WAQTEL

Validation Manual

Version v8p5

December 1, 2023

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Contents

1. heat_exchange

1.1 Purpose

This case is an example of the use of the heat exchange with atmosphere module of WAQTEL coupled with TELEMAC-3D.

1.2 Description

A square basin at rest is considered (length and width = 200 m) with flat bathymetry and elevation at 0 m.

1.3 Computational options

1.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 1.1).

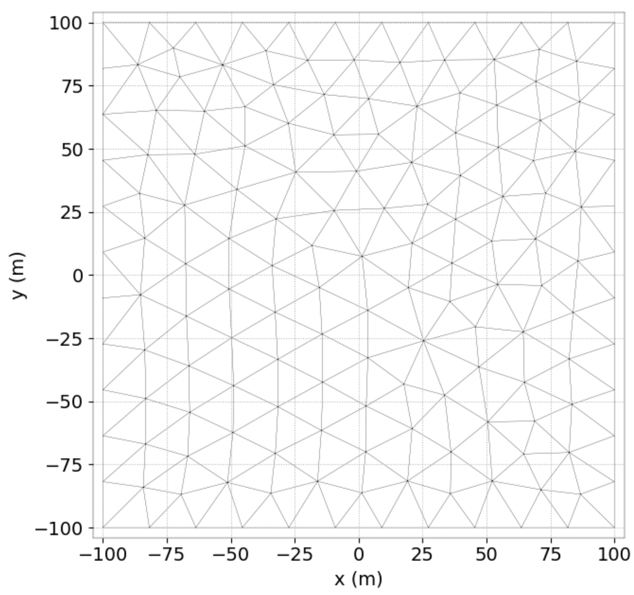

Figure 1.1: Horizontal mesh

To build the 3D mesh of prisms, 26 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (-100 ; 0) to (100 ; 0) can be seen on Figure 1.2.

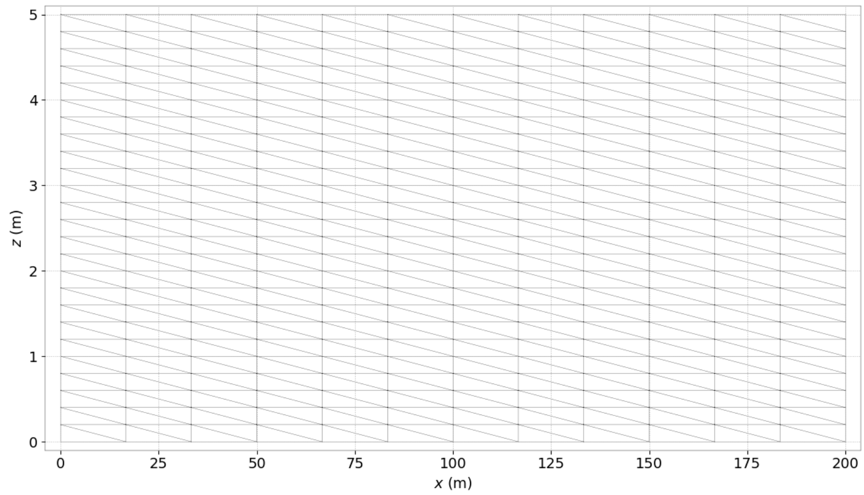

Figure 1.2: Vertical mesh

1.3.2 Physical parameters

The heat exchange module is activated by setting WATER QUALITY PROCESS = 11 in the TELEMAC-3D STEERING FILE.

The tracer used is temperature. The density is considered as a function of the water temperature:

$$\rho(T) = \rho_0 \left(1 - \alpha(T - T_0)^2\right), \tag{1.1}$$

where ρ_0 = 999.972 kg.m^{-3}, T_0 = 4 °C and α = 7.10^{-6}.

Several default values have been modified in the WAQTEL STEERING FILE:

- ATMOSPHERE-WATER EXCHANGE MODEL = 2 (i.e. heat exchange model with complete balance),
- SECCHI DEPTH = 2. (default = 0.9),
- COEFFICIENT TO CALIBRATE THE ATMOSPHERE-WATER EXCHANGE MODEL = 0.0018 (default = 0.0025).

Wind and rain are taken into account in the Navier-Stokes equations by setting the 2 booleans WIND and RAIN OR EVAPORATION to YES in addition to WATER QUALITY PROCESS = 11. They had to be set to YES so that this example works correctly.
COEFFICIENT OF WIND INFLUENCE VARYING WITH WIND SPEED has been let to its default value YES so that it was not needed to choose a constant value for COEFFICIENT OF WIND INFLUENCE.
The origin coordinates of a point representative to the atmospheric conditions of the area are given by means of the keywords LATITUDE OF ORIGIN POINT = 43.4458 ° N and LONGITUDE OF ORIGIN POINT = 5.1139 ° E. These coordinates are needed when the solar radiation is computed by the heat exchange model with complete balance.

Input meteo data are given through an ASCII file with the help of the keyword `ASCII ATMOSPHERIC DATA FILE`. For several sampled times, the following variables are needed. Since release 8.2 and the module **METEO_TELEMAC** which enables the use of flexible ASCII file for meteo data but with the need to use fixed names of variables in the first lines, the order is not mandatory anymore.
The mandatory meteo variables are:

- wind speed + wind direction (shortnames WINDS and WINDD) or wind components along x and y in m/s,
- air temperature (shortname TAIR) in °C,
- atmospheric pressure (shortname PATM) in mbar or hPa,
- relative humidity (shortname HREL) in %,
- cloud coverage (shortname CLDC) in octas,
- rain (shortname RAINC or RAINI depending if it is given as cumulated variable or an interpolated variable as other usual variables),

If the user does not provide one of this data, a constant value over the entire period of simulation is taken. These constant values can be changed by means of the following keywords in the TELEMAC-3D `STEERING FILE`:

- `WIND VELOCITY ALONG X` and `WIND VELOCITY ALONG Y`,
- `AIR TEMPERATURE`,
- `VALUE OF ATMOSPHERIC PRESSURE`,
- `RELATIVE HUMIDITY`,
- `CLOUD COVER`,
- `RAIN OR EVAPORATION IN MM PER DAY`.

Solar radiation (shortname RAY3) is not mandatory but can be given by the user to be read rather than computing it by the module: In that case, the user has to set `SOLAR RADIATION READ IN METEO FILE` = YES (default = NO).
The keywords `ORIGINAL DATE OF TIME` and `ORIGINAL HOUR OF TIME` are set and reference date and hours are filled in with **REFDATE** at the beginning of the `ASCII ATMOSPHERIC DATA FILE` so that the computation can start at a different time of this file (see TELEMAC-3D user manual).

The k-ε turbulence model is used for the vertical direction whereas a constant viscosity is used for the horizontal directions with the default value of 10^{-6} m^2/s.

1.3.3 Initial and Boundary Conditions

The initial water depth is 5 m with a fluid at rest.
The initial temperature is 20 °C in the whole domain.

There are only closed lateral boundaries with free slip condition and Nikuradse law is used to model friction at the bottom with a coefficient 0.001 m.

1.3.4 General parameters

The time step is 2 min = 120 s for a simulated period of 30 days (= 2,592,000 s).

1.3.5 Numerical parameters

The non-hydrostatic version of TELEMAC-3D is used. It is mandatory to model stratifications correctly.

To solve the advection steps, the method of characteristics is chosen for the velocities + k-ε and the PSI-type MURD scheme for the temperature for CPU time reasons.

To reach convergence when solving linear systems, the keywords `MASS-LUMPING FOR DIFFUSION` has to be set to 1. (default = 0.) whereas `MAXIMUM NUMBER OF ITERATIONS FOR PPE` has to be set to 200 (Poisson Pressure Equation).

To accelerate solving, preconditioning 34 (= 2×17) is used for every conjugate gradient solver for diffusion step (velocities, tracers and k-ε).

To enable not too long computations, the following parameters have been relaxed: `ACCURACY FOR PPE` = 10^{-4} and `ACCURACY FOR PROPAGATION` = 10^{-6} (default = 10^{-8} for both of them).

1.4 Results

Figure 1.3 shows the temperature evolution along time at 3 locations (top, middle and bottom of the water column at the center of the square, same x and y).

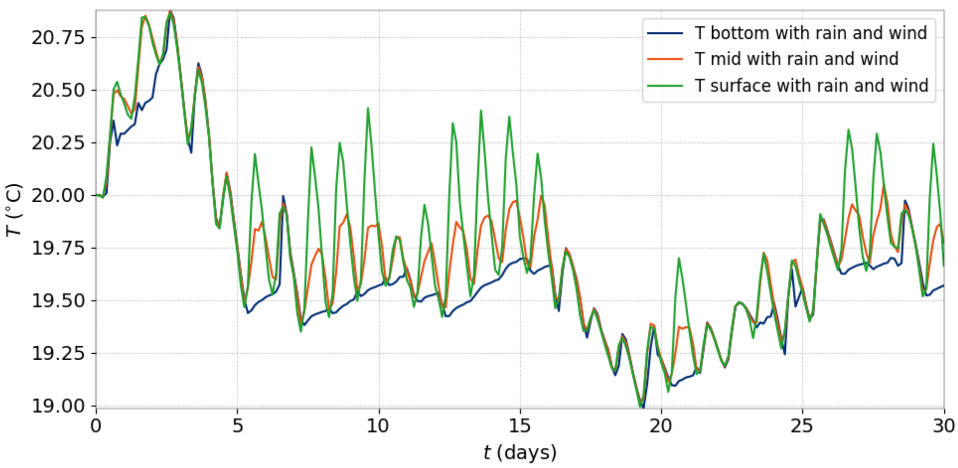

Figure 1.3: Temperature evolution

When it is not mixed (it is mixed e.g. between days 3 to 5 or 16 to 20, 21 to 23), we can see daily patterns with higher temperature at the surface during the day and a quite light stratification.

This can be confirmed by plotting temperature values on a vertical segment over time at the same x and y location, see Figure 1.4. The vertical segment is located in the middle of the square at (0 ; 0).

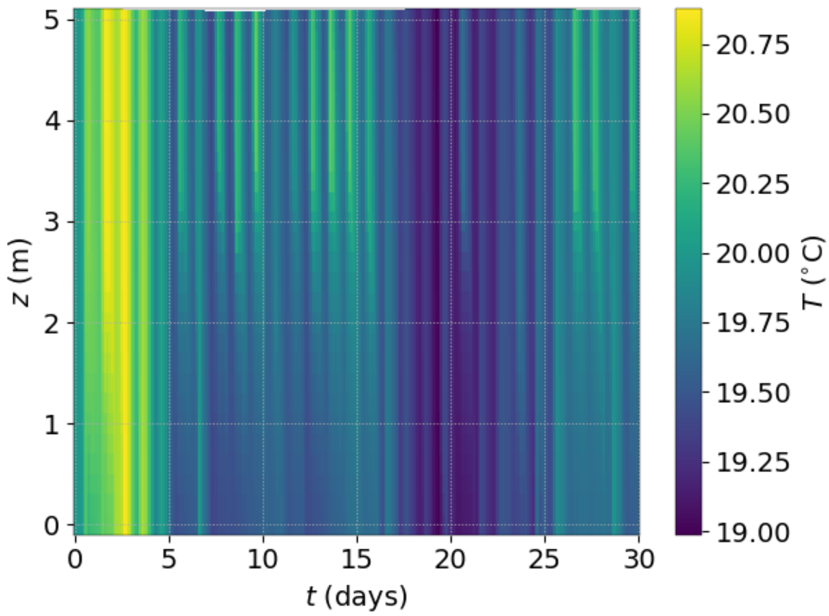

Figure 1.4: Temperature evolution

Anyway, due to wind blowing at the surface, the flow in not homogeneous in the whole domaine as it can be seen in a vertical slice in Figure 1.5 at final time.

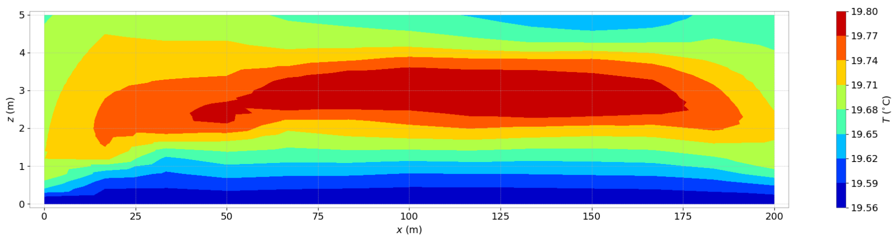

Figure 1.5: Vertical distribution of temperature at final time

1.5 Conclusion

WAQTEL is able to model heat exchange with atmosphere phenomena when coupled with TELEMAC-3D.

2. tracer_decay

2.1 Purpose

To demonstrate that TELEMAC-2D can model the transport of non-conservative tracer in a flow when coupled with WAQTEL.

2.2 Description

The validation is processed with a hypothetical one-dimensional flow with constant velocity (0.03 m/s) and constant depth (10 m).

A 11,400 m long and 50 m wide channel with a flat bottom is considered.

2.3 Computational options

2.3.1 Mesh

The triangular mesh is composed of 2,850 triangular elements (element size of triangles = 40 m along the channel bank and 10 m along the channel width) and 1,716 nodes (see Figure 2.1 with a zoom close to the left boundary in Figure 2.2).

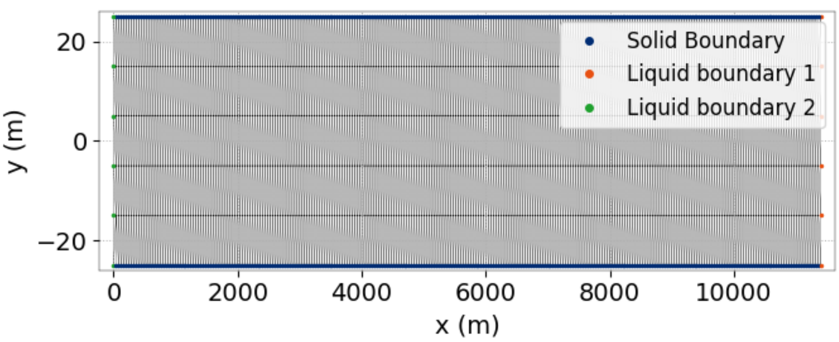

Figure 2.1: Mesh

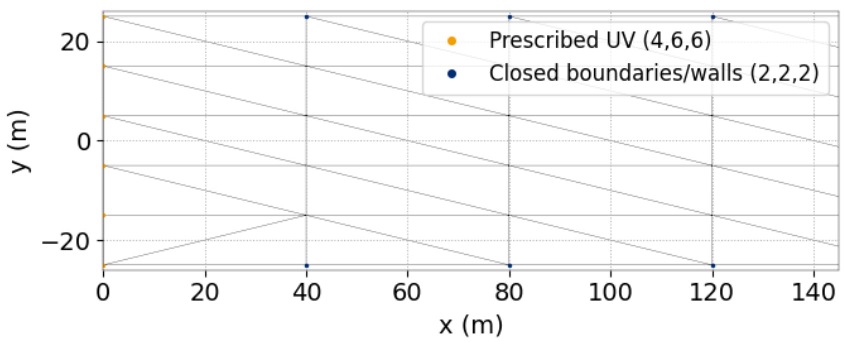

Figure 2.2: Zoom of the mesh close to the left boundary

2.3.2 Physical parameters

Initial condition:

- The concentration of the tracer is 30 mg/l at the left boundary nodes and 0 mg/l at all other nodes (as shown in Figures 2.3 and 2.4),
- Constant velocity 0.03 m/s,
- Constant water height 10 m.

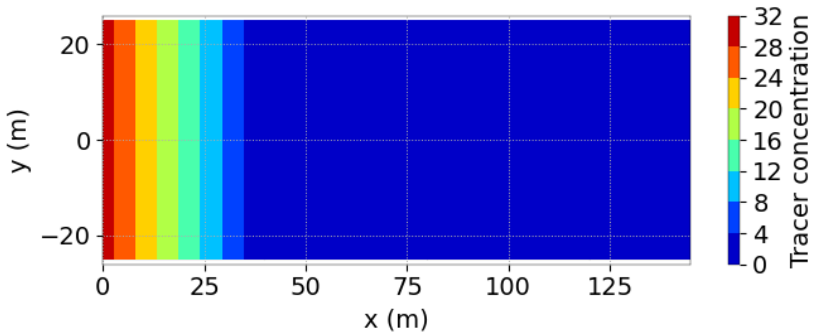

Figure 2.3: Initial state of tracer zoomed close to the left boundary

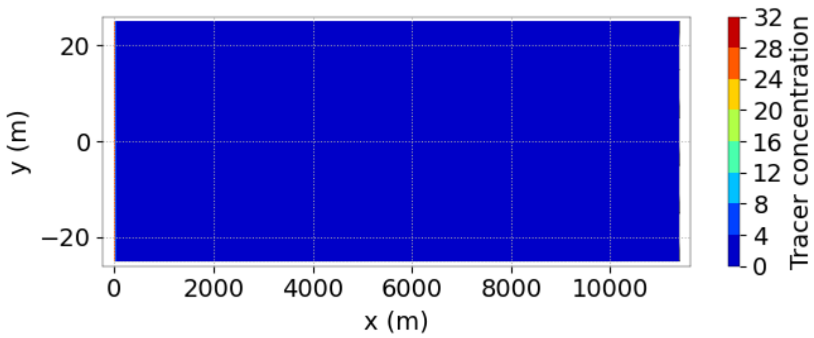

Figure 2.4: Initial state of tracer

Boundary conditions:

- Left inlet boundary:
  - Constant velocity of 0.03 m/s,
  - Constant tracer concentration of 30 mg/l for first 6 hours, 0 mg/l after,
- Right outlet boundary:
  - Constant velocity of -0.03 m/s,
  - Free tracer concentration,
- Lateral boundaries: solid smooth boundary.

Bottom:

- Flat bottom without friction.

Parameters for non-conservative tracers:

- Number of tracer: 1,
- Coefficient for diffusion of tracers: 30 m^2/s,
- Decay rate as a law for bacterial degradation: 0; 1.0/day; 2.0/day.

2.3.3 General parameters

The time step is 100 s for a simulated period of 6 days (= 518,400 s).

2.3.4 Numerical parameters

Tracer:

- Advection of tracer: method of characteristics,
- Accuracy for diffusion of tracers: 10^{-10}.

Flow and velocity:

- No diffusion,
- No advection.

2.4 Results

The tracer concentration time series of analysis and simulation at x = 2,000 m are compared (see Figure 2.5). Visually the solution produced by TELEMAC-2D shows very good agreement with the exact solution. For 6 days of simulation duration, when K_d = 0 or K_d = 1/day, the model peak time is 5 minutes earlier than the exact peak time; and for K_d = 2/day, the time difference is less than 2 minutes.

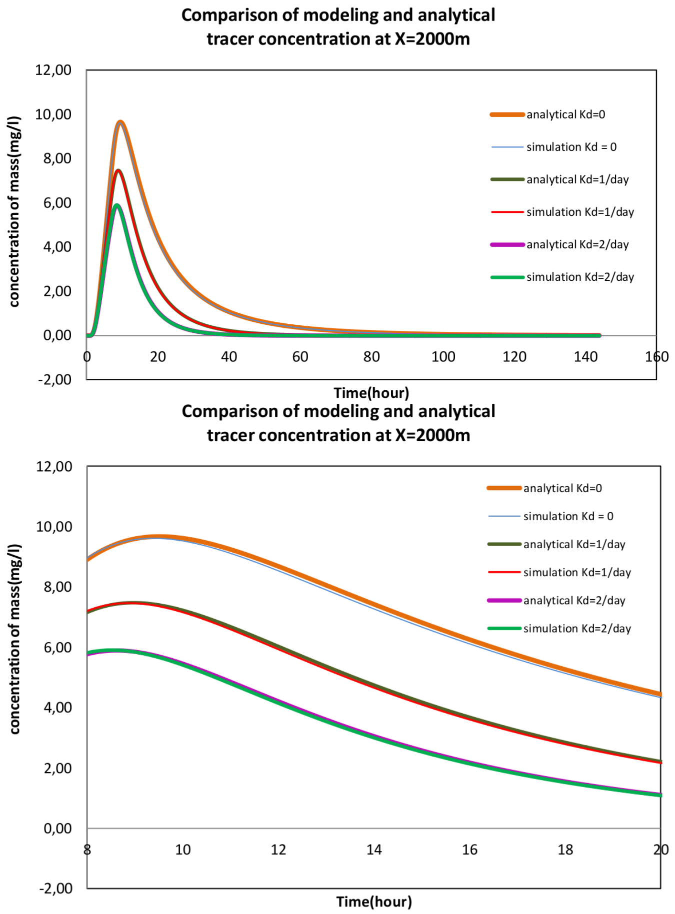

Figure 2.5: Comparison between analytical solution and TELEMAC-2D solution for non-conservative tracer transport

2.5 Conclusion

TELEMAC-2D reproduces accurately the transport of non-conservative tracers when coupled with WAQTEL.

