Nitrogen mass balance of French vertical flow treatment wetlands

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This notebook describes the carbon 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 $g N⋅pe^{−1}d^{−1}$.

## Incoming nitrogen flux

Mercoiret *et al.* (2009) estimated the incoming COD flux to 15.5 $gN⋅d^{−1}⋅PE^{−1}$.

$$F\_{N}^{inlet}=15.5 \left[g⋅d^{−1}⋅pe^{−1}\right]  \left(1\right)$$

N <- list(inlet = list(total = set\_units(15.5, g/d/pe)))

Mercoiret *et al.* (2009) also provided the ratio of NH4-N/TKN at the inlet of the VF wetland. The average value is 0.74.

Therefore, the mass balance of the inlet can be completed:

bilan.N["water - NH4-N","inlet"] <- N$inlet$total \* 0.74
bilan.N["water - Norg","inlet"] <- N$inlet$total \* 0.26

## First treatment stage

### Water

The TKN removal rate between the inlet and the outlet of the first treatment stage is obtained from Morvannou *et al.* (2015) : 59%.

The average value of the ratio NH4-N/TKN at the outlet of the first treatment stage has been obtained from an INRAE database and equals 0.79.

TKN.1st.removal <- 0.59
bilan.N["water - Norg","first.stage"] <- (1-TKN.1st.removal)\*N$inlet$total \* 0.21
bilan.N["water - NH4-N","first.stage"] <- (1-TKN.1st.removal)\*N$inlet$total \* 0.79

NOx-N are produced by the nitrification of part of the removed TKN. The $NO\_{2}−N$ emission is set to 0.005 $gN/d/pe$. For the first treatment stage, Molle *etl al.* (2008) observed a nitrification rate of 55%.

bilan.N["water - NO2-N","first.stage"] <- 0.005
bilan.N["water - NO3-N","first.stage"] <- TKN.1st.removal \* N$inlet$total \* 0.55- bilan.N["water - NO2-N","first.stage"]

### Biosolids

Molle (Molle, 2003) measured the N content in the surface deposit of treatment wetland. The estimate is 0.9% of nitrogen in the dry matter.

The biosolids accumulation rate has been estimated in the C mass balance notebook to M.biosolids = 0.02764901 [kg/d/pe].

M.biosolids <- set\_units(0.02764901, kg/d/pe)
bilan.N["solid - biosolids","first.stage"] <- 0.9/100\*M.biosolids
print(bilan.N["solid - biosolids","first.stage"])

0.2488411 [g/d/pe]

### Reeds

The nitrogen content in reeds is estimated to 58 $gN⋅m^{−2}⋅y^{−1}$ by Tanner *et al.* (1996). The surface area of reeds per person is 1.35 $m^{2}⋅pe^{−1}$. Therefore, the nitrogen content in reeds is 0.21 $gN⋅pe^{−1}⋅d^{−1}$ for the first stage.

bilan.N["solid - reed","first.stage"] <- 58 \* 1.35 / 365.25

### Nitrous oxide emissions

Gaseous emissions on French VF wetlands have been measured by (Filali et al., 2017). For the first stage, gaseous nitrous oxide emissions have been estimated to:

$$N\_{2}O−N=0.34\% N\_{input}$$

and dissolved nitrous oxide emissions have been estimated to:

$$N\_{2}O−N=0.25\% N\_{input}$$

bilan.N["gas - N2O-N","first.stage"] <- 0.34/100 \* N$inlet$total
bilan.N["water - N2O-N","first.stage"] <- 0.25/100 \* N$inlet$total

### N2 emissions

The emissions of $N\_{2}$ have been estimated by difference:

bilan.N["gas - N2-N","first.stage"] <- N$inlet$total - sum(bilan.N$first.stage)

## Second treatment stage

### Water

The TKN removal rate between the inlet and the outlet of the two stages is obtained from Morvannou *et al.* (2015) : 84%.

The average value of the ratio NH4-N/TKN at the outlet of the first treatment stage has been obtained from an INRAE database and equals 0.79.

