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Contribution to the Modeling of the Gradual Submersion of Phosphorus in the Hammam Bouhgrara Dam (Wilaya of Tlemcen, Algeria)

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Abstract

Incthe present study, carried out on the Hammam Boughrara dam (impounded in 1999), a number of phosphorus balance models were applied, namely, Vollenweider (1969), Dillon and Rigler (1975), Walker (1977), Reckhow (1977) and Ostrofsky (1978) models. In order to take into account, the rate of gradual submergence of flooded surfaces which is ordinarily characterized by an important increase in the trophic status as a result of endogenous inputs of phosphorus by leaching we have tried to adapt the Ostrofsky model (1978) to the reality of studied dam, by adding a new dimension. The obtained results show that the proposed model seems relevant.

Keywords: balance; eutrophication; Hammam Boughrara; modeling; phosphorus.

INTRODUCTION

Balance models of nutrient elements in a lacustrine system date back to the early 1960s. Reductionist researchers prefer to study a system globally to calculate the concentration of a nutrient in the lake on the basis of input loads [1]. We are principally interested by this type of models. Numerous researchers have attempted to explain both anthropic and natural actions on a lake by a model using phosphorus as an interference tool on the quality of a lake [2-5].

The big interest of using this kind of models led us to formulate two guiding objectives for the present study on Hammam Boughrara dam. They are:

- In one part, to determine whether these models are suitable to the lake and, in the other, to examine their accuracy with respect to observed reality.
- To explore the possibility of adapting this methodology to the artificial ecosystem (dam). Hence, it is important to develop the period following the impoundment, which is often marked with an enrichment of the water by leaching. On the basis of Ostrofsky model [6], we have added a dimension allowing us to take into account the progressive flooding of surfaces.

MATERIALS AND METHODS

Presentation of the site

The basin of Oued Mouillah, which belongs to the watershed of the Tafna (7245 km^2) and regulated by the dam Hammam Boughrara, is located in the extreme northwest of the province of Tlemcen (Western Algeria). It occupies an area of 2000 km^2 with a perimeter of 241 km. The basin is largely shared with Morocco (Fig-1).

It is characterized by a semi-arid climate. The annual temperatures vary between 15.7 and 18.4 °C (period of 1977-1995). The precipitations are relatively low and unevenly distributed during the year. The annual average is 297 mm (period of 1977-1995). Actual evaporation on the open water at the level of confluence of Oued Mouillah and Tafna was estimated at about 1167 mm per year [7].

Annual specific sediment registered yields are in majority weak, they vary between 17.3 and 1038.4 $t.km^{-2}.\ yr^{-1}$ and the interannual average is 252.1 $t.km^{-2}.\ yr^{-1}$ [8]. Consequently, a flow deficit of around 70% has been resulted since the late 1970s [9]. It is emphasized that during the study period, the flow rate interannual did not exceed 6% and that this basin is part of Tafna that receives less aggressive rains [10].

Hammam Boughrara dam is located at the confluence of Oueds Mouillah and Tafna. A capacity of

177 million m^3 of which 59 million m^3 are regularized and 23.30 million m^3 constitutes the dead volume. The area of its water body varies from 2.5 to 4.8 km^2. Its average and maximum depths are 15m and 32m respectively. The dam is designed mainly to satisfy the drinking water power needs of Oran (33 million m^3) and Maghnia (17 million m^3) cities. Nine (9) hm3 are planned for irrigation. It was noticed that before the dam construction, no ecological study allowing predicting the development of its water quality has been conducted [7].

Mathematical Modeling Of The Phosphorus Balance

Ostrofsky Model [6]

This model is based on the Vollenweider approach. The author suggests taking account inputs of phosphorus from flood-borne soil and vegetation when establishing the balance equation during impoundment of the reservoir. The Vollenweider [2] conventional balance equation can be written as:

$$\frac{dP_t}{dt} = P_E - (\rho + \sigma)\, P_t \quad \text{(01)}$$

Ostrofsky suggests completing the Vollenweider model [2] with another variable that has a temporal dimension to account for indigenous inputs of phosphorus due to leaching of organic matter in newly flooded soils. He estimates that the amount of phosphorus leached from the basin of the reservoir can be expressed by the following global equation:

$$P_{Lt} = P_F\,(1 - e^{-\alpha t}) \quad \text{(02)}$$

Where:

P_{L_t} : Total phosphorus leached at time *t* (kg);

P_F : Quantity of potentially leachable of phosphorus (kg);

α : Coefficient of leaching (yr^{-1})

Where the rate of phosphorus leached will be given by:

$$\frac{dP_{Lt}}{dt} = \alpha P_F e^{-\alpha t} = \mathrm{B} e^{-\alpha t} \quad \text{(03)}$$