3. tracer_decrease

3.1 Purpose

This case is an example of the use of the degradation law of WAQTEL coupled with TELEMAC-2D.

3.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

3.3 Computational options

3.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 3.1).

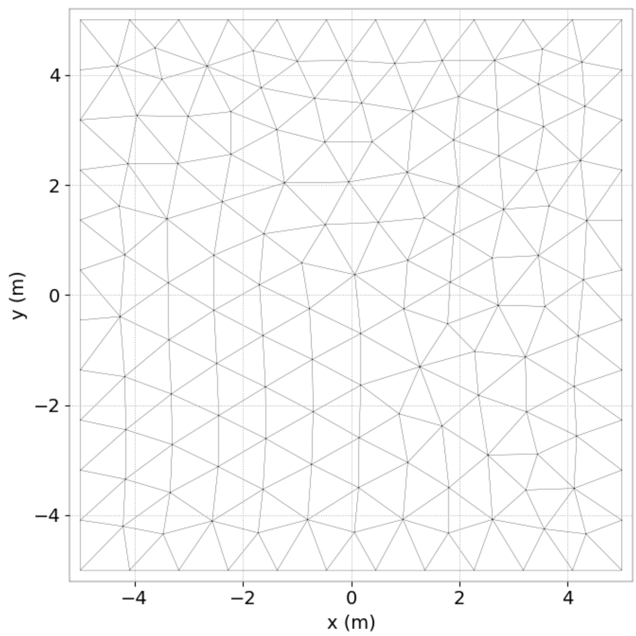

Figure 3.1: Mesh

3.3.2 Physical parameters

The degradation law is activated by setting WATER QUALITY PROCESS = 17 in the TELEMAC-2D STEERING FILE.

Several tracers are considered:

- the 1st one without any degradation law,
- the 2nd one with a 1st order law for bacterial degradation with a T_{90} coefficient = 6 h,
- the 3rd one with a 1st order degradation law with a constant of tracer kinetic degradation = 0.3833333333333333 h^{-1},
- the 4th one with a 1st order degradation law with a constant of tracer kinetic degradation = 9.2 day^{-1},
- the 5th one with a degradation law implemented by user. As an example, a 1st order degradation law with a constant of tracer kinetic degradation = 0.00010648148148148147 s^{-1} has been implemented with the help of **USER_CALCS2D_DEGRADATION** subroutine.

The T_{90} or k_1 coefficients can be specified with the keyword COEFFICIENT 1 FOR LAW OF TRACERS DEGRADATION (one per tracer, expressed in hours for tracer 2, in h^{-1} for tracer 3, in day^{-1} for tracer 4).

3.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial concentrations are homogeneous = (100, 200, 200, 200, 200).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

3.3.4 General parameters

The time step is 10 s for a simulated period of 86,400 s = 1 day.

3.3.5 Numerical parameters

Basin at rest (no advection nor diffusion). No diffusion neither for hydrodynamics or tracers.

2 default values for the diffusion of the tracers are modified in the TELEMAC-2D STEERING FILE :

- ACCURACY FOR DIFFUSION OF TRACERS = 10^{-10} (current default = 10^{-6}),
- IMPLICITATION COEFFICIENT OF TRACERS = 1 (current default = 0.6).

3.4 Results

Figure 3.2 shows the tracers evolution along time for the tracers numbers 2, 3, 4 and 5 (with degradation law). The analytical solution is also plotted with circle markers.

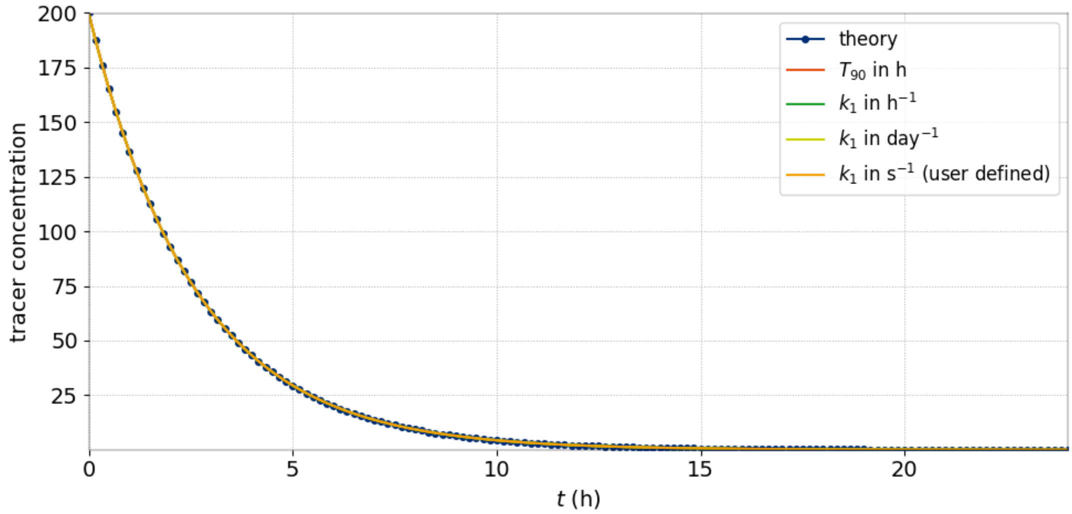

Figure 3.2: Tracers evolution for different expressions of the same degradation law

3.5 Conclusion

WAQTEL is able to model a 1st order degradation law when coupled with TELEMAC-2D.

4. waq2d_biomas

4.1 Purpose

This case is an example of the use of the BIOMASS module of WAQTEL coupled with TELEMAC-2D.

4.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

4.3 Computational options

4.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 4.1).

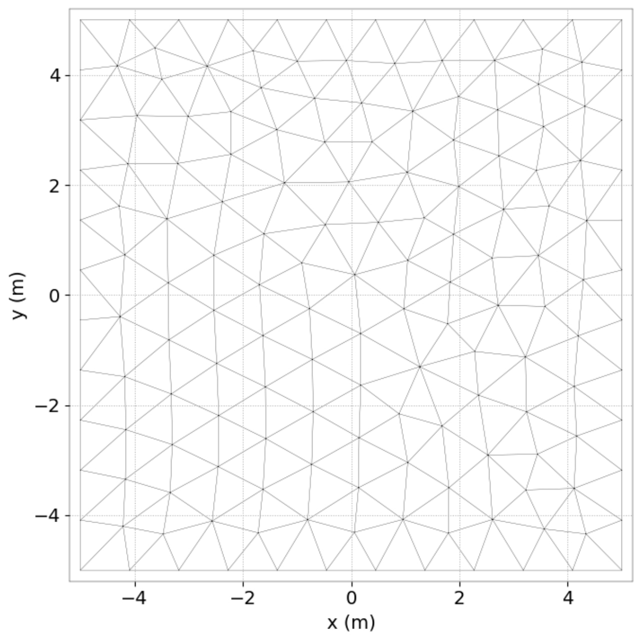

Figure 4.1: Mesh

4.3.2 Physical parameters

The BIOMASS module is activated by setting `WATER QUALITY PROCESS` = 3 in the TELEMAC-2D `STEERING FILE`.

5 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `SECCHI DEPTH` = 0.1 m,
- `VEGETAL TURBIDITY COEFFICIENT WITHOUT PHYTO` = 0.01 m^{-1},
- `SUNSHINE FLUX DENSITY ON WATER SURFACE` = 0.01 W/m^2,
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

4.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([PHY],[PO4],[POR],[NO3],[NOR]) = (0.5 μgChlA/l, 3 mg/l, 1.1 mg/l, 0.2 mg/l, 4.9 mg/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

4.3.4 General parameters

The time step is 4 s for a simulated period of 86,400 s = 1 day.

4.3.5 Numerical parameters

Basin at rest (no advection nor diffusion).

4.4 Results

Figure 4.2 shows the 5 tracers evolution along time.

Dissolved PO_4, dissolved NO_3 and non assimilated NOR are constant in time whereas phytoplankton PHY and non assimilated POR decrease during the simulation (less quicker for POR).

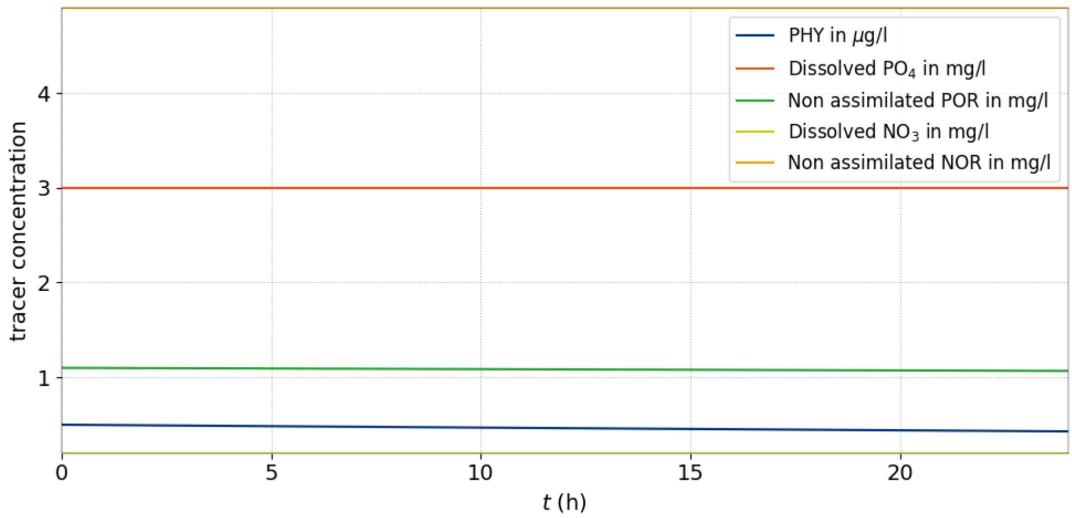

Figure 4.2: Tracers evolution for different tracers of the BIOMASS module

4.5 Conclusion

The BIOMASS module of WAQTEL can be coupled with TELEMAC-2D.

5. waq2d_eutro

5.1 Purpose

This case is an example of the use of the EUTRO module of WAQTEL coupled with TELEMAC-2D.

5.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

5.3 Computational options

5.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 5.1).

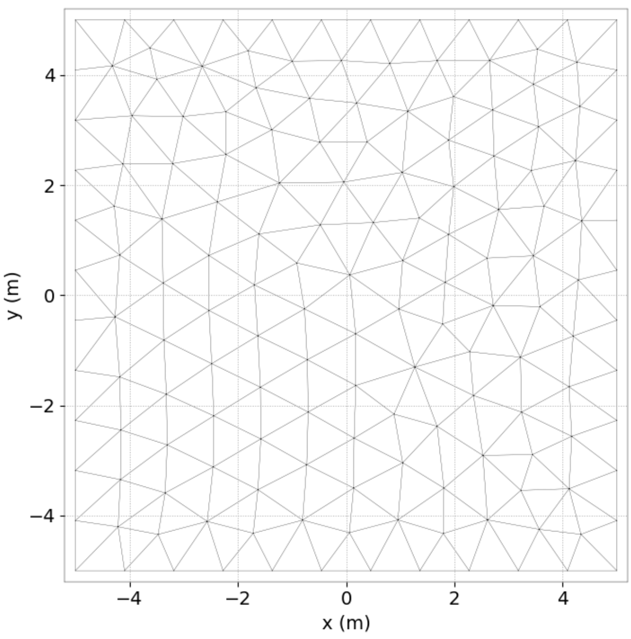

Figure 5.1: Mesh

5.3.2 Physical parameters

The EUTRO module is activated by setting `WATER QUALITY PROCESS` = 5 in the TELEMAC-2D `STEERING FILE`.

8 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),
- ammoniacal load (NH_4),
- organic load (L),
- dissolved oxygen (O_2).

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `K2 REAERATION COEFFICIENT` = 0.3,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `O2 SATURATION DENSITY OF WATER (CS)` = 9 mgO_2/l (C_s is constant),
- `SECCHI DEPTH` = 0.1 m,
- `VEGETAL TURBIDITY COEFFICIENT WITHOUT PHYTO` = 0.01 m^{-1},
- `SUNSHINE FLUX DENSITY ON WATER SURFACE` = 0.01 W/m^2,
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

5.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([PHY],[PO4],[POR],[NO3],[NOR],[NH_4],[L],[O_2]) = (0.5 μgChlA/l, 3 mg/l, 1.1 mg/l, 0.2 mg/l, 4.9 mg/l, 5.5 mgNH_4/l, 0.7 mgO_2/l, 1 mgO_2/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

5.3.4 General parameters

The time step is 1 h = 3,600 s for a simulated period of 8,760 h = 365 days.

5.3.5 Numerical parameters

Basin at rest (no advection nor diffusion).

5.4 Results

Figure 5.2 shows the 8 tracers evolution along time. All of them rather quickly reach an asymptote.

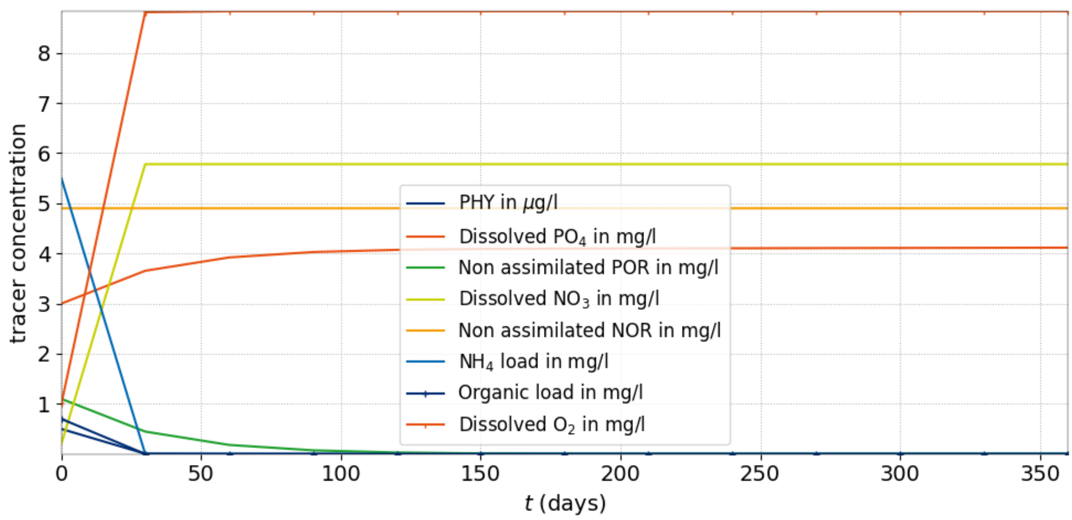

Figure 5.2: Tracers evolution for different tracers of the EUTRO module

5.5 Conclusion

The EUTRO module of WAQTEL can be coupled with TELEMAC-2D.

6. Streeter and Phelps experiment using Benson and Krause formula (waq2d_eutro_streeter_phelps)

6.1 Purpose

This case is an example of the use of the EUTRO module of WAQTEL coupled with TELEMAC-2D with Benson and Krause formula to compute oxygen saturation concentration C_s.

6.2 Description

In 1925, Streeter and Phelps published a work on the dissolved oxygen "sag curve" representative of the oxygen decrease with downstream distance in the Ohio River due to the degradation of soluble organic biochemical oxygen demand (BOD). They proposed a mathematical equation to describe this observation, which has since become widely known as the Streeter-Phelps equation.
A channel is considered (30 000 m long, 400 m wide, flat horizontal bottom = -10 m).

6.3 Computational options

6.3.1 Mesh

The triangular mesh is composed of 3,200 triangular elements and 1,809 nodes (see Figure 6.1).

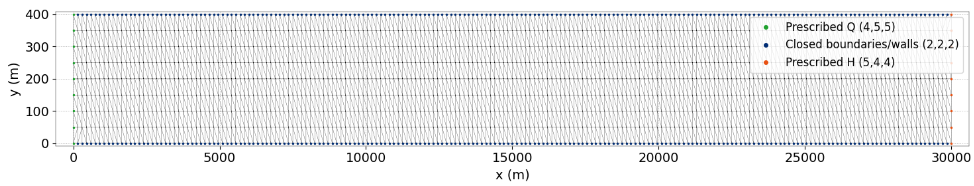

Figure 6.1: Mesh

6.3.2 Physical parameters

Horizontal constant viscosity for velocity: with default value (10^{-6} m^2/s)
No diffusion for tracers
Bottom friction: no friction on the bottom

The EUTRO module is activated by setting `WATER QUALITY PROCESS` = 5 in the TELEMAC-2D `STEERING FILE`.

8 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),
- ammoniacal load (NH_4),
- organic load (L),
- dissolved oxygen (O_2).

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `FORMULA FOR COMPUTING CS` = 3 (i.e. Benson and Krause),
- `CONSTANT OF DEGRADATION OF ORGANIC LOAD K120` = 0.36 d^{-1},
- `BENTHIC DEMAND` = 0 $gO_2/m^2/d$,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `WATER TEMPERATURE` = 20°C (which is the mean water temperature).
- `WATER SALINITY` = 0 g/l (which is the mean water salinity).

Water temperature is 20°C. Salinity is 0 mg/l.

6.3.3 Initial and Boundary Conditions

The initial water elevation is 0 m (= 10 m water depth).
A flow rate of 200 m^3/s is prescribed upstream.
An elevation of 0 m is prescribed downstream.

The initial values, upstream and downstream conditions for tracers [PHY],[PO4],[POR],[NO3],[NOR],[NH_4] are homogeneous and nil.
The initial conditions are 0 mg/l for [L] and 9.0921 mgO_2/l for [O_2], which is the saturation concentration.
The upstream boundary conditions are 10 mg/l for [L] and 9.0921 mgO_2/l for [O_2].
The downstream boundary conditions are 0 mg/l for [L] and 9.0921 mgO_2/l for [O_2].

6.3.4 General parameters

The time step is 10 s for a simulated period of 691,200 s = 8 days. This is the duration needed to reach equilibrium state.
The first 24 hours are the initialisation with the discharge rate increasing from zero to 200 m^3/s.

6.3.5 Numerical parameters

The PSI scheme is chosen to solve the advection for the last 2 tracers (L and O_2) whereas for the other tracers no advection scheme nor diffusion scheme are used. It means that only tracers L and O_2 are activated. Water temperature and salinity are constant parameters of the simulation. Moreover, the method of characteristics is chosen to solve the advection for the velocities.

6.4 Analytical solution

An analytical solution for the longitudinal distribution of the DO concentration can be calculated in the case of steady hydrodynamic conditions:

$$DO(x) = C_s - (C_s - DO_o)e^{-k_a x/u} - \frac{k_d L_0}{k_a - k_d}(e^{-k_d x/u} - e^{-k_a x/u})$$

Where L_0 is the upstream concentration of the organic load L, u is the stream velocity (m/s), x is the distance from the upstream boundary (m), k_a is the coefficient of reaeration (s^{-1}), k_d is the kinetic degradation of organic load (s^{-1}), C_s is the saturation concentration (mgO_2/l) and DO_o is the DO upstream concentration (mgO_2/l).

Other representative values of the DO sag curve can be evaluated:

- The minimum dissolved oxygen DO_{min} concentration occurring along the river stretch:

$$DO_{\text{min}} = C_s + \frac{k_d L_0}{k_a} e^{-k_d x/u}$$

- The Critical distance x_c where the minimum dissolved oxygen concentration occurs:

$$x_c = \frac{u}{k_a - k_d} \log\left[\frac{k_a}{k_d}\left(1 - \frac{k_a - k_d}{k_d}\frac{DO - C_s}{L_0}\right)\right]$$

The results with the parameters chosen are DO_{min} = 6.92 mg/l and x_c = 7 330.33 m.

6.5 Results

Figure 6.2 shows the longitudinal profile of the modelled dissolved oxygen concentration compared to the analytical solution at the last time step of the simulation.

