Phosphorous mass balance of French vertical flow treatment wetlands

Nicolas Forquet

Pascal Molle

Karine Dufossé

Last modified September, 2024

This notebook describes the phosphorous mass balance estimation for French Vertical Flow (VF) wetlands. It is based on the first LCA inventory carried out by Risch *et al.* (2010). This updated version aims to take better account of experimental data. In particular, it focuses on data collected from a large number of full-scale French VF wetlands.

The mass balance is expressed in $g P⋅pe^{−1}d^{−1}$.

## Influent

Mercoiret *et al.* (2009) estimated the incoming COD flux to 2.1 $gP⋅d^{−1}⋅PE^{−1}$.

$$F\_{P}^{inlet}=2.1 \left[g⋅d^{−1}⋅pe^{−1}\right]  \left(1\right)$$

P <- list(inlet = list(total = set\_units(2.1, g/d/pe)))

This production is divided into 75% in the form of $P−PO\_{4}$ (1.575 g/d/PE) and 0.525 in organic form.

bilan.P["water - PO4-P","inlet"] <- set\_units(1.575, g/d/pe)
bilan.P["water - Porg","inlet"] <- set\_units(0.525, g/d/pe)

## Treatment wetland

For phosphorous, we do not make distincition between the first and second treatment stage. Phosphorous organic forms are assumed to be completely removed by filtration. However part of the phosphorous leaches out after the mineralization of the organic matter.

Based on the PlanteDefi database, the overall phosphorous removal efficiency is estimated to 20% and the outlet concentration mainly consists of $P−PO\_{4}$.

bilan.P["water - PO4-P","outlet"] <- (1-0.20) \* P$inlet$total

The difference between the $PO\_{4}−P$ inlet and outlet concentrations is assumed to be leached phosphorous.

leached.phosphorous <- bilan.P["water - PO4-P","outlet"] - bilan.P["water - PO4-P","inlet"]

The rest of the P-org is either stored in the biosolids or exported by the reeds.

P.stored <- bilan.P["water - Porg","inlet"] - leached.phosphorous

According to Tanner *et al.* (1996), the above ground above ground biomass production is 5 g/m²/yr and the below ground production is 6 g/m²/yr. It is assumed that the below-ground biomass will mineralize over time and is therefore neglected.

The above part is exported by mowing.

bilan.P["solid - reed","stored"] <- set\_units(5, g/m^2/yr) \* set\_units(1.35, m^2/pe) + set\_units(5, g/m^2/yr) \* set\_units(0.9, m^2/pe)

Consequently, the rest of the P-org is stored in the biosolids.

bilan.P["solid - biosolids","stored"] <- P.stored - bilan.P["solid - reed","stored"]

## Estimation of the phosphorous stored in the biosolids

Instead of estimating the phosphorous stored in the biosolids by difference, we can estimate it by considering the quantity of phosphorous that can actually be stored in the surface deposit. This can be done using measurements carried out by Molle (2003). The quantity of phosphorous stored in the surface deposit represent a significant fraction of the phosphorous stored in the biosolids but not its totality as some biosolids are entrapped within the porous media of the first and second treatment stage.

Molle (**Molle2003?**) measured the $P\_{2}O\_{5}$ concentration in the surface deposit (biosolids) to 1.46% of the dry matter. Considering the deposit accumulation rate of 2.5 cm/y (Molle, 2014) and the biosolid density of 300 $kg/m^{3} (Vincent, 2011), the mass of P2O5 accumulating in the biosolids can be estimated:

 P2O5.biosolids <- 0.0146
 biomass.density <- set\_units(300, kg/m^3)
 biosolids.growth.rate <- set\_units(2.5/365.5, cm/d)
 surface.1st.stage <- set\_units(1.35, m^2/pe)

 P2O5.accumulated <- P2O5.biosolids \* biomass.density \* biosolids.growth.rate \* surface.1st.stage
 set\_units(P2O5.accumulated, g/d/pe)

0.404446 [g/d/pe]

Using the stocheometry of P2O5, we can convert this value to P:

 P.surface.deposit <- P2O5.accumulated \* 0.436

Thsi value is within the range of magnitude of the P stored in the biosolids.

## Summary

kable(bilan.P)

|  | inlet | stored | outlet |
| --- | --- | --- | --- |
| water - Porg | 0.525 [g/d/pe] | 0.00000000 [g/d/pe] | 0.00 [g/d/pe] |
| water - PO4-P | 1.575 [g/d/pe] | 0.00000000 [g/d/pe] | 1.68 [g/d/pe] |
| solid - biosolids | 0.000 [g/d/pe] | 0.38919852 [g/d/pe] | 0.00 [g/d/pe] |
| solid - reed | 0.000 [g/d/pe] | 0.03080148 [g/d/pe] | 0.00 [g/d/pe] |

Results can also be presented using a Sankey plot:

Inputs <- as.numeric(c(bilan.P$inlet[1], bilan.P$inlet[2]))
Inputs <- round(Inputs,2)

Losses <- as.numeric(c(
 bilan.P$outlet[2],
 bilan.P$stored[3],
 bilan.P$stored[4]
))
Losses <- round(Losses,2)
Labels <- c("PO4-P", "Porg", "PO4-P", "biosolids", "reeds")
SankeyR(inputs = Inputs, losses = Losses, unit = "g/d/pe", labels = Labels)



Mercoiret, L., 2009. Qualité des eaux usées domestiques produites par les petites collectivités. ONEMA.

Molle, P., 2014. French vertical flow constructed wetlands: a need of a better understanding of the role of the deposit layer. Water Science and Technology 69, 106–112. <https://doi.org/10.2166/wst.2013.561>

Molle, P., 2003. [Filtres plantés de roseaux : limites hydrauliques et rétention du phosphore](https://hal.inrae.fr/tel-02583262) (PhD thesis).

Risch, E., Boutin, C., 2010. Rapports d’ACV et données d’inventaire.

Tanner, C.C., 1996. Plants for constructed wetland treatment systems A comparison of the growth and nutrient uptake of eight emergent species. Ecological Engineering 7, 59–83. [https://doi.org/10.1016/0925-8574(95)00066-6](https://doi.org/10.1016/0925-8574%2895%2900066-6)

Vincent, J., 2011. [Les lits de séchage de boue plantés de roseaux pour le traitement des boues activées et les matières de vidange : Adapter la stratégie de gestion pour optimiser les performances](http://www.theses.fr/2011MON20179) (PhD thesis).