So phosphorus balance model can be written as follows:

$$\frac{dP_{Lt}}{dt} = P_E + Be^{-\alpha t} - (\rho + \sigma) P_t \quad \text{(04)}$$

Where:

$Be^{-\alpha t}$: indigenous phosphorus intake;

The analytical solution of the equation 04 is:

$$P_t = \frac{P_E}{\phi}\left(1 - e^{-\phi t}\right) + \frac{B}{(\phi - \alpha)}\left(e^{-\alpha t} - e^{-\phi t}\right) + P_o e^{-\phi t} \quad \text{(05)}$$

Where:

$\phi = \rho + \sigma$ *:* Mathematical artifice.

P_0 : Initial quantity of phosphorus in the reservoir.

Adapting the Ostrofsky model [6]

The weakest hypothesis that we have noticed in the Ostrofsky model [6] is that it takes reservoir filling time as instantaneous, marking the immediate commencement of leaching on all flooded surfaces of the reservoir. On this precise point, we have suggested replacing this hypothesis with a gradual participation in leaching of flooded areas.

To account for the time of filling when estimating indigenous phosphorus leaching inputs after the impoundment of a reservoir, we have assumed that the amount of potentially leachable phosphorus (P_F) is directly proportional to the surface of the submerged area, which can be given by:

$$P_F = KS_i \quad \text{(06)}$$

Where:

S_i : Flooded area (m^2);

K : Proportionality constant (mg P.m^{-2}) (Potentially leachable phosphorus per m^2 flooded area, also called P_F unitary).

It means that:

$$P_{Lt} = KS_i(1-e^{-\alpha t}) \quad \text{...} (07)$$

So for S_1, we will have $KS_1(1-e^{-\alpha(t^*-0)})$;

For S_2- S_1 we will have $K\left(S_2-S_1\right)(1-e^{-\alpha(t^*-t_1)})$;

For S_n- S_{n-1} we will have $K\left(S_n-S_{n-1}\right)(1-e^{-\alpha(t^*-t_{n-1})})$;

The summation gives the total quantity of leached phosphorus at time t^*. It is easy to check that the following integral formula holds*:*

$$P_{L_{t^*}} = \int_0^{t^*} KS'(t)\left(1-e^{-\alpha(t^*-t)}\right)dt \quad \text{...} (08)$$

Where: $S'(t) = \dfrac{dS}{dt}$

To estimate the leaching rate $\dfrac{dP_{L_{t^*}}}{dt^*}$ we use Leibnizt rule of differentiation of an integral. Therefore, it remains

$$\frac{dP_{L_{t^*}}}{dt^*} = \int_0^{t^*} \alpha KS'(t)e^{-\alpha(t^*-t)}dt \quad \text{...} (09)$$

Otherwise, the flooded area depending on time can be expressed by a function such as:

$$S(t) = S_{\max}\left(1-e^{-at}\right) \quad \text{...} (10)$$

$S_{\max}$: Total flood area (km²);

a : Submersion coefficient (yr^{-1});

t : Elapsed time since the start of impoundment (yr).

The flood rate $\dfrac{dS(t)}{dt}$ will be given by:

$$S'(t) = a.S_{\max}.e^{-at} \quad \text{...} (11)$$

Substituting in the equation 09 we obtain the leaching rate:

$$\frac{dP_{L_t}}{dt} = \int_0^t \alpha Ka.S_{\max}.e^{-ax}e^{-\alpha(t-x)}dx \quad \text{...} (12)$$

$$\frac{dP_{L_t}}{dt} = a\alpha K.S_{\max}\left(\frac{e^{-at}-e^{-\alpha t}}{\alpha-a}\right) \quad \text{...} (13)$$

For $\alpha \neq a$

One can rewrite the modified equation of the balance sheet as follows:

$$\frac{dP_{L_t}}{dt} = P_E + a\alpha K.S_{\max}\left(\frac{e^{-at}-e^{-\alpha t}}{\alpha-a}\right) - (\rho+\sigma)P_t \quad \text{..............} (14)$$

The equation (14) will have the solution:

$$P_t = \frac{P_E}{\phi}\left(1-e^{-\phi t}\right)+\frac{L}{(\alpha-a)}\left(\frac{\left(e^{-at}-e^{-\phi t}\right)}{(\phi-a)}+\frac{\left(e^{-\phi t}-e^{-\alpha t}\right)}{(\phi-\alpha)}\right)+P_0e^{-\phi t} \;... (15)$$

We find that this model is therefore a generalization of those of Ostrofsky [6] and Vollenweider [2]. This being the case, if the parameter "a" tends to infinity, this model is identical to that of Ostrofsky. If the time "t" tends to infinity, the response of the model is the same as Vollenweider [2].