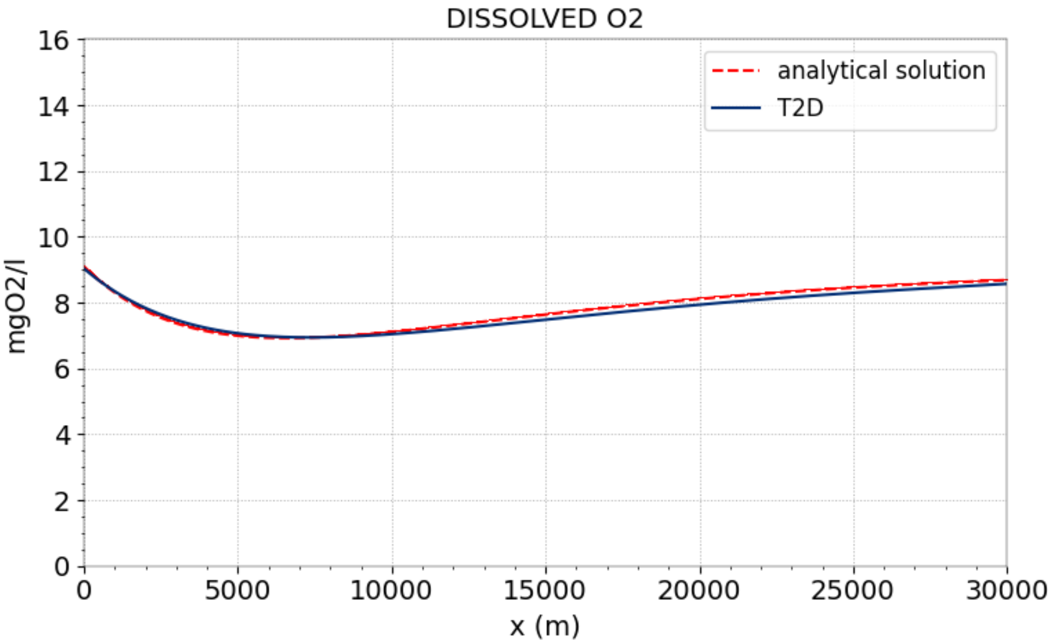

Figure 6.2: Dissolved oxygen

6.6 Conclusion

The submodule EUTRO of WAQTEL can be coupled with TELEMAC-2D to model unsteady flows and is validated against the analytical solution of the Streeter-Phelps dissolved oxygen sag curve.

7. waq2d_micropol

7.1 Pollutant transport: one-step reversible model

7.1.1 Purpose

This case is an example of the use of the MICROPOL module of WAQTEL coupled with TELEMAC-2D for one-step reversible interactions between SPM and micro-pollutant species.

7.1.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

7.1.3 Computational options

7.1.4 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 7.1).

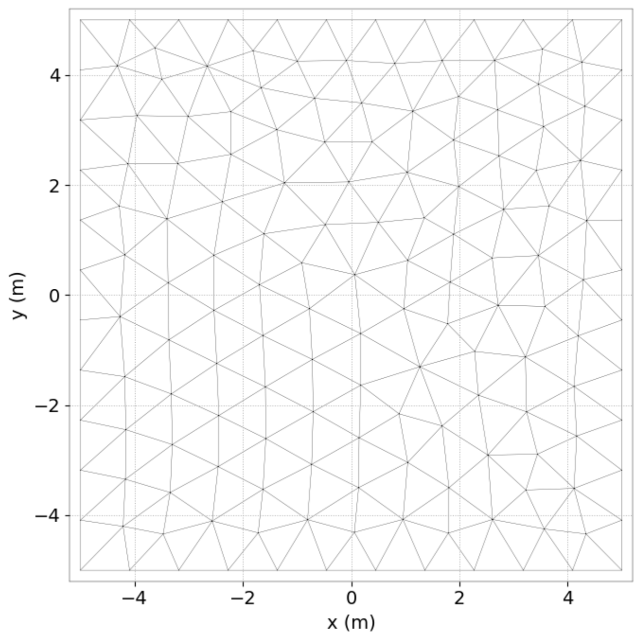

Figure 7.1: Mesh.

7.1.5 Physical parameters

No diffusion neither for hydrodynamics or tracers.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-2D `STEERING FILE`.

5 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2),
- micro-pollutant species in dissolved form (C) (Bq/m^3),
- fraction adsorbed by suspended sediments (C_{ss}) (Bq/m^3),
- fraction adsorbed by bed sediments (C_{ff}) (Bq/m^2).

The settling velocity w (m/s) and the exponential decay constant L (s^{-1}) are adapted in each test case in order to individually model sedimentation, sorption, desorption and decay. The distribution coefficient K_d (L/g) is set at a value of 1. All other parameters are taken with the default values in the WAQTEL `STEERING FILE`.

7.1.6 Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest. The initial values for tracers are homogeneous in each test cases:

- The first test case is a simple sorption with no sedimentation or erosion.
  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 1, 0, 0) and (w, L) = (0, 0).

- Test case 2 evaluates deposition of SPM in the basin at rest.
  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 0, 0) and (w, L) = (4E-7, 0).

- The third test case evaluates both sorption of micropollutants from dissolved form toward SPM, and deposition.
  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 1, 0, 0) and (w, L) = (4E-7, 0).

- Test case 4 evaluates both desorption of micropollutants from SPM toward dissolved form, and deposition.
  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 1, 0) and (w, L) = (4E-7, 0).

- Test case 5 is equivalent to test case 4 but a law of exponential micropollutant decay is added.
  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 1, 0) and (w, L) = (4E-7, 1.13E-7).

There are only closed lateral boundaries with free slip condition and no friction at the bottom.

7.1.7 General parameters

The time step is 1 h = 3,600 s for a simulated period of 3,200 h $\approx$ 133 days.

7.1.8 Analytical solution

An analytical solution can be calculated in the case of simple steady hydrodynamic conditions:

- With an unitary constant water depth ($h = 1$ m) and no erosion ($U = 0$ m/s) the deposition flux SED follows:
$$SED = w\,SS$$
and the suspended sediment concentration (SS) is:
$$SS(t) = SS_0\, e^{-wt}$$
Similarly the bottom sediments follow:
$$SF(t) = SF_0 + SS_0(1 - e^{-wt})$$
- In the case where the settling velocity w is nil, there is no sediment evolution and the exchanges remain exclusively in the micropollutant tracers. By setting the initial concentration of micropollutants adsorbed by SPM (C_{ss}) at 1 Bq/m^3 and 0 otherwise, an analytical solution under these conditions is:
$$C_{ss}(t) = \frac{SS_0}{SS_0+1}(1 - e^{-k_{-1}(SS_0+1)t})$$
$$C(t) = \frac{1}{SS_0+1}(SS_0 + e^{-k_{-1}(SS_0+1)t})$$

7.1.9 Results

Next figures show the 5 tracers evolution along time for each test case. MICROPOL module results are compared with the analytical solutions from 16.4.3.

Figure 7.2 shows the results of a simple sorption with no sedimentation or erosion.

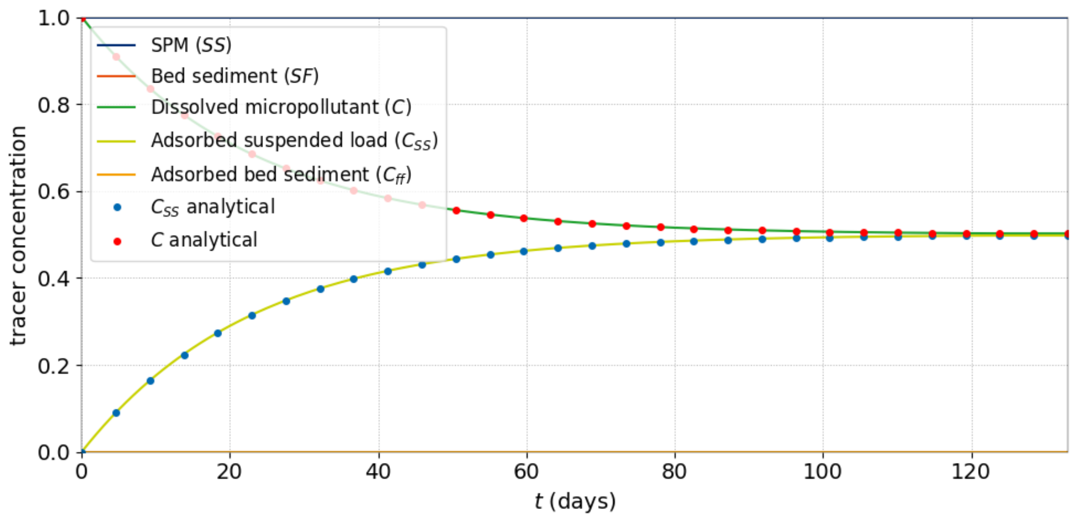

Figure 7.2: Tracers evolution for test case 1.

Figure 7.3 evaluates deposition of SPM in the basin at rest.

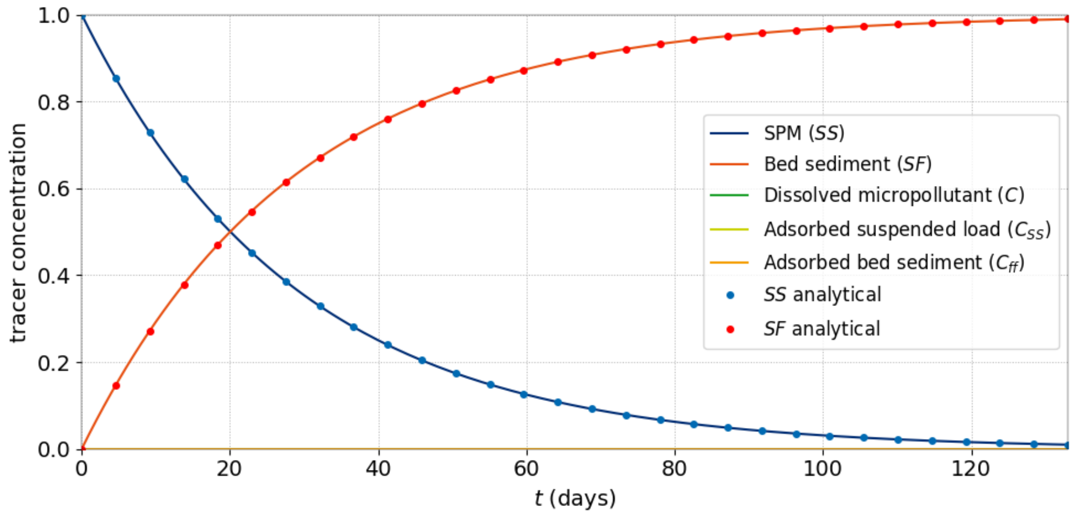

Figure 7.3: Tracers evolution for test case 2.

Figure 7.4 displays both sorption of micropollutants from dissolved form toward SPM, and deposition results.

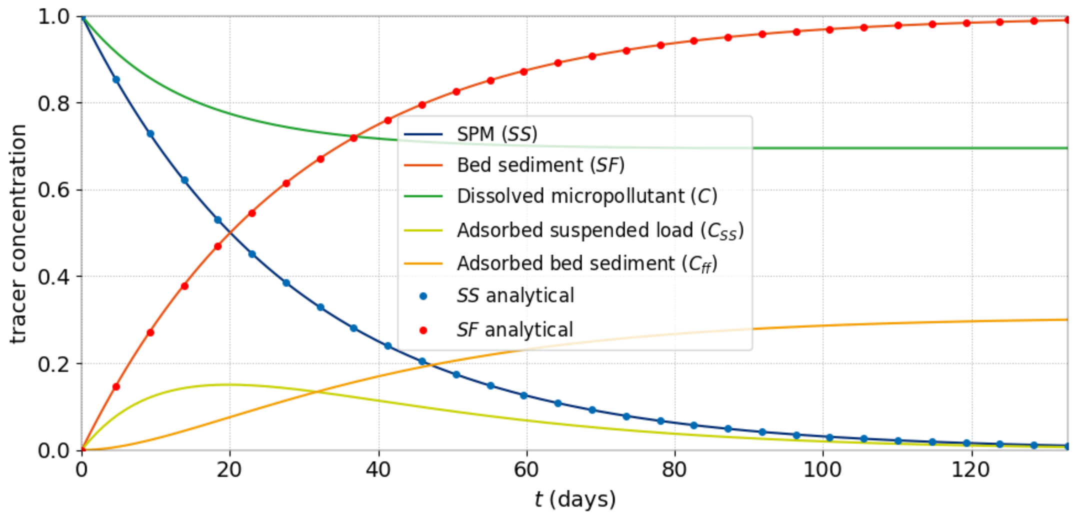

Figure 7.4: Tracers evolution for test case 3.

In Figure 7.5 is shown both desorption of micropollutants from SPM toward dissolved form, and deposition.

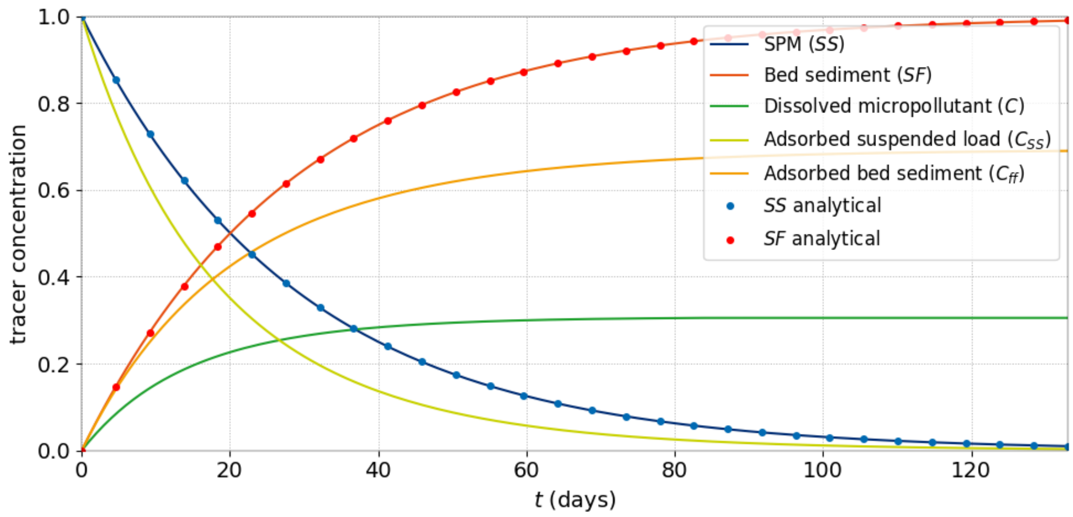

Figure 7.5: Tracers evolution for test case 4.

Results of Figure 7.6 are equivalent to test case 4 but a law of exponential micropollutant decay is added.

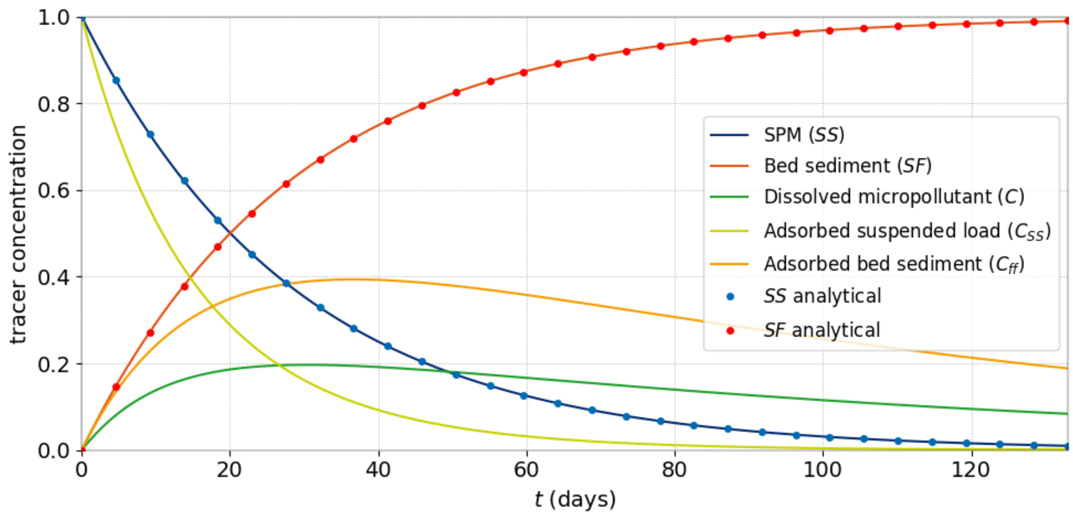

Figure 7.6: Tracers evolution for test case 5.

7.2 Pollutant transport: two-step reversible model

7.2.1 Purpose

This case is an example of the use of the MICROPOL module of WAQTEL coupled with TELEMAC-2D for two-step reversible interactions between SPM and micro-pollutant species.

7.2.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

7.2.3 Computational options

7.2.4 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 7.7).

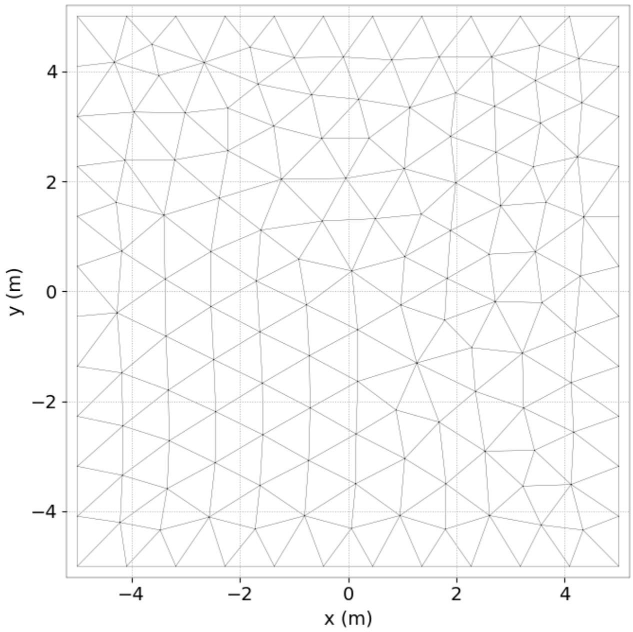

Figure 7.7: Mesh.

7.2.5 Physical parameters

No diffusion neither for hydrodynamics or tracers.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-2D `STEERING FILE`.
The two-step reversible model is activated by setting the keyword `KINETIC EXCHANGE MODEL` = 2 in the WAQTEL `STEERING FILE`.

7 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2),
- micro-pollutant species in dissolved form (C) (Bq/m^3),
- fraction adsorbed by suspended sediments weak site (C_{ss1}) (Bq/m^3),
- fraction adsorbed by bed sediments weak site (C_{ff1}) (Bq/m^2).
- fraction adsorbed by suspended sediments strong site (C_{ss2}) (Bq/m^3),
- fraction adsorbed by bed sediments strong site (C_{ff2}) (Bq/m^2).

The settling velocity w (m/s) and the exponential decay constant L (s^{-1}) are adapted in each test case in order to individually model sedimentation, sorption, desorption and decay. The distribution coefficients K_d and K_{d2} (L/g) are set at a value of 2. The sorption reaction rates k_1 and k_2 (L/g/s) are set at a value of 0.1. All other parameters are taken with the default values in the WAQTEL `STEERING FILE`.

7.2.6 Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest. The initial values for tracers are homogeneous in each test cases:

- The first test case is a simple sorption with no sedimentation or erosion.
  (SS, SF, C, C_{SS1}, C_{ff1},C_{ss2},C_{ff2}) = (1, 0, 1, 0, 0, 0, 0) and (w, L) = (0, 0).

- Test case 2 evaluates deposition of SPM in the basin at rest.
  (SS, SF, C, C_{SS1}, C_{ff1},C_{ss2},C_{ff2}) = (1, 0, 0, 0, 0, 0, 0) and (w, L) = (4E-7, 0).

- The third test case evaluates both sorption of micropollutants from dissolved form toward SPM, and deposition.
  (SS, SF, C, C_{SS1}, C_{ff1},C_{ss2},C_{ff2}) = (1, 0, 1, 0, 0, 0, 0) and (w, L) = (4E-7, 0).

- Test case 4 evaluates both desorption of micropollutants from SPM toward dissolved form, and deposition.
  (SS, SF, C, C_{SS1}, C_{ff1},C_{ss2},C_{ff2}) = (1, 0, 0, 1, 0, 0, 0) and (w, L) = (4E-7, 0).