TKN.overall.removal <- 0.84
bilan.N["water - Norg","second.stage"] <- (1-TKN.overall.removal)\*N$inlet$total \* 0.21
bilan.N["water - NH4-N","second.stage"] <- (1-TKN.overall.removal)\*N$inlet$total \* 0.79

The $NO\_{2}−N$ concentration is assumed to be unchanged and equal to 0.005 $gN/d/pe$.

bilan.N["water - NO2-N","second.stage"] <- 0.005

In the PlanteDefi database, the average value of the ratio $\frac{NO3−N\_{outlet}}{TKN\_{inlet}}$ is 0.477.

bilan.N["water - NO3-N","second.stage"] <- N$inlet$total \* 0.477

### Reeds

The nitrogen content in reeds is estimated to 58 $g N \cdot m^{-2} \cdot y^{-1$ by Tanner *et al.* (1996). The surface area of reeds per person is 0.90 $m^{2}⋅pe^{−1}$. Therefore, the nitrogen content in reeds is 0.14 $gN⋅pe^{−1}⋅d^{−1}$ for the second stage.

bilan.N["solid - reed","second.stage"] <- 58 \* 0.9 / 365.25

### Nitrous oxide emissions

Gaseous emissions on French VF wetlands have been measured by (Filali et al., 2017). For the first stage, gaseous nitrous oxide emissions have been estimated to:

$$N\_{2}O−N=0.43\% N\_{input}$$

and dissolved nitrous oxide emissions have been estimated to:

$$N\_{2}O−N=0.21\% N\_{input}$$

bilan.N["gas - N2O-N","second.stage"] <- 0.43/100 \* N$inlet$total
bilan.N["water - N2O-N","second.stage"] <- 0.21/100 \* N$inlet$total + bilan.N["water - N2O-N","first.stage"]

Biosolid accumulation at the second stage is negligible and therefore not taken into account.

### N2 emissions

The $N\_{2}$ emissions have been estimated by difference:

bilan.N["gas - N2-N","second.stage"] <- bilan.N["water - Norg","first.stage"] +
 bilan.N["water - NH4-N","first.stage"] +
 bilan.N["water - NO3-N","first.stage"] +
 bilan.N["water - NO2-N","first.stage"] +
 bilan.N["water - N2O-N","first.stage"] -
 sum(bilan.N$second.stage)

## Summary

kable(bilan.N)

|  | inlet | first.stage | second.stage |
| --- | --- | --- | --- |
| water - Norg | 4.03 [g/d/pe] | 1.3345500 [g/d/pe] | 0.5208000 [g/d/pe] |
| water - NH4-N | 11.47 [g/d/pe] | 5.0204500 [g/d/pe] | 1.9592000 [g/d/pe] |
| water - NO3-N | 0.00 [g/d/pe] | 5.0247500 [g/d/pe] | 7.3935000 [g/d/pe] |
| water - NO2-N | 0.00 [g/d/pe] | 0.0050000 [g/d/pe] | 0.0050000 [g/d/pe] |
| water - N2O-N | 0.00 [g/d/pe] | 0.0387500 [g/d/pe] | 0.0713000 [g/d/pe] |
| gas - N2O-N | 0.00 [g/d/pe] | 0.0527000 [g/d/pe] | 0.0666500 [g/d/pe] |
| gas - N2-N | 0.00 [g/d/pe] | 3.5605852 [g/d/pe] | 1.2641342 [g/d/pe] |
| solid - biosolids | 0.00 [g/d/pe] | 0.2488411 [g/d/pe] | 0.0000000 [g/d/pe] |
| solid - reed | 0.00 [g/d/pe] | 0.2143737 [g/d/pe] | 0.1429158 [g/d/pe] |

Results can also be presented using a Sankey plot:

Inputs <- as.numeric(c(bilan.N$inlet[1],
 bilan.N$inlet[2]))
Inputs <- round(Inputs,2)
Losses <- as.numeric(c(
 bilan.N$second.stage[6]+bilan.N$first.stage[6],
 bilan.N$second.stage[7]+bilan.N$first.stage[7],
 bilan.N$second.stage[1],
 bilan.N$second.stage[2],
 bilan.N$second.stage[4],
 bilan.N$second.stage[5],
 bilan.N$first.stage[8],
 bilan.N$first.stage[9]+bilan.N$second.stage[9],
 bilan.N$second.stage[3]
 ))
Losses <- round(Losses,2)
Labels <- c("N-org", "NH4-N",
 "N2O-N", "N2-N",
 "N-org", "CNH4-N",
 "NO2-N",
 "N2O-N", "biosolids-N",
 "reed", "NO3-N")

SankeyR(inputs = Inputs,
 losses = Losses,
 unit = "g/d/pe",
 labels = Labels
 )



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