between the settlement velocity and the particle size and their distribution has been used for our calculation (see Table 2).

The background loading has been calculated as the sum of the total phosphorous connected to the three separate fractions:

$$L_{0,i} = C_0 \cdot p_i \cdot Q_{ht} \tag{5}$$

and

$$L_0 = \Sigma L_{0,I} \tag{6}$$

Where, $L_{0,I}$ is the background loading connected to a certain fraction of the sediment of the Danube [g/s];

$C_0$ is the suspended sediment concentration of the Danube at Baja [g/m$^3$];

$p_i$ is the occurrence probability of a given particle fraction in the suspended sediment [-];

$Q_{ht}$ is the aggregated discharge for the study area

**Table 2 Suspended sediment fractions and their settlement velocities for the Danube.**

| Fraction type | Average particle size [mm] | Ratio of the total sediment [%] | Settlement velocity [cm/s] |
|---|---|---|---|
| Lean clay | 0.0067 | 22 | 0.004 |
| Silt | 0.0202 | 51 | 0.037 |
| Fine sand | 0.0750 | 27 | 0.505 |

from a certain discharge at the Danube, based on the hydrodynamic model [$m^3/s$];

$L_0$ is the total background loading for a study area [g/s].

*5.5 The Amount of the Suspended Solids, Total Nitrogen and Total Phosphorus in the Areas*

The TN and TP concentrations are related to the settled suspended solids, and the assumed advective transport processes were calculated by the hydro-dynamic model ARES mentioned in a previous chapter.

The rate of the settlement depends on the background concentration, the average depth on the floodplain, the residence time and the settlement velocity. With respect to the latter one the settled suspended sediment has been determined for each particle fraction separately assuming advective transport:

$$C_i = p_i \cdot C_0 \cdot \exp(-1/h_m \cdot v_{s,i} \cdot t_r) \quad (7)$$

$$L = \Sigma L_i = \Sigma Q_{h,t} \cdot C_i \quad (8)$$

Where,

$L_i$ is the mass flow leaving the study area for each particle fraction [g/s];

$C_0$ suspended sediment and total P concentration of the Danube main channel [$g/m^3$];

$C_i$ suspended sediment and total phosphorus concentrations connected to each fraction [$g/m^3$];

$h_m$ mean water depth over a certain study area for a certain discharge [m];

$v_{s,I}$ settling velocity for a certain particle fraction [m/hour];

$t_r$ is the residence time in a given study area at a certain discharge [hour];

dL is the total suspended sediment or phosphorus settling over the floodplain of a study area, which is calculated as the difference of the outgoing and incoming mass flow:

$$dL = \Sigma p_i \cdot Q_{h,t} \cdot C_0 - L_i \text{ [tonnes/year]} \quad (9)$$

As a last step of our study, the total removed suspended solid quantity has been calculated as a difference between the background loading and the mass flow leaving the study area for the whole year and the annual probability of the related water surface elevation was also taken into account. The sum of the values belonging to each of these intervals gave us the total quantity of the annual suspended solid retention.

Based on empirical relationships a density of 1.8 $t/m^3$ was assumed for the suspended sediments, therefore an average annual sediment thickness caused by the floods of the Danube was possible to be estimated over the surface area of each study area.

In case of the total phosphorus and total nitrogen, measured concentrations in the soil (which is the sediment of the suspended solids) were applied as proportions:

$$C_{TP} = 0.8 \text{ g TP/m}^3 \text{ sediment} \quad (10)$$

$$C_{TN} = 3.0 \text{ g TP/m}^3 \text{ sediment} \quad (11)$$

## 6. Modelling and Nutrient Retention Calculation results

The hydrodynamic simulations executed for this study resulted several output data concerning each part of the floodplain areas, and these results were applied in the further calculations. The final results of the nutrient reduction calculations will be presented in this chapter.

The results suggest that with the increasing water level the flow rates are increasing as well as the flooded areas, flood volume and water depth, and also the residence time. As it was explained before, the total flood durations (probabilities) are decreasing with the rise of the water level.

Our final results are presented in Table 3.

Due to the accuracy of our calculations, it is expedient to give intervals for the total amount of the

**Table 3 Final nutrient retention results for the Gemenc-Béda-Karapancsa study area.**

| Area | Surface | Sedimentation SS | | Nutrient retention TN | TP |
|---|---|---|---|---|---|
| number-name | ha | cm/yr | t/yr | t/yr | t/yr |
| 1-Veránka | 1,704 | 1.067 | 10,297 | 30.9 | 8.2 |
| 2-Buvat | 713 | 0.349 | 7,425 | 22.3 | 5.9 |
| 3-Mocskos | 3,321 | 0.262 | 12,651 | 38.0 | 10.1 |
| 4-Sió-mente | 2,066 | 0.044 | 4,274 | 12.8 | 3.4 |
| 5-Gemenc | 1,298 | 0.368 | 4,865 | 14.6 | 3.9 |
| 6-Báta | 1,766 | 0.240 | 10,319 | 31.0 | 8.3 |
| 7-Fekete-Erdő Grébec) | 782 | 0.115 | 5,562 | 16.7 | 4.4 |
| 8-Kerülő-Duna | 760 | 0.283 | 3,865 | 11.6 | 3.1 |
| 9-Báli | 621 | 0.333 | 8,310 | 24.9 | 6.6 |
| 10-Móric | 324 | 0.105 | 1,994 | 6.0 | 1.6 |
| 11-Nagy-Pandúr | 1,534 | 0.085 | 9,086 | 27.3 | 7.3 |
| Total | 14,890 | | 78,649 | 235.9 | 62.9 |

annually retained quantities. Thus, the hydro-dynamically proved retention capacity of the GBK area for the suspended solids is 60000-90000 tonnes/year, for the total nitrogen 200-250 tonnes/year and for the total phosphorus 50-70 tonnes/year. The nutrient reduction capacity of the whole floodplain is about 7-10 times the annual retention of the side branches and oxbows.

## 7. Conclusion and Proposal

The sinking of the Danube river bed–an impact of human activities–is significant and it influences the water communication between the main river and the floodplain water system in a harmful way.

In case of floods characterized by higher Danube water levels, the suspended solid sedimentation and the nutrient retention occurs at a higher intensity but these–efficient–flood events happen rarely. Therefore, the summarized retention of the studied components had to be calculated in function of the probability (annual duration) of the flood events.

If a given water coverage eventuated at a higher probability, the nutrient reduction capacity of the water system could increase. The water communication of the side branches and oxbows could be improved by small interventions and these could also lead to an improvement of the ecological status of the area.

The nutrient reduction capacity of the whole floodplain is about 7-10 times the annual retention of the side branches and oxbows, and if the whole floodplain could be involved in frequent flood events, the quantity of the retained nutrients of the Gemenc-Béda-Karapancsa area could reach a very good efficiency. In this case it also has to be noted that drastic interventions-which would lead to better nutrient retention efficiency-could be harmful to the nature, hence the objectives and the possible effects have to be examined before the constructions.

After the modelling work and calculations, we can conclude that these results should be corrected after justification measurements and further modelling work.

## Acknowledgements

The problem identification of the study took part in the Nutrient reduction GEF project of Hungary (#TF 055978), the methodological concept and the development of the hydrodynamic model took part of the WateRisk project (TECH_08_A4/2-2008-0169) and the ecological water budget is a field of the SCENES project (032822)–which are all projects of the Budapest University of Technology and Economics (BME), Department of Sanitary and Environmental Engineering.

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