- Test case 5 is equivalent to test case 4 but a law of exponential micropollutant decay is added.
  (SS, SF, C, C_{SS1}, C_{ff1},C_{ss2},C_{ff2}) = (1, 0, 0, 1, 0, 0, 0) and (w, L) = (4E-7, 1.13E-7).

There are only closed lateral boundaries with free slip condition and no friction at the bottom.

7.2.7 General parameters

The time step is 0.1 s for a simulated period of 125 s.

7.2.8 Analytical solution

An analytical solution can be calculated in the case of simple steady hydrodynamic conditions:

- In the case where the settling velocity w is nil, there is no sediment evolution and the exchanges remain exclusively in the micropollutant tracers. By setting the initial concentration of micropollutants in the water (C) at 1 Bq/m^3 and 0 otherwise, an analytical solution under these conditions is:

$$C(t) = \frac{1}{7}(1+(3+\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} + (3-\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

$$C_{ss1}(t) = \frac{1}{7}(2-(1-2\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} - (1+2\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

$$C_{ss2}(t) = \frac{1}{7}(4-(2+3\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} - (2-3\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

7.2.9 Results

Next figures show the 5 tracers evolution along time for each test case. MICROPOL module results are compared with the analytical solutions from 16.4.3.

Figure 7.8 shows the results of a simple sorption with no sedimentation or erosion.

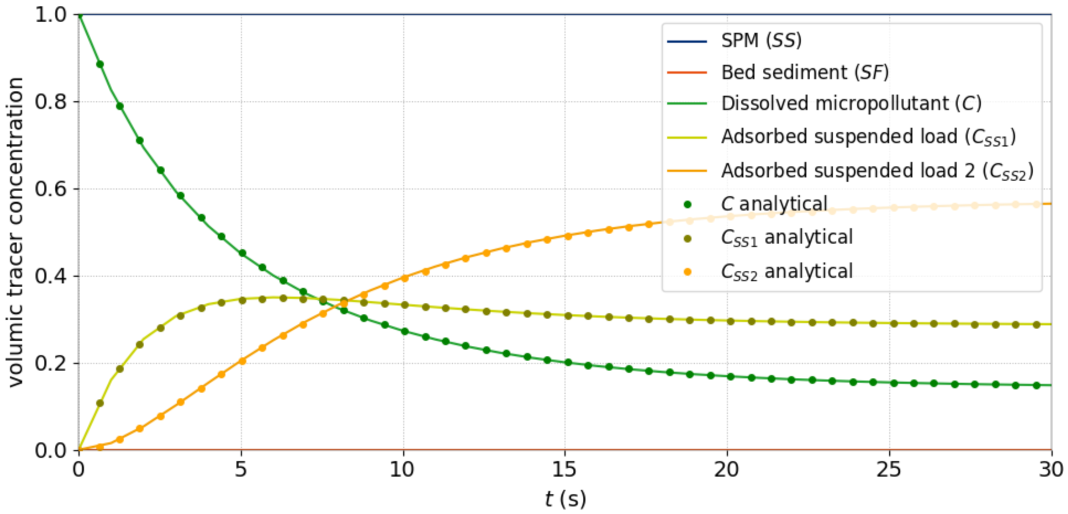

Figure 7.8: Tracers evolution for test case 1.

Figure 7.9 evaluates deposition of SPM in the basin at rest.

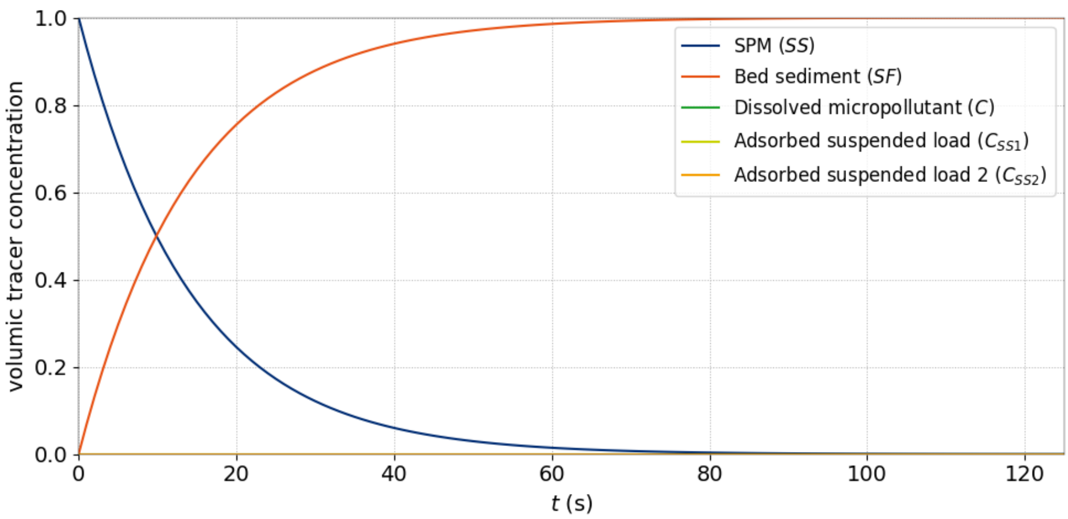

Figure 7.9: Tracers evolution for test case 2.

Figure 7.10 displays both sorption of micropollutants from dissolved form toward SPM, and deposition results.

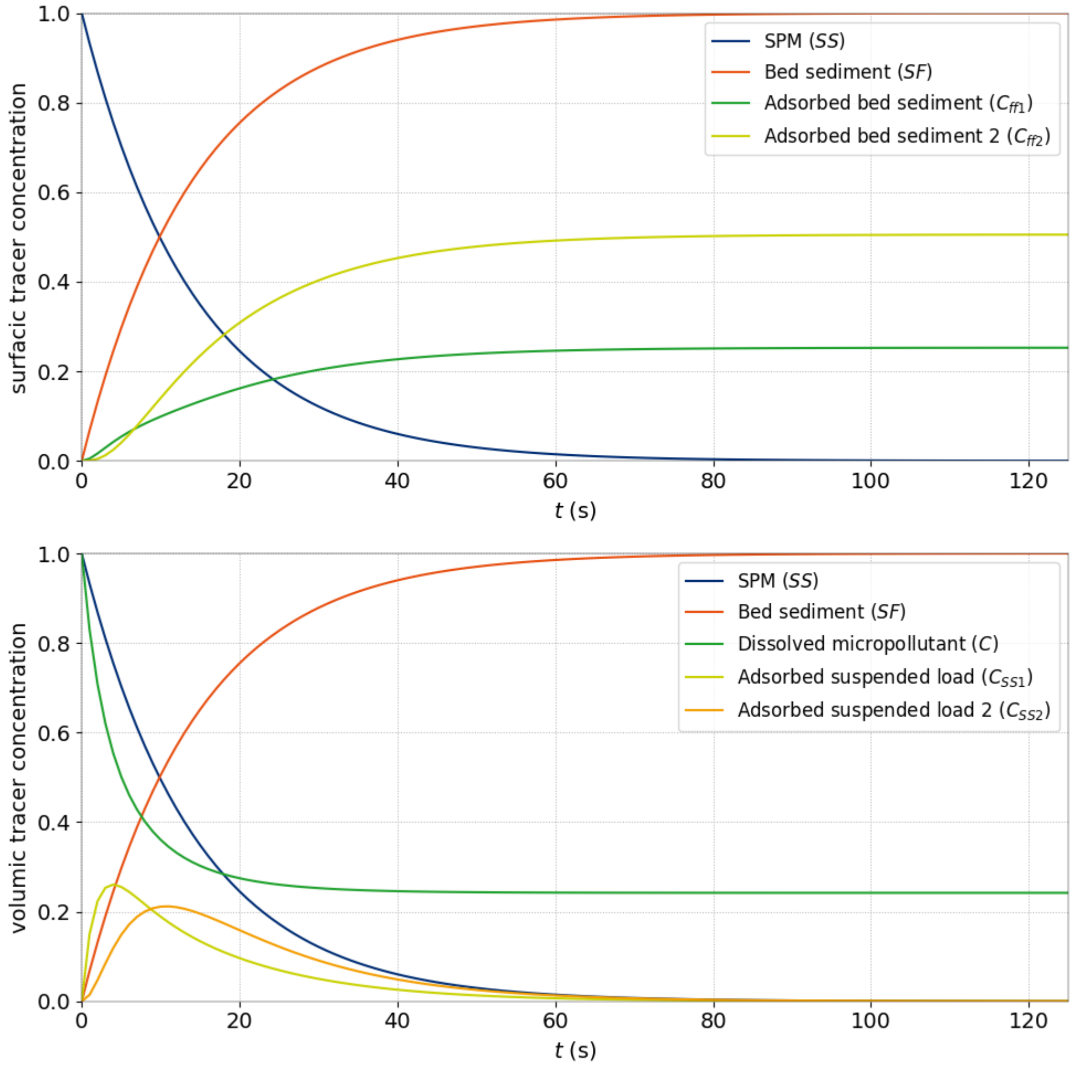

Figure 7.10: Tracers evolution for test case 3.

In Figure 7.11 is shown both desorption of micropollutants from SPM toward dissolved form, and deposition.

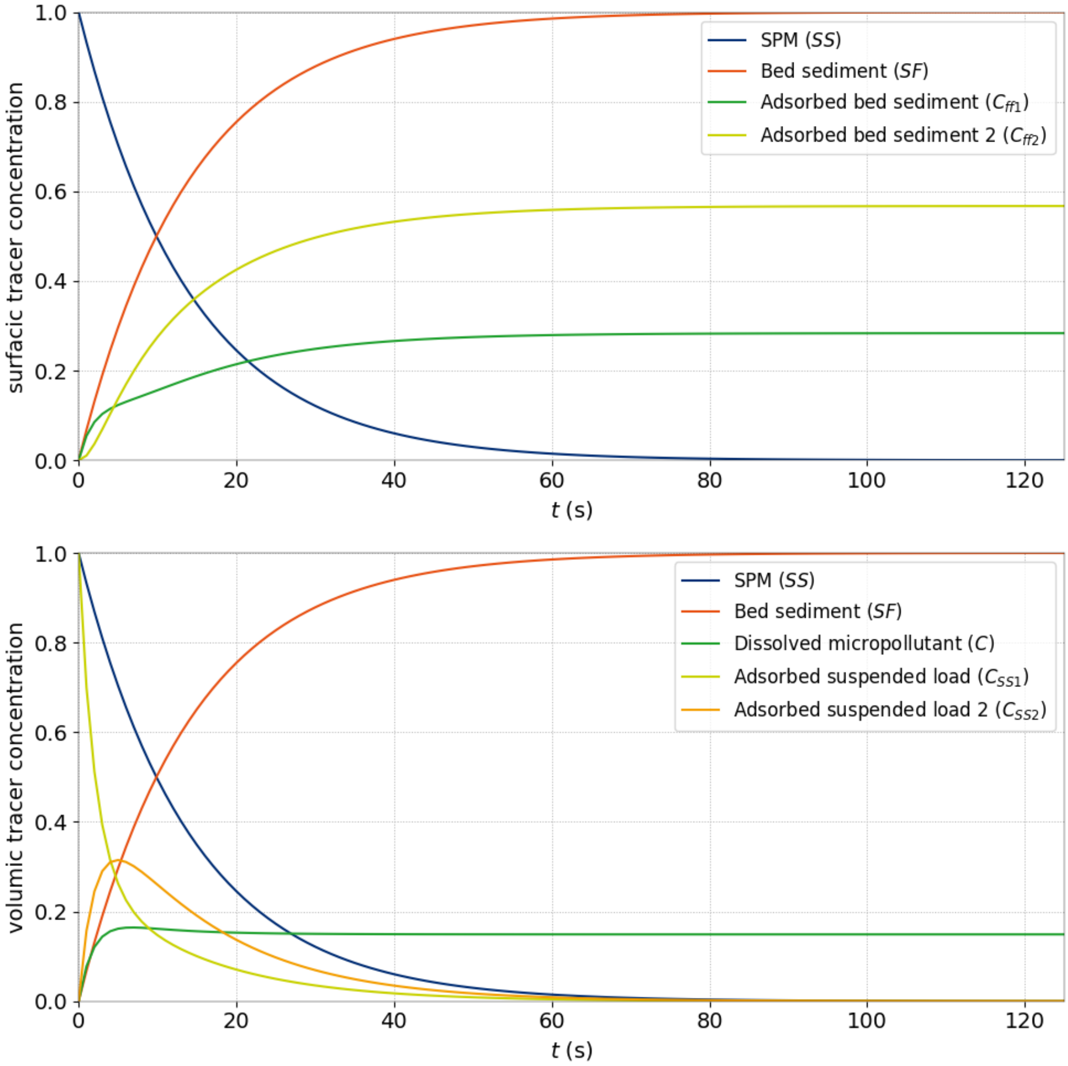

Figure 7.11: Tracers evolution for test case 4.

Results of Figure 7.12 are equivalent to test case 4 but a law of exponential micropollutant decay is added.

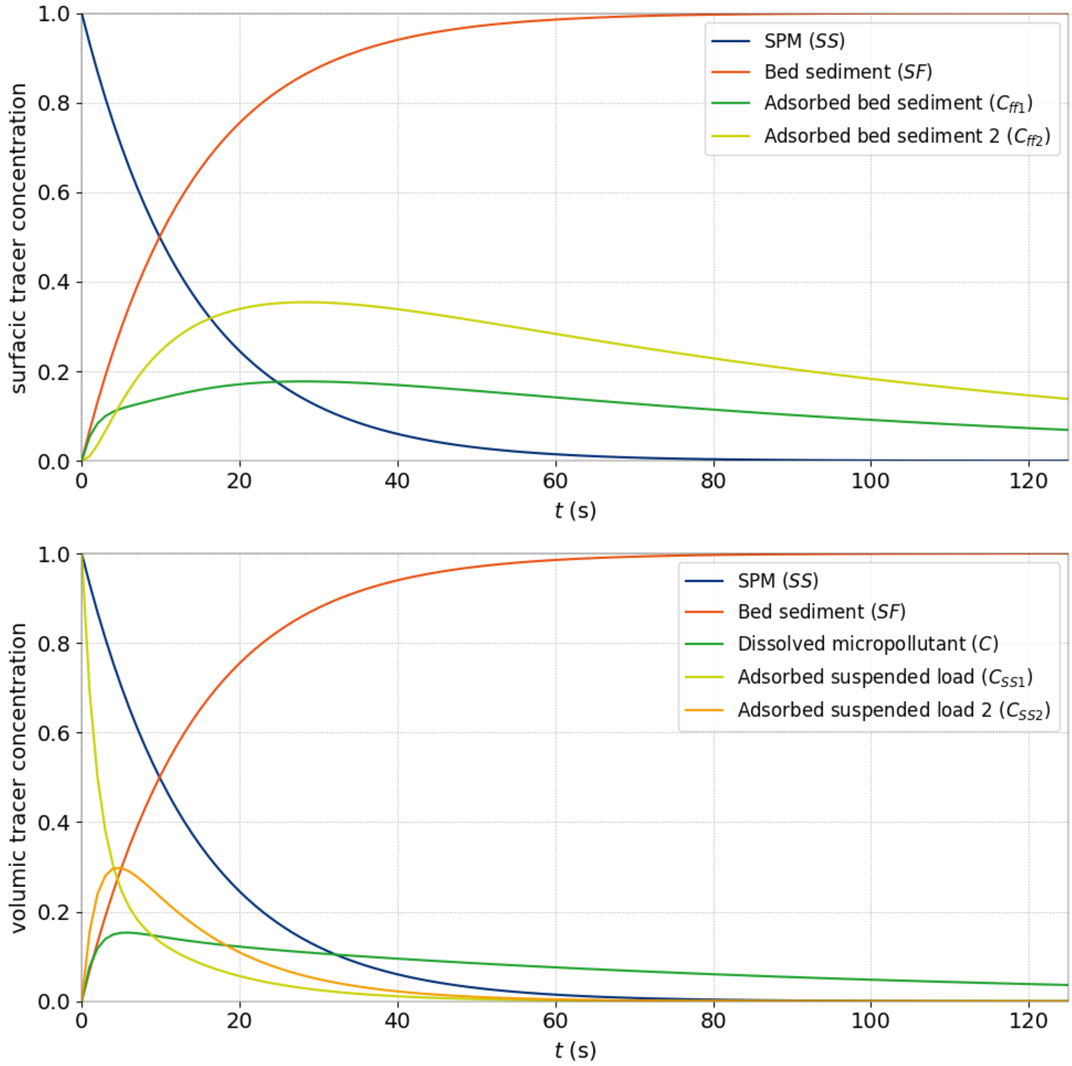

Figure 7.12: Tracers evolution for test case 5.

7.3 Conclusion

The MICROPOL module of WAQTEL can be coupled with TELEMAC-2D.

8. waq2d_o2

8.1 Purpose

This case is an example of the use of the O_2 module of WAQTEL coupled with TELEMAC-2D.

8.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

8.3 Computational options

8.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 8.1).

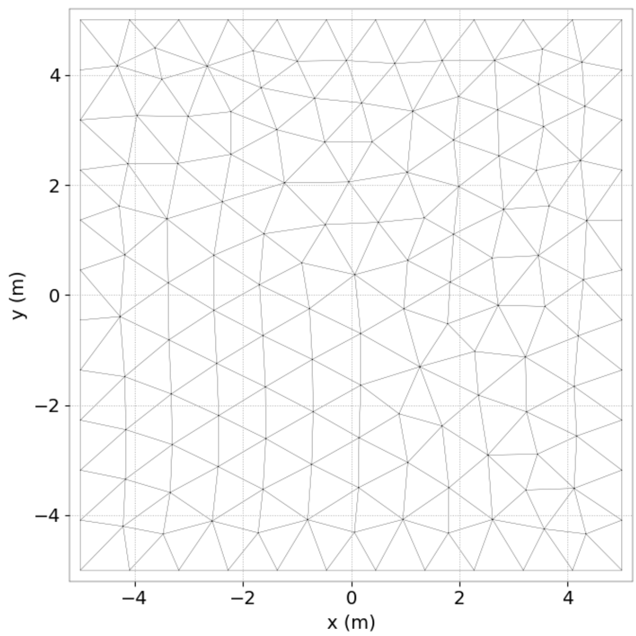

Figure 8.1: Mesh

8.3.2 Physical parameters

No diffusion neither for hydrodynamics or tracers.

The O_2 module is activated by setting `WATER QUALITY PROCESS` = 2 in the TELEMAC-2D `STEERING FILE`.

3 tracers are considered:

- dissolved O_2,
- NH_4 load,
- organic load.

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `K2 REAERATION COEFFICIENT` = 0.3,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `O2 SATURATION DENSITY OF WATER (CS)` = 9 mgO_2/l (C_s is constant),
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

8.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([O_2], [L], [NH_4]) = (5 mgO_2/l, 3 mgO_2/l, 0.01 mgNH_4/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

8.3.4 General parameters

The time step is 4 s for a simulated period of 86,400 s = 1 day.

8.3.5 Numerical parameters

Basin at rest (no advection nor diffusion).

8.4 Results

Figure 8.2 shows the 3 tracers evolution along time. All of them vary with time (even NH_4 load).

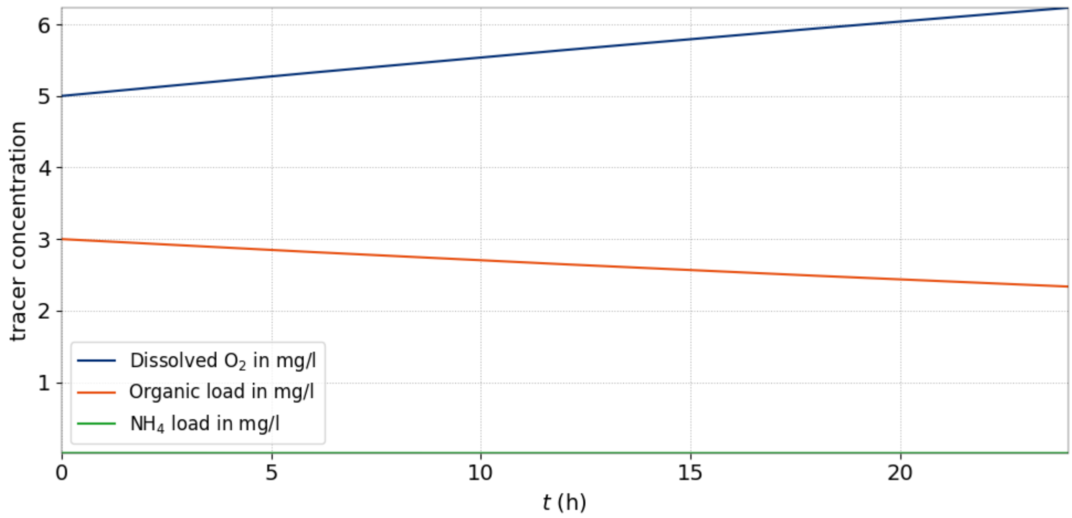

Figure 8.2: Tracers evolution for different tracers of the O_2 module

8.5 Conclusion

The O_2 module of WAQTEL can be coupled with TELEMAC-2D.