RESULTS AND DISCUSSION

Application of the Ostrofsky model allowed us to plot the curve for the total concentration of phosphorus in the reservoir over time (Fig-1). It is noticed that this curve is divided into two main parts and that in the second part of the curve, from the 27th to the 108th months, the aspects of the Ostrofsky and Vollenweider models were combined, which gives the steady state of the Vollenweider equation.

Comparison of the values predicted by Ostrofsky and Vollenweider models with those measured shows that they are all of the same order. However, the measured values are slightly higher. From this, we can see that the model gives an overestimation in early impoundment, particularly from the 1st to the 26th months. This led us to recheck and discuss the initial assumptions of the Ostrofsky model, in which it consider the reservoir filling time is instantaneous. That means it gives a very short period of time to fill the reservoir (in the order of a month). In other words, the hypothesis assumes that any flooded area immediately releases phosphorus into the reservoir. Indeed, this seems to us the weakest hypothesis of Ostrofsky model—an appreciation echoed by Ostrofsky himself, who criticizes it as "the least realistic hypothesis of the model".

Consequently, we found it is necessary to deepen the Ostrofsky suggestion to take the filling time into account when estimating endogenous inputs of phosphorus in water. To do this, we have first estimated the gradually inundation of surfaces by applying equation (10).

The measured results and the values calculated by application of equation 15 (Fig-1) seem to us both satisfactory and consistent. The observations are well represented by the model. This allows us to say that the proposed model in the present study is closer to the reality of the dam than that of Ostrofsky.

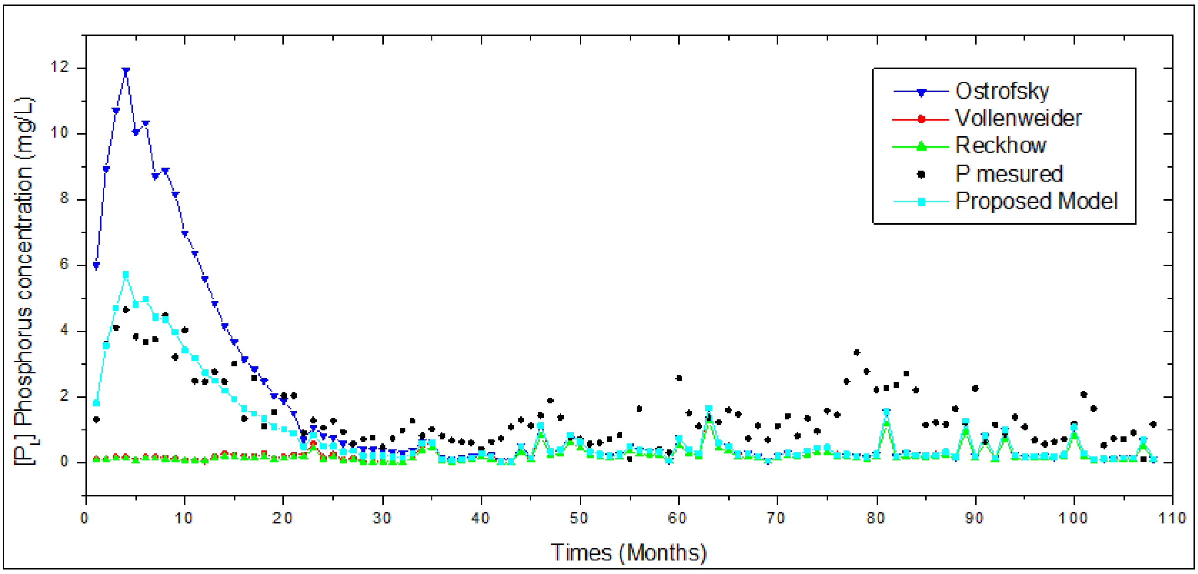

Fig-1: Total phosphorus concentrations versus time, observed and calculated by the model of Ostrofsky, Vollenweider, Reckhow and those proposed in this study after the impoundment of the dam

CONCLUSION

The application of these models to the Hammam Bouhgrara dam allowed us to highlight two important parameters. The first is characterized by a consideration of the temporal dimension in the flooding of areas during impoundment of the dam. As for the second, it takes into account the effect of the gradual flooding of flooded areas to leaching. Comparison of the obtained results with real in-situ measurements, that we possess, shows a good concordance and gives a good representation of the real situation of Hammam Boughrara dam.

Finally, the realized work in this study represents a step forward, nevertheless they should be improved by additional relevant studies to adjust and adapt their use to water bodies in the Mediterranean area.

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