9. waq2d_thermic

9.1 Purpose

This case is an example of the use of the heat exchange with atmosphere module of WAQTEL (called THERMIC) coupled with TELEMAC-2D.

9.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

9.3 Computational options

9.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 9.1).

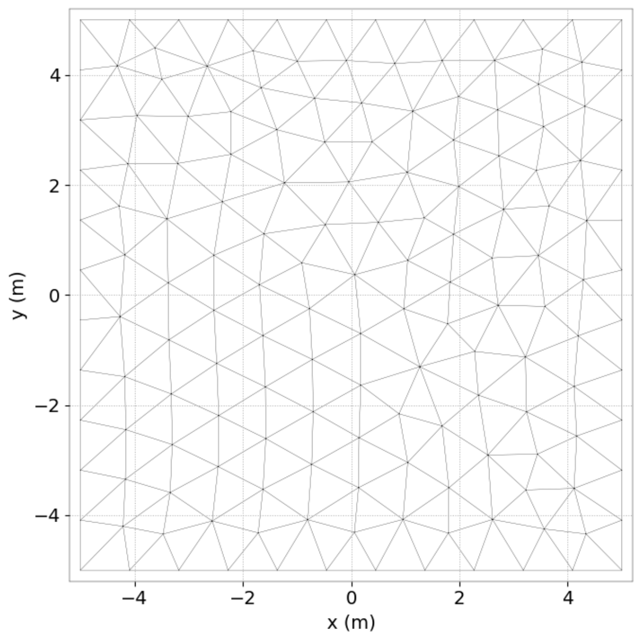

Figure 9.1: Mesh

9.3.2 Physical parameters

The heat exchange module is activated by setting `WATER QUALITY PROCESS` = 11 in the TELEMAC-2D `STEERING FILE`.

Only temperature is considered as a tracer.

Several default values are modified in the WAQTEL `STEERING FILE`:

- `WATER DENSITY` = 1,000 kg/m^3 (default = 999.972 kg/m^3),
- `COEFFICIENTS OF AERATION FORMULA` = (0.025 ; 0.025) (default = (0.002 ; 0.0012)),
- `COEFFICIENT OF CLOUDING RATE` = 0.2 (usual value in 2D, but default = 0.17),
- `COEFFICIENTS FOR CALIBRATING ATMOSPHERIC RADIATION` = 0.85 (default = 0.97).

One default value is modified in the TELEMAC-2D `STEERING FILE` (`AIR PRESSURE` = YES) whereas the keyword `ATMOSPHERE-WATER EXCHANGE MODEL` = 0 must not be changed in 2D!

9.3.3 Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest.
The initial temperature is 17 °C in the whole domain.

There are only closed lateral boundaries with free slip condition and no friction at the bottom.

9.3.4 General parameters

The time step is 10 min = 600 s for a simulated period of 30 days (= 2,592,000 s).

9.3.5 Numerical parameters

Basin at rest (no advection nor diffusion). No diffusion neither for hydrodynamics or tracers.

9.4 Results

Figure 9.2 shows the temperature evolution along time.

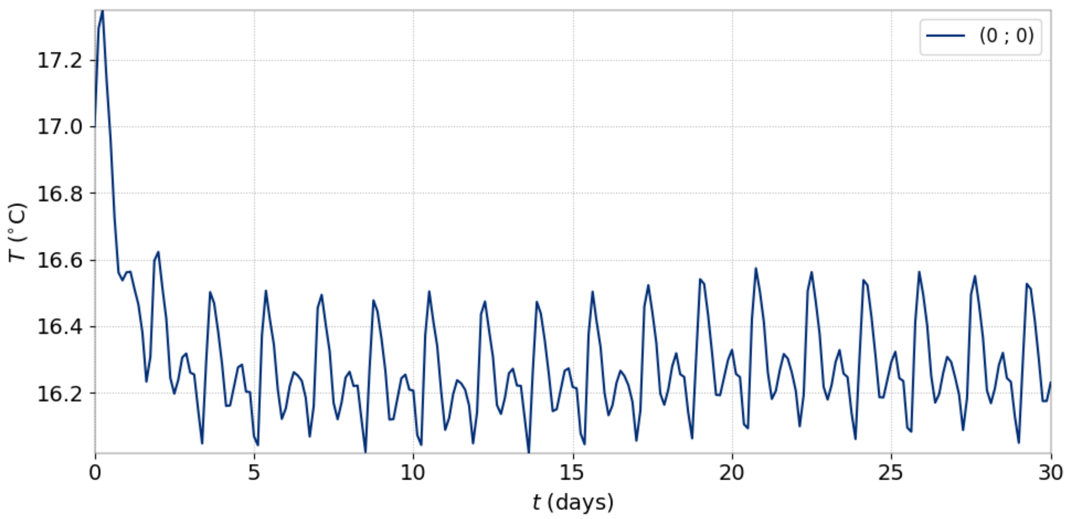

Figure 9.2: Temperature evolution

9.5 Conclusion

WAQTEL is able to model heat exchange with atmosphere phenomena when coupled with TELEMAC-2D.

10. Coupling TELEMAC-3D with AED2 in a basin (waq3d_aed2)

10.1 Purpose

This test shows the coupling between TELEMAC-3D and the water quality library AED2.

10.2 Description

A perfectly still basin is considered (length 1 m, width 1 m, and constant water depth 5 m) with flat bottom ($z = 0$ m).

10.3 Computational options

10.3.1 Mesh

The triangular mesh is composed of 49 triangular elements and 36 nodes (see Figure 10.1).

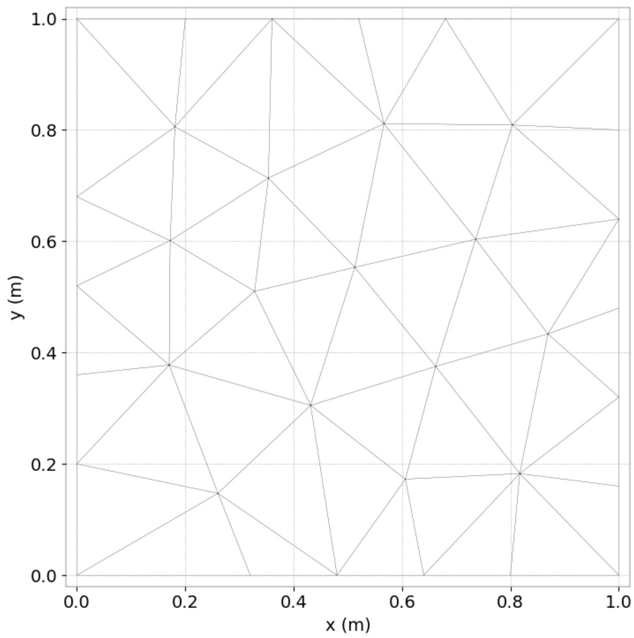

Figure 10.1: Horizontal mesh

To build the 3D mesh of prisms, 11 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (0 ; 0.5) to (1 ; 0.5) can be seen on Figure 10.2.

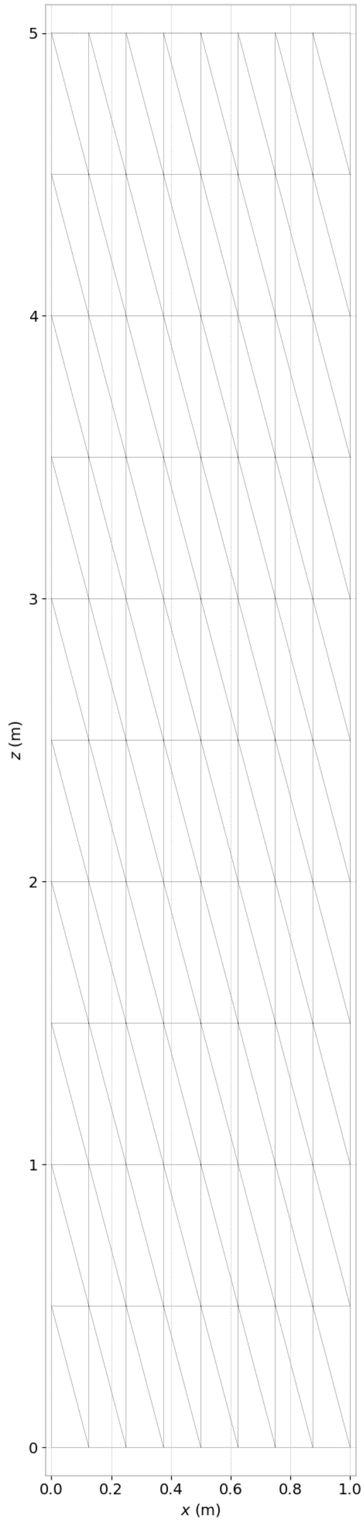

Figure 10.2: Vertical mesh

10.3.2 Water quality parameters

Coupling with WAQTEL and water quality processes = 13 (AED2), aed2.nml file contains the AED2 parametrization. The following modules are activated:

- sedflux,
- oxygen,
- carbon,
- silica,
- nitrogen,
- phosphorus,
- organic matter,
- phytoplankton,
- tracer.

As there are 25 tracers taken into account, the value of `MAXIMUM NUMBER OF TRACERS` has to be inscreased compared to its default value (20).

10.3.3 Initial and Boundary Conditions

The initial water depth is 5 m with a fluid at rest.
The initial concentrations are homogeneous.

There are only closed lateral boundaries with free slip condition and Nikuradse law is used to model friction at the bottom with a coefficient 0.001 m.

10.3.4 General parameters

The time step is 1 s for a simulated period of 1,000 s.

10.3.5 Numerical parameters

The non-hydrostatic version of TELEMAC-3D is used (default option). The LIPS scheme is chosen to solve the advection for the tracers (default option). But as the fluid is at rest, no specific effects can be seen.

10.3.6 Comments

Among the tracers, only the temperature, oxygen (O_2), ammonium (NH_4), nitrate (NO_3), phosphate (PO_4), Dissolved Organic Phosphorus (DOP), Dissolved Organic Nitrogen (DON) and Particulate Organic Phosphorus (POP) concentrations are written in the result files for this example.

10.4 Results

As an example, Figure 10.3 shows the oxygen, ammonium, nitrate, phosphate, DOP, DON concentrations at the end of the calculation in a vertical section. They vary in the water column. Temperature and POP remain homogeneous in the domain.

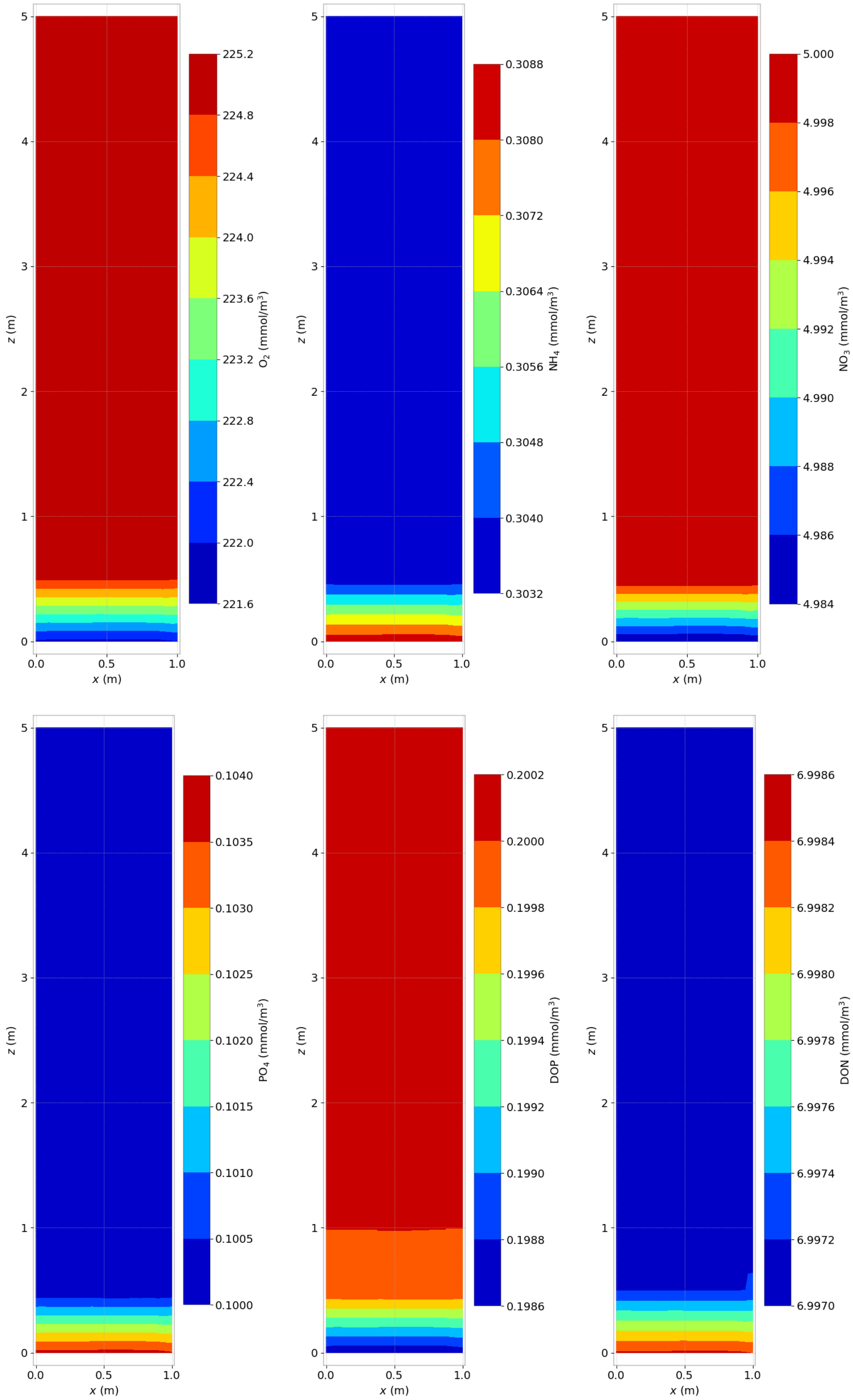

Figure 10.3: Vertical distribution of oxygen, ammonium, nitrate, phosphate, DOP, DON (from left to right then top to bottom at the end of computation)

10.5 Conclusion

TELEMAC-3D can be coupled with AED2 to model water quality processes.

11. Coupling TELEMAC-3D with AED2 in a flume (waq3d_aed2_flume)

11.1 Purpose

This test shows the coupling between TELEMAC-3D and the water quality library AED2. It checks if AED2 coupling works well when water is flowing.

11.2 Description

A simple channel is considered, the same as canal example (500 m long, 100 m wide, flat horizontal bottom).
The hydrodynamic parametrization is exactly the same as canal example.

11.3 Computational options

11.3.1 Mesh

The triangular mesh is composed of 551 triangular elements and 319 nodes (see Figure 11.1).

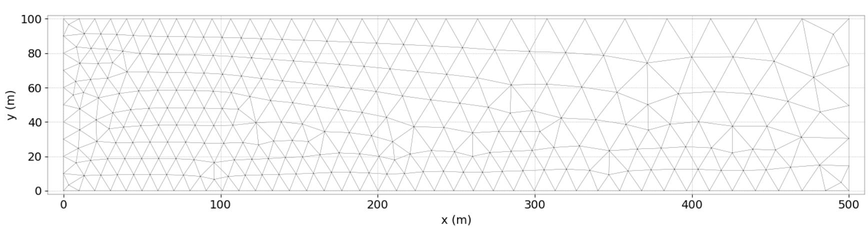

Figure 11.1: Horizontal mesh

To build the 3D mesh of prisms, 10 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (0 ; 50) to (500 ; 50) can be seen on Figure 11.2.

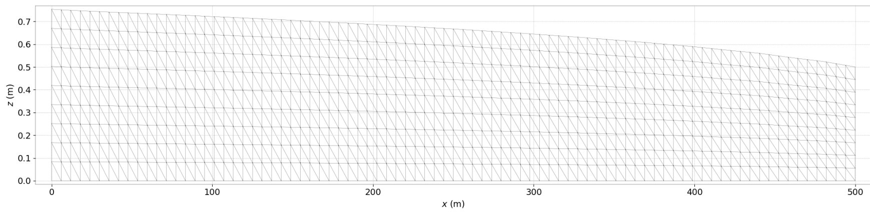

Figure 11.2: Vertical mesh

11.3.2 Physical parameters

Horizontal constant viscosity: with default value (10^{-6} m^2/s)
Vertical turbulence model: Nezu and Nakagawa mixing length model
Wind: no
Bottom friction: Nikuradse law with coefficient 0.001 m

11.3.3 Water quality parameters

Coupling with WAQTEL and water quality processes = 13 (AED2), aed2.nml file contains the AED2 parametrization. The following modules are activated :

- sedflux,
- oxygen,
- carbon,
- silica,
- nitrogen,
- phosphorus,
- organic matter,
- phytoplankton,
- tracer.

As there are 25 tracers taken into account, the value of `MAXIMUM NUMBER OF TRACERS` has to be inscreased compared to its default value (20).
It is the same water quality parametrization as waq3d_aed2 test case.

11.3.4 Initial and Boundary Conditions

The flow is steady (previous result file to start).
The initial concentrations are homogeneous with the same values as prescribed values for upstream boundary.

A flow rate of 50 m^3/s is prescribed upstream.
An elevation of 0.5 m is prescribed downstream.
Constant concentrations of tracers are prescribed at the inlet boundary, the same as the initial conditions for each tracer.

11.3.5 General parameters

The time step is 1 s for a simulated period of 160 s.

11.3.6 Numerical parameters

The non-hydrostatic version of TELEMAC-3D is used (default option). The LIPS scheme is chosen to solve the advection for the tracers (default option) whereas the method of characteristics is chosen to solve the advection for the velocities only for CPU time reasons.

11.3.7 Comments

Among the tracers, only the temperature, oxygen (O_2), ammonium (NH_4), nitrate (NO_3), phosphate (PO_4), Dissolved Organic Phosphorus (DOP), Dissolved Organic Nitrogen (DON) and Particulate Organic Phosphorus (POP) concentrations are written in the result files for this example.

11.4 Results

As an example, Figure 11.3 shows the oxygen, ammonium, nitrate, phosphate, DOP, DON concentrations at the end of the calculation (= 160 s) in a vertical section. They vary in the water column and along the channel. Temperature and POP remain homogeneous in the domain. 160 s corresponds to a transitory step of the flow.

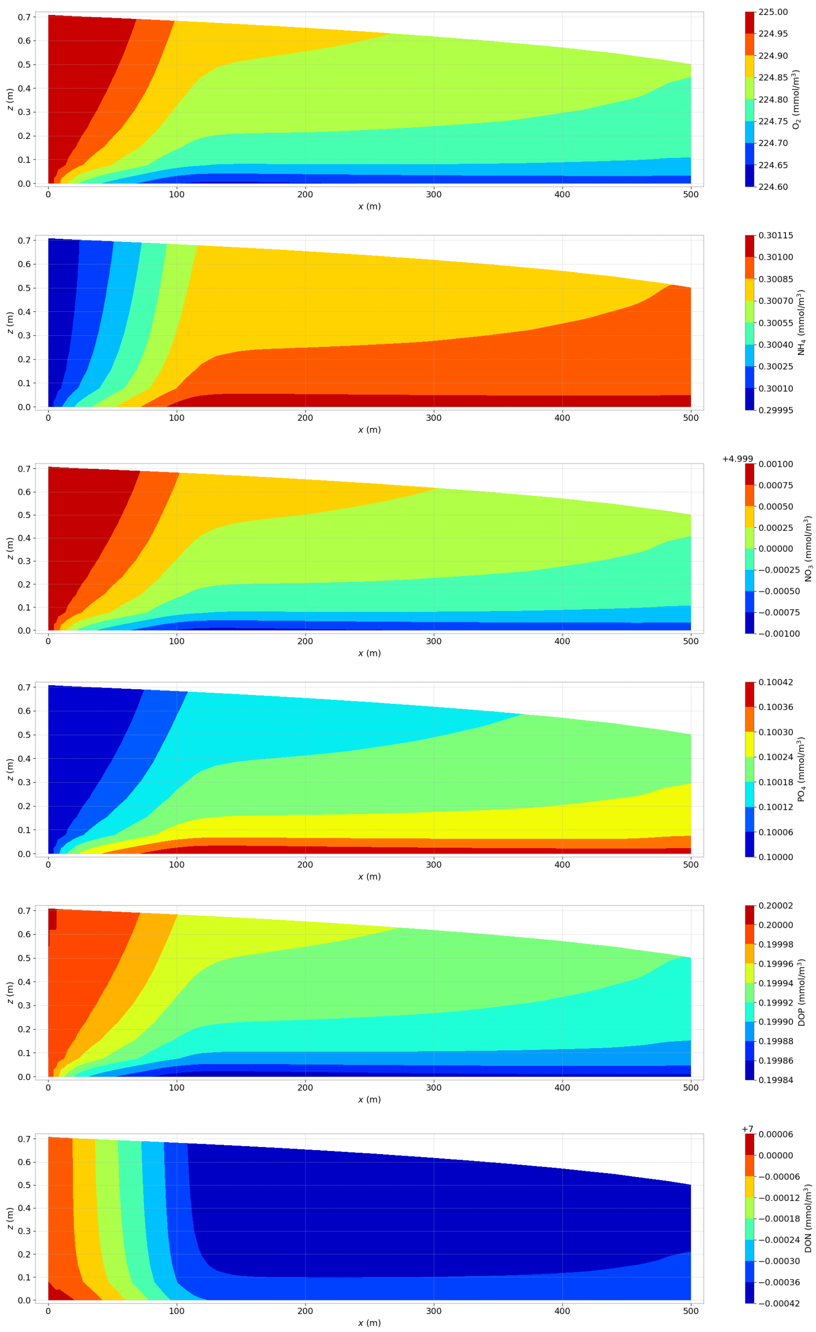

Figure 11.3: Vertical distribution of oxygen, ammonium, nitrate, phosphate, DOP, DON after 160 s

11.5 Conclusion

TELEMAC-3D can be coupled with AED2 to model unsteady flows.

12. waq3d_biomas

12.1 Purpose

This case is an example of the use of the BIOMASS module of WAQTEL coupled with TELEMAC-3D.

12.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

12.3 Computational options

12.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 12.1).

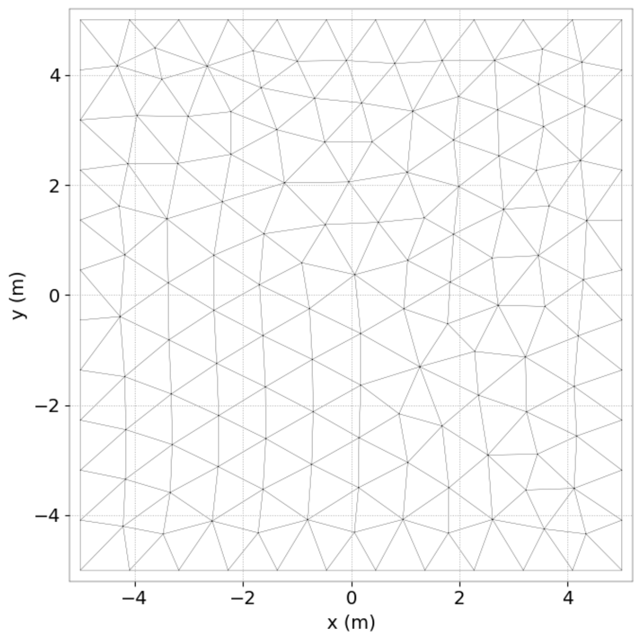

Figure 12.1: Mesh

To build the 3D mesh of prisms, 3 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (-5 ; 0) to (5 ; 0) can be seen on Figure 12.2.

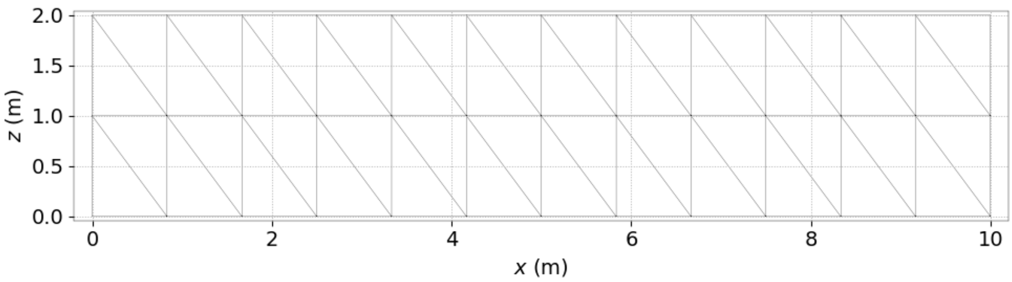

Figure 12.2: Vertical mesh

This number of 3 planes has been changed to decrease the CPU time to run this example in the global validation process, as nothing seems to happen over the vertical (checked for 11 planes with differences over the vertical lower than 10^{-15}).

12.3.2 Physical parameters

The BIOMASS module is activated by setting `WATER QUALITY PROCESS` = 3 in the TELEMAC-3D `STEERING FILE`.

5 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `METHOD OF COMPUTATION OF RAY EXTINCTION COEFFICIENT` = 2 (Moss formula, Secchi depth is unknown),
- `VEGETAL TURBIDITY COEFFICIENT WITHOUT PHYTO` = 0.005 m^{-1},
- `RATE OF TRANSFORMATION OF NOR TO NO3` = 0.35 d^{-1},
- `SUNSHINE FLUX DENSITY ON WATER SURFACE` = 0.01 W/m^2,
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

12.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([PHY],[PO4],[POR],[NO3],[NOR]) = (50 μgChlA/l, 3 mg/l, 0.01 mg/l, 2.9 mg/l, 9 mg/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

12.3.4 General parameters

The time step is 1 h = 3,600 s for a simulated period of 8,760 h = 365 days.

12.3.5 Numerical parameters

Basin at rest (no advection nor diffusion for hydrodynamics).

The advection scheme for the tracers is LIPS (new default value since release 8.1) activated with the combo `SCHEME FOR ADVECTION OF TRACERS` = 5 and `SCHEME OPTION FOR ADVECTION OF TRACERS` = 4.
Moreover, the `ACCURACY FOR DIFFUSION OF TRACERS` is to be set to 10^{-15} to get mass balance with a good accuracy. For this example, the current default value = 10^{-8} is not enough.

12.4 Results

Figure 12.3 shows the 5 tracers evolution along time. All of them rather quickly reach an asymptote.

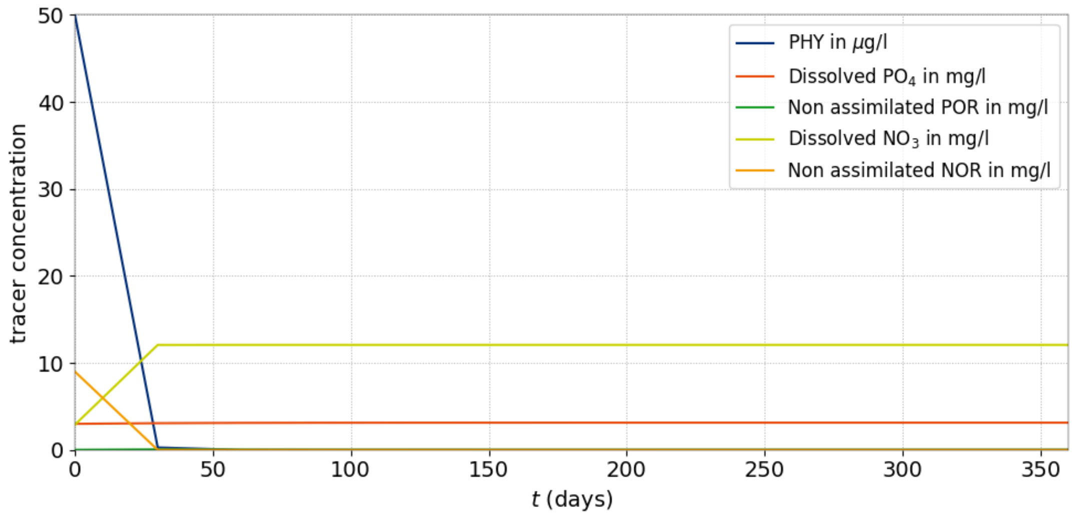

Figure 12.3: Tracers evolution for different tracers of the BIOMASS module

12.5 Conclusion

The BIOMASS module of WAQTEL can be coupled with TELEMAC-3D.

13. waq3d_degradation

13.1 Purpose

This case is an example of the use of degradation laws of WAQTEL coupled with TELEMAC-3D.

13.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

13.3 Computational options

13.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 13.1).

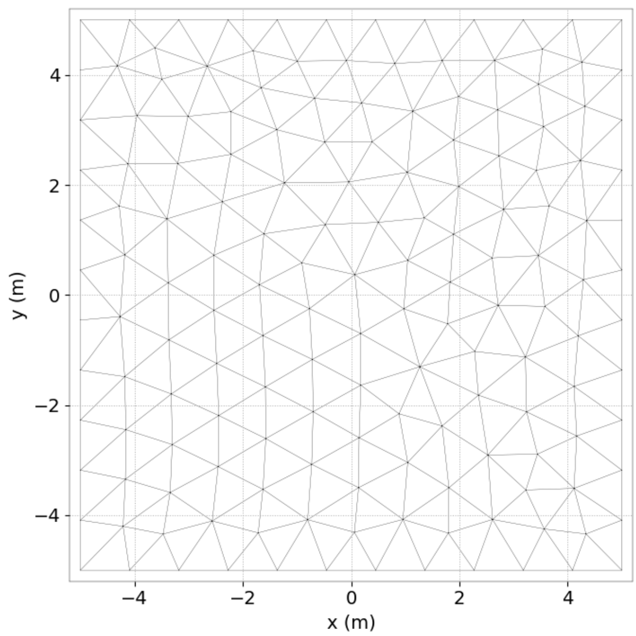

Figure 13.1: Horizontal mesh

To build the 3D mesh of prisms, 5 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (-5 ; 0) to (5 ; 0) can be seen on Figure 13.2.

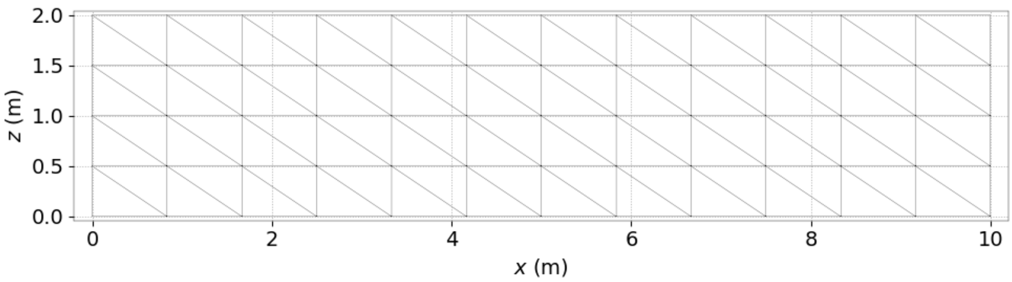

Figure 13.2: Vertical mesh

13.3.2 Physical parameters

The degradation law is activated by setting `WATER QUALITY PROCESS` = 17 in the TELEMAC-3D `STEERING FILE`.

Several tracers are considered:

- the 1st one without any degradation law,
- the 2nd one with a 1st order law for bacterial degradation with a T_{90} coefficient = 6 h,
- the 3rd one with a 1st order degradation law with a constant of tracer kinetic degradation = 0.3833333333333333 h^{-1},
- the 4th one with a 1st order degradation law with a constant of tracer kinetic degradation = 9.2 day^{-1},
- the 5th one with a degradation law implemented by user. As an example, a 1st order degradation law with a constant of tracer kinetic degradation = 0.00010648148148148147 s^{-1} has been implemented with the help of **USER_CALCS3D_DEGRADATION** subroutine.

The T_{90} or k_1 coefficients can be specified with the keyword `COEFFICIENT 1 FOR LAW OF TRACERS DEGRADATION` (one per tracer, expressed in hours for tracer 2, in h^{-1} for tracer 3, in day^{-1} for tracer 4).

13.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial concentrations are homogeneous = (100, 200, 200, 200, 200).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

13.3.4 General parameters

The time step is 600 s = 10 min for a simulated period of 86,400 s = 1 day.

13.3.5 Numerical parameters

Basin at rest (no advection nor diffusion).

13.4 Results

Figure 13.3 shows the tracers evolution along time for the tracers numbers 2, 3, 4 and 5 (with degradation law). The analytical solution is also plotted with circle markers.

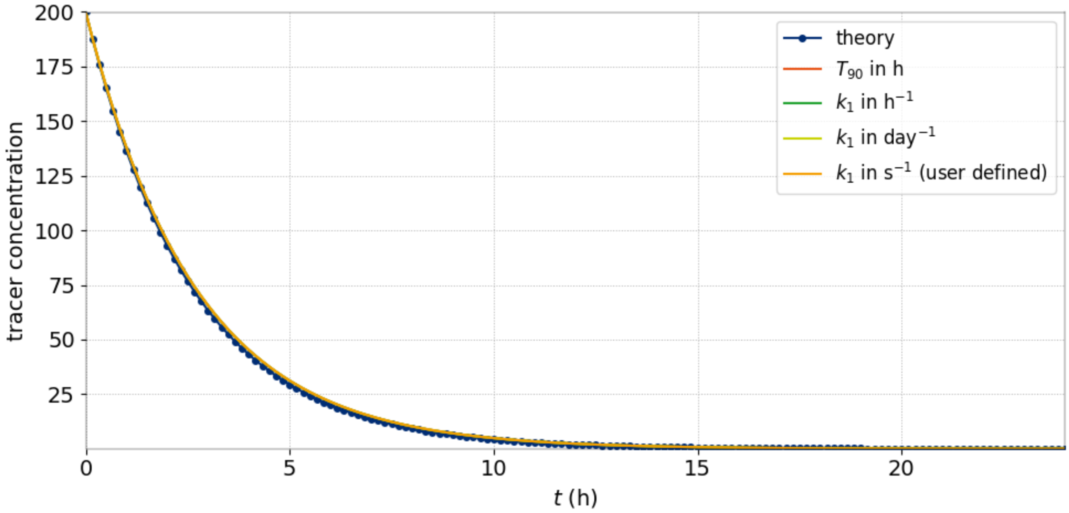

Figure 13.3: Tracers evolution for different expressions of the same degradation law

13.5 Conclusion

WAQTEL is able to model a 1st order degradation law when coupled with TELEMAC-3D.

14. waq3d_eutro

14.1 Purpose

This case is an example of the use of the EUTRO module of WAQTEL coupled with TELEMAC-3D.

14.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

14.3 Computational options

14.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 14.1).

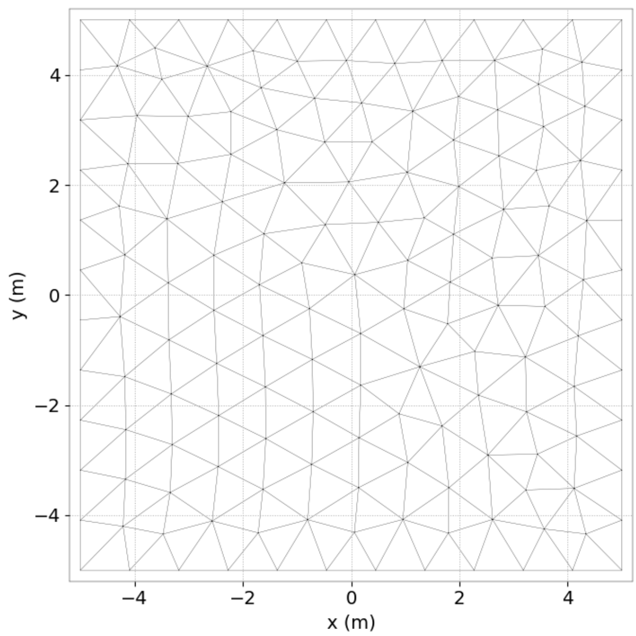

Figure 14.1: Mesh

To build the 3D mesh of prisms, 5 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (-5 ; 0) to (5 ; 0) can be seen on Figure 14.2.

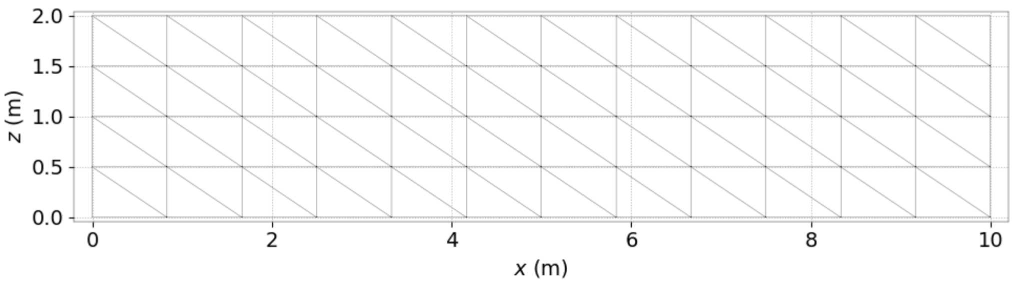

Figure 14.2: Vertical mesh

14.3.2 Physical parameters

The EUTRO module is activated by setting `WATER QUALITY PROCESS` = 5 in the TELEMAC-3D `STEERING FILE`.

8 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),
- ammoniacal load (NH_4),
- organic load (L),
- dissolved oxygen (O_2).

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `K2 REAERATION COEFFICIENT` = 0.3,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `O2 SATURATION DENSITY OF WATER (CS)` = 9 mgO_2/l (C_s is constant),
- `SECCHI DEPTH` = 0.1 m,
- `VEGETAL TURBIDITY COEFFICIENT WITHOUT PHYTO` = 0.01 m^{-1},
- `SUNSHINE FLUX DENSITY ON WATER SURFACE` = 0.01 W/m^2,
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

14.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([PHY],[PO4],[POR],[NO3],[NOR],[NH_4],[L],[O_2]) = (50 μgChlA/l, 3 mg/l, 0.01 mg/l, 2.9 mg/l, 9 mg/l, 1 mgNH_4/l, 0.2 mgO_2/l, 0.06 mgO_2/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

14.3.4 General parameters

The time step is 1 h = 3,600 s for a simulated period of 8,760 h = 365 days.

14.3.5 Numerical parameters

Basin at rest (no advection nor diffusion for hydrodynamics).

The advection scheme for the tracers is LIPS (new default value since release 8.1) activated with the combo `SCHEME FOR ADVECTION OF TRACERS` = 5 and `SCHEME OPTION FOR ADVECTION OF TRACERS` = 4.
Moreover, the `ACCURACY FOR DIFFUSION OF TRACERS` is to be set to 10^{-15} to get mass balance with a good accuracy. For this example, the current default value = 10^{-8} is not enough.

14.4 Results

Figure 14.3 shows the 8 tracers evolution along time. All of them rather quickly reach an asymptote.

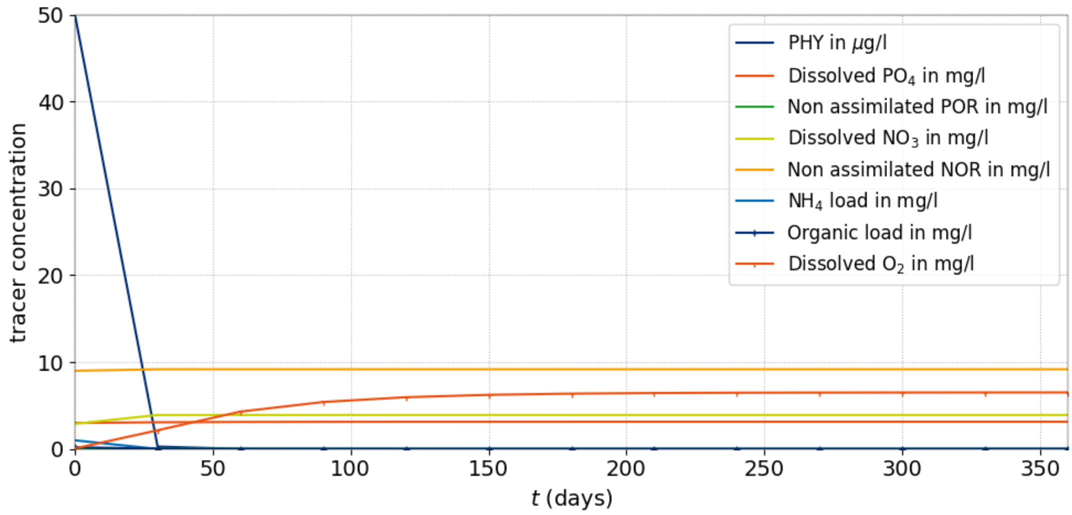

Figure 14.3: Tracers evolution for different tracers of the EUTRO module

14.5 Conclusion

The EUTRO module of WAQTEL can be coupled with TELEMAC-3D.

15. Streeter and Phelps experiment using Benson and Krause formula (waq3d_eutro_streeter_phelps)

15.1 Purpose

This case is an example of the use of the EUTRO module of WAQTEL coupled with TELEMAC-3D with Benson and Krause formula to compute oxygen saturation concentration C_s.

15.2 Description

A channel is considered (30 000 m long, 400 m wide, flat horizontal bottom = -10 m).

15.3 Computational options

15.3.1 Mesh

The triangular mesh is composed of 3,200 triangular elements and 1,809 nodes (see Figure 15.1).

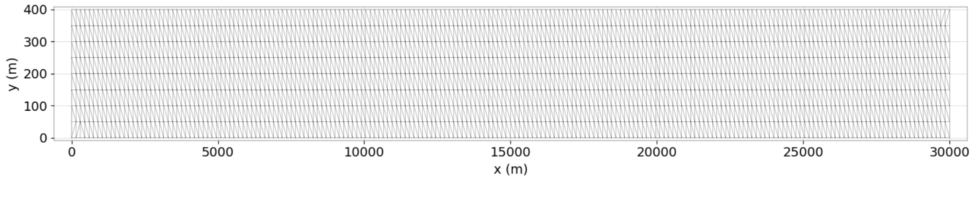

Figure 15.1: Mesh

To build the 3D mesh of prisms, 10 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (0 ; 200) to (30,000 ; 200) can be seen on Figure 15.2.

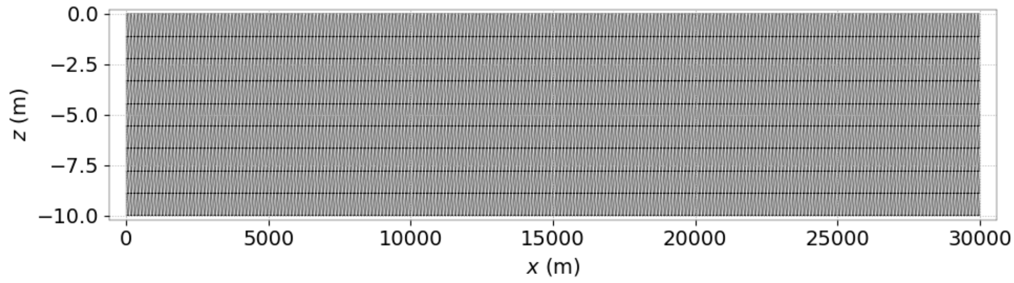

Figure 15.2: Vertical mesh

15.3.2 Physical parameters

Horizontal constant viscosity: with default value (10^{-6} m^2/s)
Vertical turbulence model: Prandtl mixing length model (default)
Bottom friction: no friction on the bottom

The EUTRO module is activated by setting `WATER QUALITY PROCESS` = 5 in the TELEMAC-3D `STEERING FILE`.

8 tracers are considered:

- phytoplanktonic biomass (PHY),
- dissolved mineral phosphorus (PO_4),
- degradable phosphorus non assimilated by phytoplankton (POR),
- dissolved mineral nitrogen assimilated by phytoplankton (NO_3),
- degradable nitrogen assimilated by phyto phytoplankton (NOR),
- ammoniacal load (NH_4),
- organic load (L),
- dissolved oxygen (O_2).

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `FORMULA FOR COMPUTING CS` = 3 (i.e. Benson and Krause),
- `CONSTANT OF DEGRADATION OF ORGANIC LOAD K120` = 0.36 d^{-1},
- `BENTHIC DEMAND` = 0 $gO_2/m^2/d$,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `SECCHI DEPTH` = 0.1 m,
- `VEGETAL TURBIDITY COEFFICIENT WITHOUT PHYTO` = 0.01 m^{-1},
- `SUNSHINE FLUX DENSITY ON WATER SURFACE` = 0.01 W/m^2,
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

15.3.3 Initial and Boundary Conditions

The initial water elevation is 0 m (= 10 m water depth).

The initial values for tracers are homogeneous with the same values as prescribed values for upstream except the penultimate one ([L] which is equal to 0 mgO_2/l for initial conditions and 10 mgO_2/l for upstream boundary condition):
(salinity,temperature,[PHY],[PO4],[POR],[NO3],[NOR],[NH_4],[L],[O_2]) = (35 g/l, 20 °C,0 μgChlA/l, 0 mg/l, 0 mg/l, 0 mg/l, 0 mg/l, 0 $mgNH_4$/l, 0 mgO_2/l, 7.39 mgO_2/l).
A flow rate of 200 m^3/s is prescribed upstream.
An elevation of 0 m is prescribed downstream.
Constant concentrations of tracers are prescribed at the inlet boundary, the same as the initial conditions for each tracer except the penultimate one ([L] which is equal to 0 mgO_2/l for initial conditions and 10 mgO_2/l for upstream boundary condition).

15.3.4 General parameters

The time step is 10 s for a simulated period of 172,800 s = 48 h.

15.3.5 Numerical parameters

The hydrostatic version of TELEMAC-3D is used. The PSI scheme is chosen to solve the advection for the last 2 tracers (L and O_2) whereas for the other tracers no advection scheme nor diffusion scheme are used. Moreover, the method of characteristics is chosen to solve the advection for the velocities.
The `ACCURACY FOR DIFFUSION OF TRACERS` is let to default value = 10^{-8}.

15.4 Results

Figure 15.3 shows the last 2 tracers evolution along time.

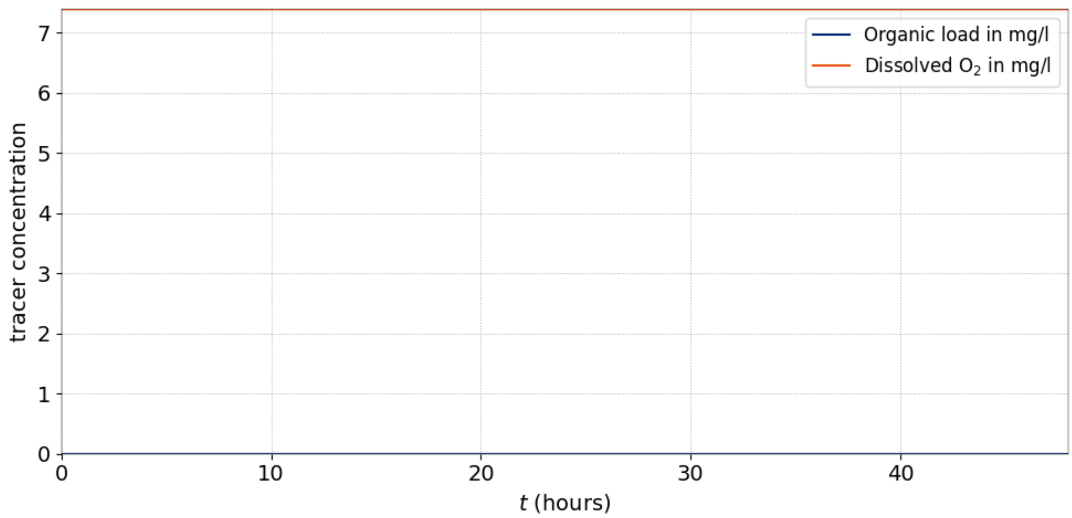

Figure 15.3: Tracers evolution for 2 tracers of the EUTRO module

15.5 Conclusion

The EUTRO module of WAQTEL can be coupled with TELEMAC-3D to model unsteady flows.

16. waq3d_micropol

16.1 sedimentation

16.1.1 Purpose

This case is an example of the use of the MICROPOL module of WAQTEL coupled with TELEMAC-3D.

16.1.2 Description

Exchanges between suspended sediments and bed sediments are studied here. A concentration of suspended sediment is initially placed on top of the water column and settling and deposition processes are observed. A 50 m long and 2.5 m wide rectangular basin at rest is considered with flat bathymetry and elevation at 0 m.

16.1.3 Computational options

Mesh

5 superimposed layers are regularly spaced vertically. The triangular mesh is composed of 500 triangular elements and 306 nodes (see Figure 16.1 and 16.2).

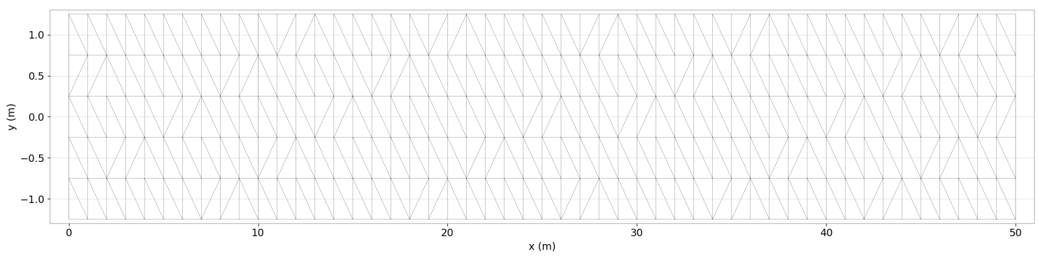

Figure 16.1: Horizontal mesh

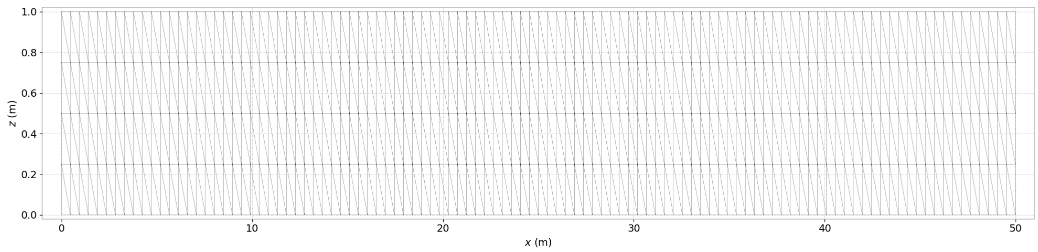

Figure 16.2: Vertical mesh

Physical parameters

There is no diffusion for hydrodynamics and tracer variables.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-3D `STEERING FILE`.

2 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2).

The settling velocity w is set at 4.10^{-3} m/s in the WAQTEL `STEERING FILE`.

Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest. The initial values for the suspended sediment tracer is set at a concentration of 1 kg/m^3 in the top layer (z = 1 m) (see Figure 16.3). The bed sediment tracer is initially set to zero.

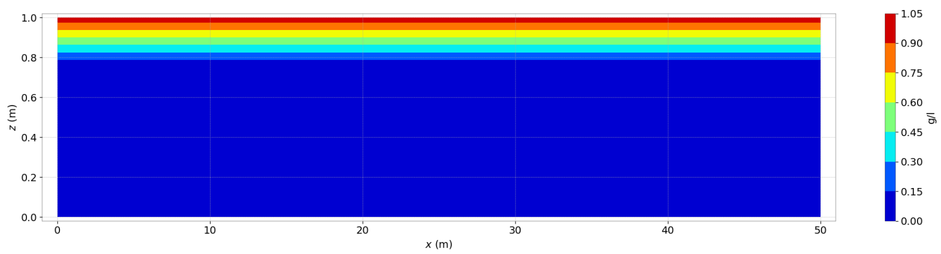

Figure 16.3: Suspended sediment initial concentrations

General parameters

The time step is 1 s for a simulated period of 1,000 s ≈ 17 min.

16.1.4 Results

Next figures show the suspended sediment (SS) (kg/m^3) and bed sediment (kg/m^2) evolution along time at different water depths. The blue dashed line represents the water depth divided by the sediment settling velocity, it can help to estimate the time magnitude for the SPM to reach the bottom layer.

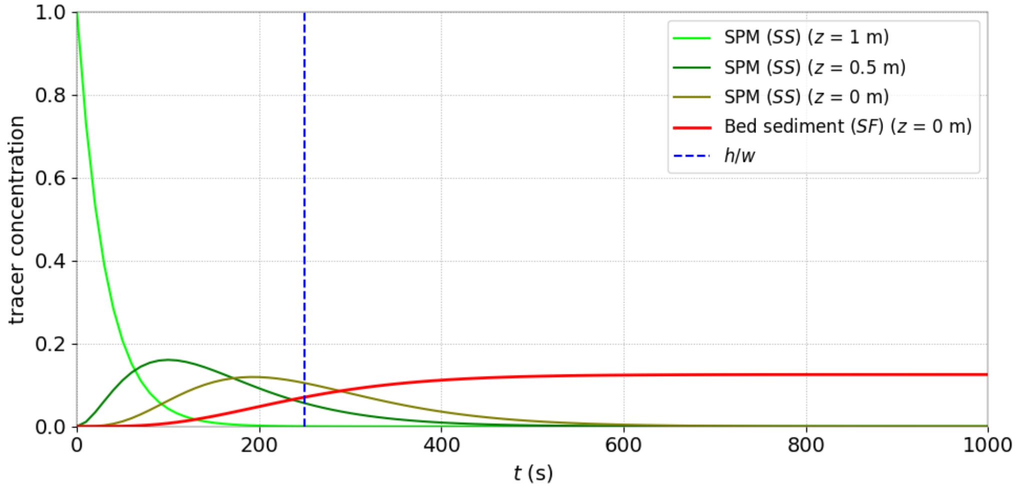

Figure 16.4: Suspended sediment and bed sediment evolution

At t = 1,000 s only residual suspended sediments are still being deposited in the bottom layer:

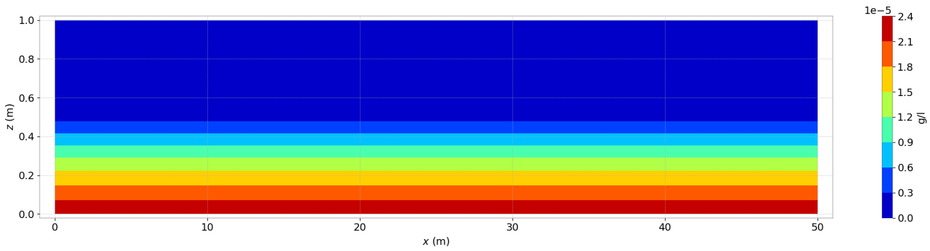

Figure 16.5: Suspended sediment final concentrations

16.1.5 Conclusion

The MICROPOL module of WAQTEL can be coupled with TELEMAC-3D for sediment settling deposition.

16.2 bump

16.2.1 Description

Exchanges between suspended sediments and bed sediments are studied here. An initial bump of bed sediment is placed at the bottom layer under a constant water velocity, erosion process is observed. A 10 m long and 2.5 m wide rectangular basin at rest is considered with flat bathymetry and elevation at 0 m.

16.2.2 Computational options

Mesh

10 superimposed layers are regularly spaced vertically. The triangular mesh is composed of 400 triangular elements and 231 nodes (see Figure 16.6 and 16.7).

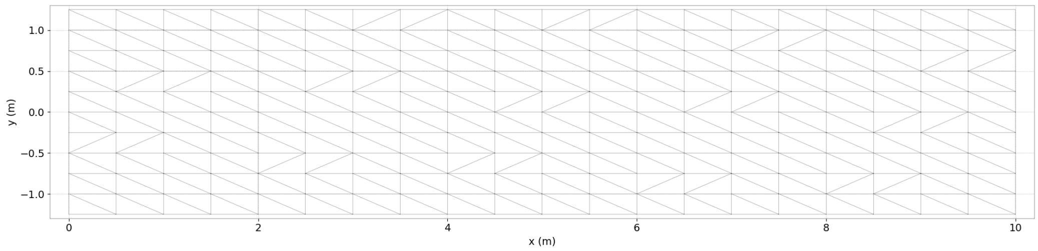

Figure 16.6: Horizontal mesh

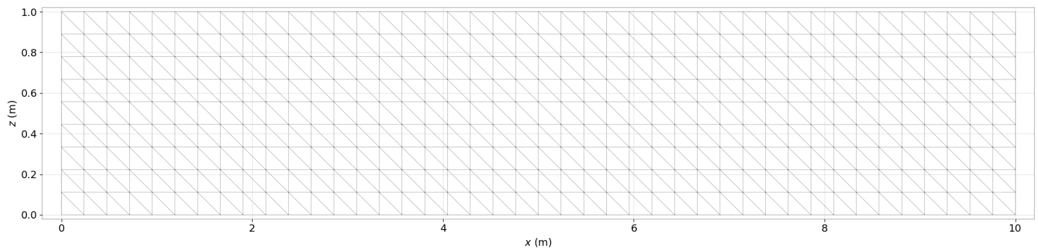

Figure 16.7: Vertical mesh

Physical parameters

There is no diffusion for hydrodynamics variables.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-3D `STEERING FILE`.

2 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2).

The settling velocity w is set at 0.02 m/s in the WAQTEL `STEERING FILE`.
Critical shear stresses of resuspension and sedimentation τ_r and τ_s are set to 0.01 Pa.
The erosion rate (or Partheniades constant) e is set at 10^{-3} kg/m^2/s.

Initial and Boundary Conditions

- The initial water depth is 1 m.
- The initial values for the suspended sediment tracer is set to zero and the initial values of the bed sediment are placed as a polynomial concentration:

$$SF(t=0) = \max(0, 5(x-7)(3-x))$$

- For the solid walls, a slip condition is used.
- Upstream flowrate equal to 1.5 m^3.s^{-1} is imposed.
- Downstream, the water level boundary condition is equal to 1 m.

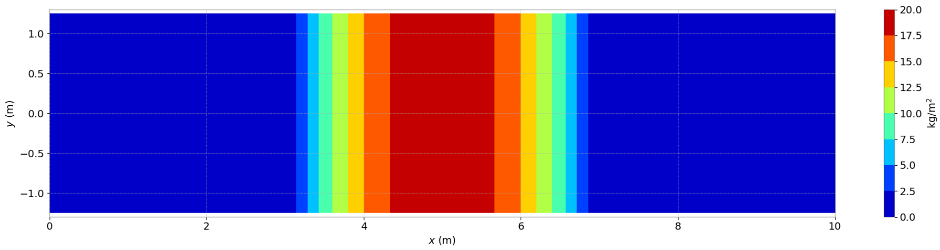

Figure 16.8: Bed sediment initial concentrations

General parameters

The time step is 0.1 s for a simulated period of 150 s.

16.2.3 Results

Next figures show the suspended sediment (*SS*) (kg/m^3) and bed sediment (kg/m^3) evolution along time on a vertical cross section.

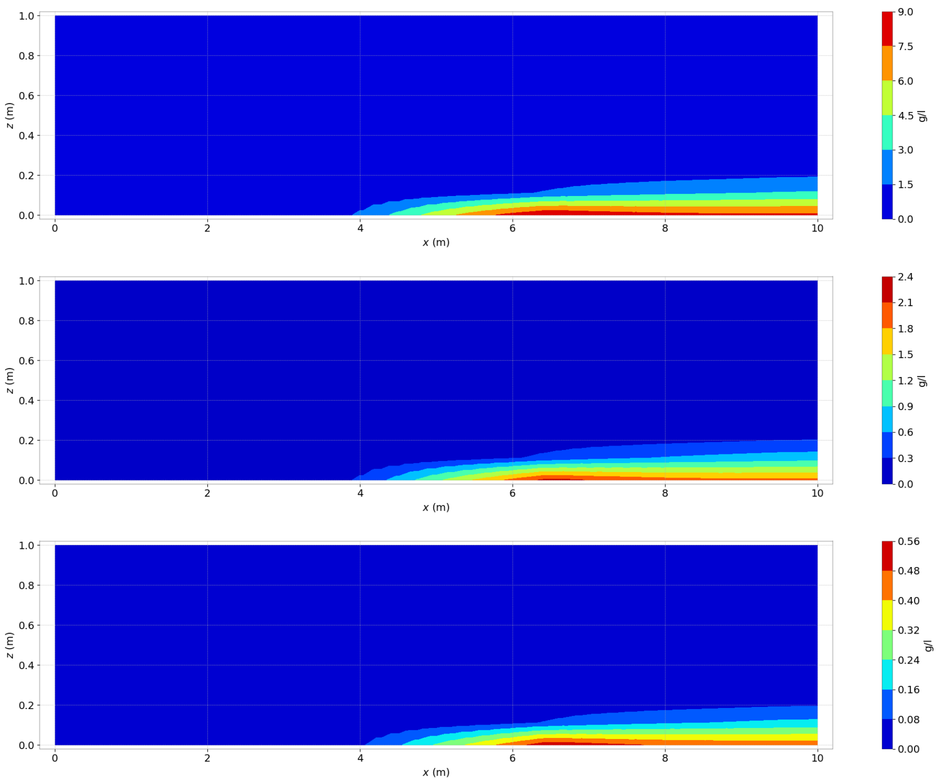

Figure 16.9: Suspended sediment concentrations at t = 5, 75 and 150 s

And bed sediment final concentrations:

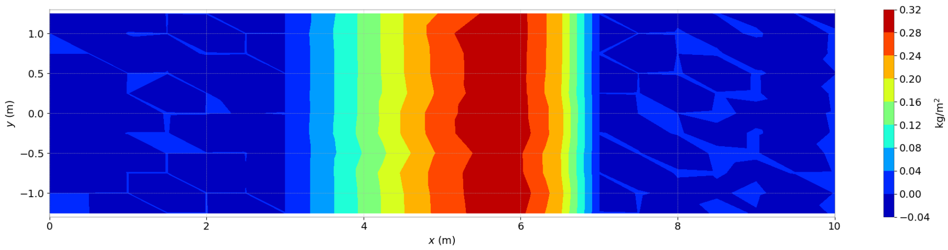

Figure 16.10: Bed sediment final concentrations

16.2.4 Conclusion

The MICROPOL module of WAQTEL, coupled with TELEMAC-3D, is able to represent sediment erosion.

16.3 Pollutant transport: one-step reversible model

16.3.1 Purpose

This case is an example of the use of the MICROPOL module of WAQTEL coupled with TELEMAC-3D for one-step reversible interactions between SPM and micro-pollutant species.

16.3.2 Description

A 50 m long and 2.5 m wide rectangular basin at rest is considered with flat bathymetry and elevation at 0 m.

16.3.3 Computational options

Mesh

5 layers are regularly spaced vertically. The triangular mesh is composed of 500 triangular elements and 306 nodes (see Figure 16.18 and 16.19).

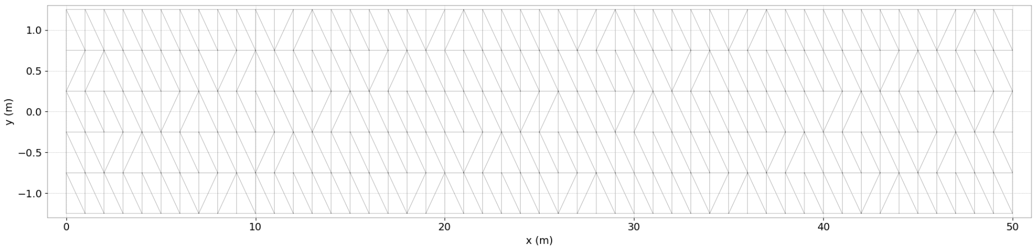

Figure 16.11: Horizontal mesh

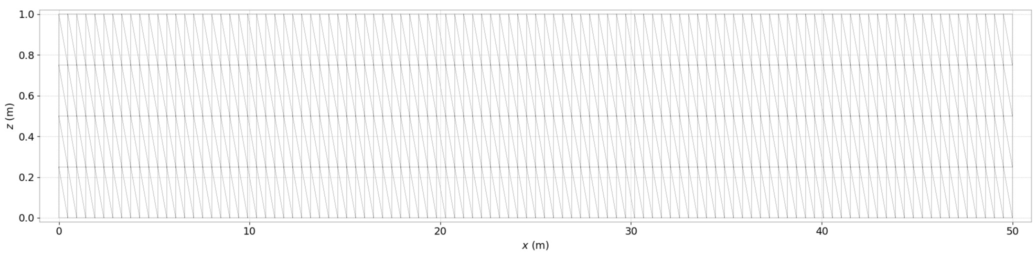

Figure 16.12: Vertical mesh

Physical parameters

No diffusion neither for hydrodynamics or tracers is considered.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-3D `STEERING FILE`.

5 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2),
- micro-pollutant species in dissolved form (C) (Bq/m^3),
- fraction adsorbed by suspended sediments (C_{SS}) (Bq/m^3),
- fraction adsorbed by bed sediments (C_{ff}) (Bq/m^2).

The settling velocity w (m/s) and the exponential decay constant L (s^{-1}) are adapted in each test case in order to individually model sedimentation, sorption, desorption and decay. The distribution coefficient K_d (l/g) is set at a value of 1 and the constant of kinetic desorption k_{-1} (s^{-1}) is set at a value of 0.01. All other parameters are taken with the default values in the WAQTEL `STEERING FILE`.

Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest. The initial values for tracers are homogeneous in each test cases:

- The first test case is a simple sorption with no sedimentation nor erosion.

  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 1, 0, 0) and (w, L) = (0, 0).

- Test case 2 evaluates deposition of SPM in the basin at rest.

  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 0, 0) and (w, L) = (0.07, 0).

- The third test case evaluates both sorption of micropollutants from dissolved form toward SPM, and deposition.

  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 1, 0, 0) and (w, L) = (0.07, 0).

- Test case 4 evaluates both desorption of micropollutants from SPM toward dissolved form, and deposition.

  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 1, 0) and (w, L) = (0.07, 0).

- Test case 5 is equivalent to test case 4 but a law of exponential micropollutant decay is added.

  (SS, SF, C, C_{SS}, C_{ff}) = (1, 0, 0, 1, 0) and (w, L) = (0.07, 8.3E-3).

There are only closed lateral boundaries with free slip condition and no friction at the bottom.

General parameters

The time step is 0.1 s for a simulated period of 125 s.

Analytical solution

An analytical solution can be calculated in the case of simple steady hydrodynamic conditions:

- In the case where the settling velocity w is nil, there is no sediment evolution and the exchanges remain exclusively in the micropollutant tracers. By setting the initial concentration of micropollutants adsorbed by SPM (C_{SS}) at 1 Bq/m^3 and 0 otherwise, an analytical solution under these conditions is:

$$C_{SS}(t) = \frac{SS_0}{SS_0+1}(1-e^{-k_{-1}(SS_0+1)t})$$

$$C(t) = \frac{1}{SS_0+1}(SS_0+e^{-k_{-1}(SS_0+1)t})$$

16.3.4 Results

Next figures show the 5 tracers evolution at the bottom layer (z = 0 m) along time for each test case. MICROPOL module results are compared with the analytical solutions from 16.4.3.

Figure 16.13 shows the results of a simple sorption with no sedimentation or erosion.

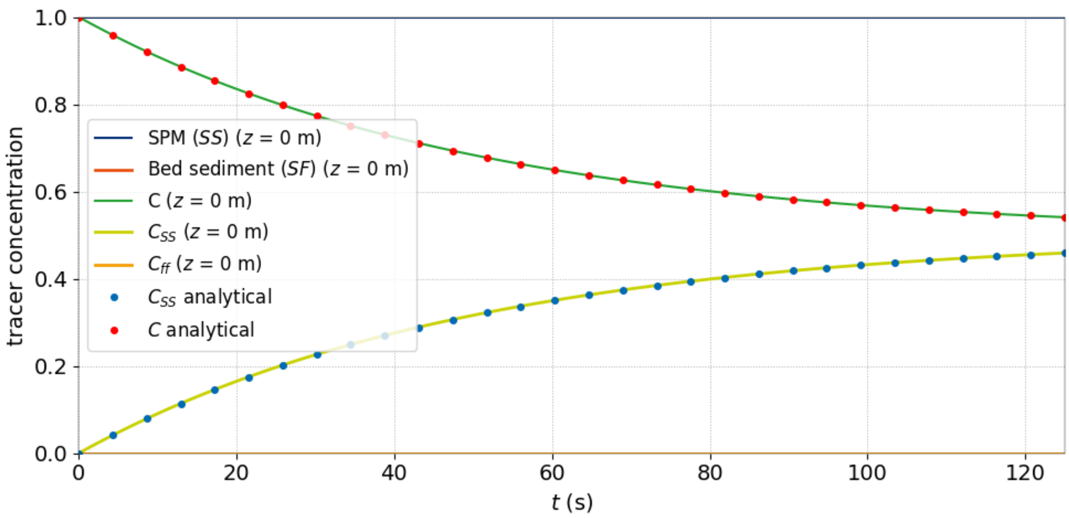

Figure 16.13: Tracers evolution for test case 1

Figure 16.14 evaluates deposition of SPM in the basin at rest. Depending on the bottom layer thickness, suspended sediments concentration accumulates before reaching the bed sediment layer.

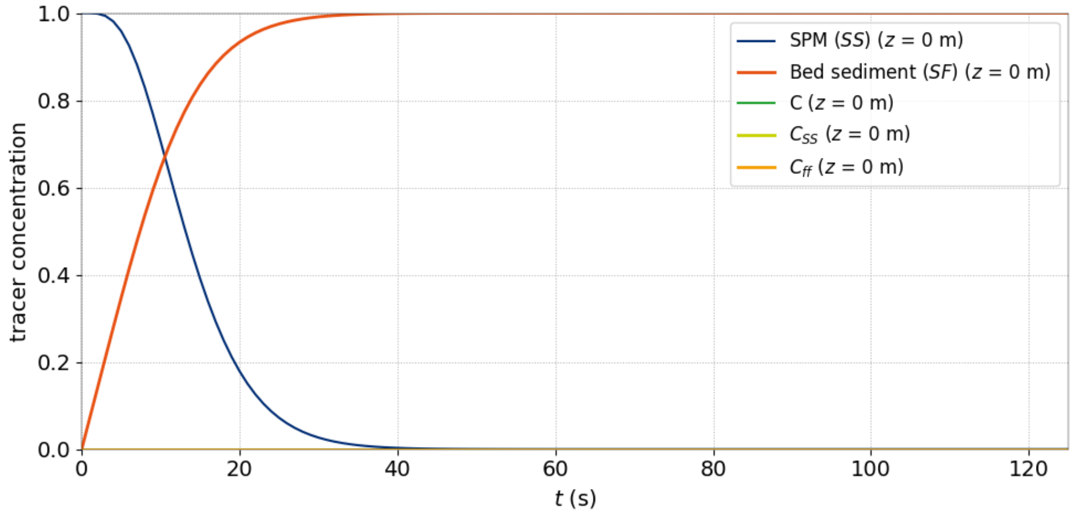

Figure 16.14: Tracers evolution for test case 2

Figure 16.15 displays both sorption of micropollutants from dissolved form toward SPM, and deposition results.

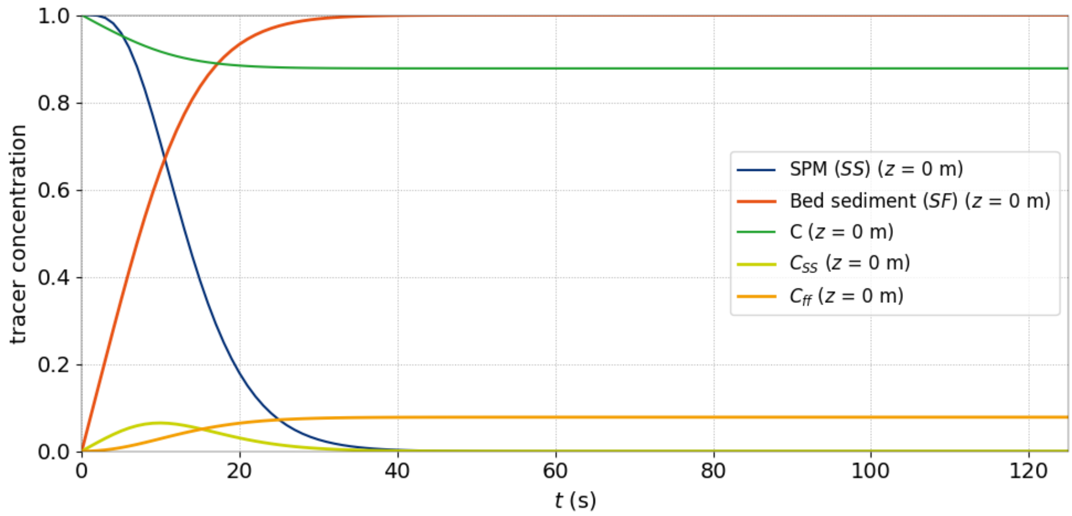

Figure 16.15: Tracers evolution for test case 3

In Figure 16.16 are shown both desorption of micropollutants from SPM toward dissolved form, and deposition.

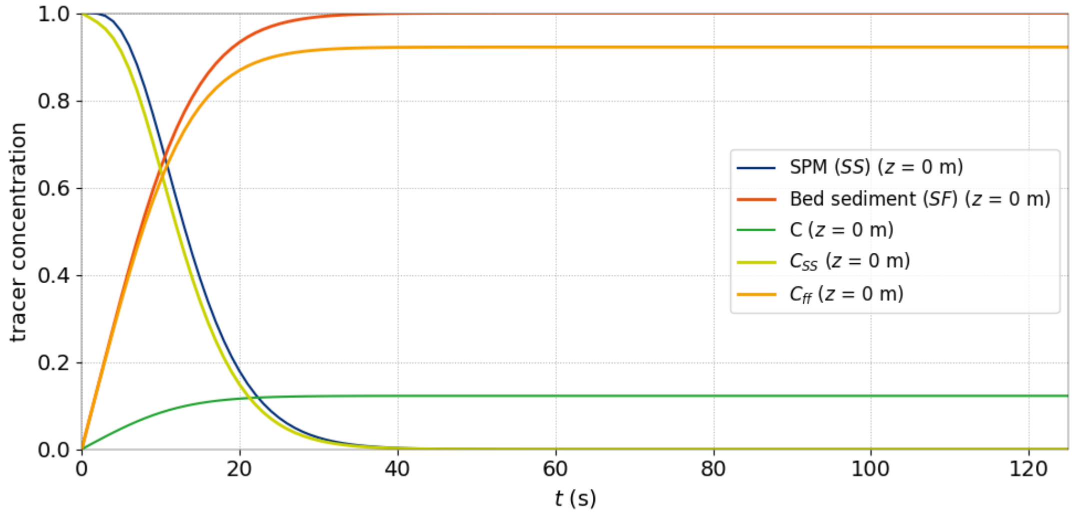

Figure 16.16: Tracers evolution for test case 4

Results of Figure 16.17 are equivalent to test case 4 but a law of exponential micropollutant decay is added.

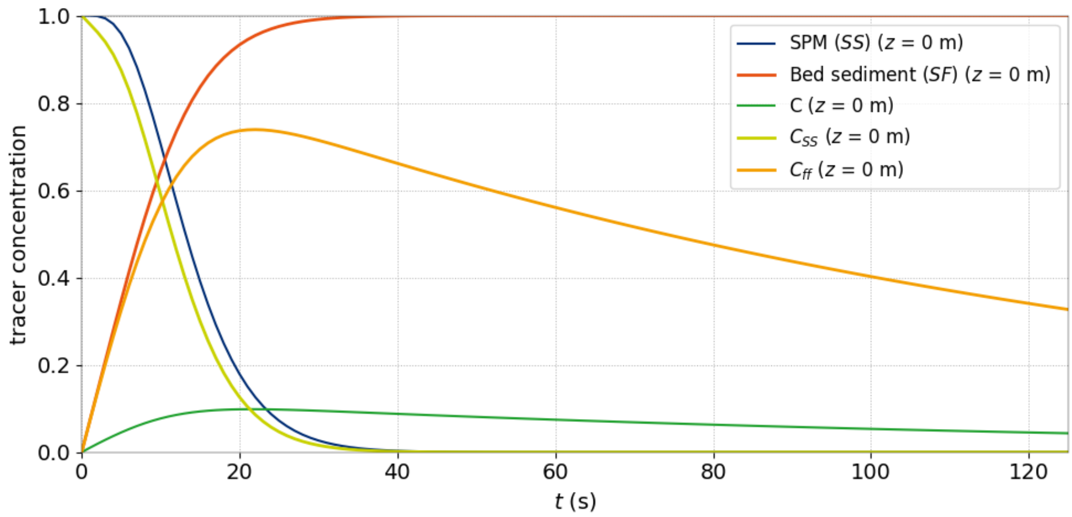

Figure 16.17: Tracers evolution for test case 5

16.3.5 Conclusion

The MICROPOL module of WAQTEL can be coupled with TELEMAC-3D for micropollutant and sediment interactions.

16.4 Pollutant transport: two-step reversible model

16.4.1 Purpose

This case is an example of the use of the MICROPOL module of WAQTEL coupled with TELEMAC-3D for two-step reversible interactions between SPM and micro-pollutant species.

16.4.2 Description

A 50 m long and 2.5 m wide rectangular basin at rest is considered with flat bathymetry and elevation at 0 m.

16.4.3 Computational options

Mesh

5 layers are regularly spaced vertically. The triangular mesh is composed of 500 triangular elements and 306 nodes (see Figure 16.18 and 16.19).

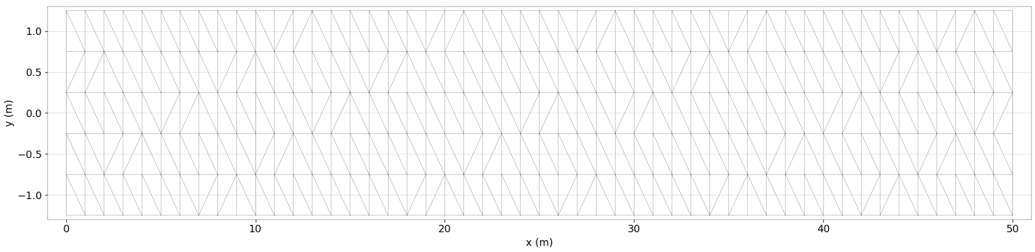

Figure 16.18: Horizontal mesh

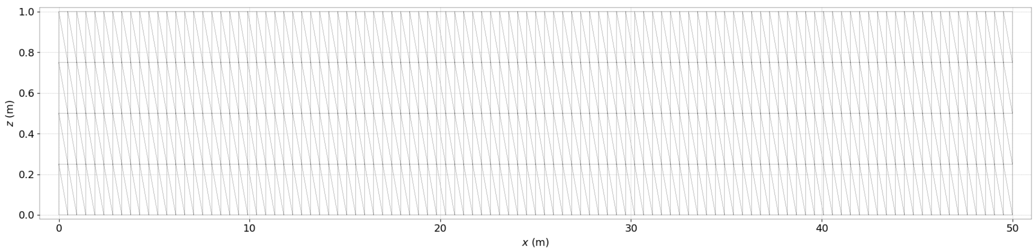

Figure 16.19: Vertical mesh

Physical parameters

No diffusion neither for hydrodynamics or tracers is considered.
The MICROPOL module is activated by setting `WATER QUALITY PROCESS` = 7 in the TELEMAC-3D `STEERING FILE`.
The two-step reversible model is activated by setting the keyword `KINETIC EXCHANGE MODEL` = 2 in the WAQTEL `STEERING FILE`.

7 tracers are considered:

- suspended sediments (SS) (kg/m^3),
- bed sediments (SF) (kg/m^2),
- micro-pollutant species in dissolved form (C) (Bq/m^3),
- fraction adsorbed by suspended sediments weak site (C_{ss1}) (Bq/m^3),
- fraction adsorbed by bed sediments weak site (C_{ff1}) (Bq/m^2).
- fraction adsorbed by suspended sediments strong site (C_{ss2}) (Bq/m^3),
- fraction adsorbed by bed sediments strong site (C_{ff2}) (Bq/m^2).

The settling velocity w (m/s) and the exponential decay constant L (s^{-1}) are adapted in each test case in order to individually model sedimentation, sorption, desorption and decay. The distribution coefficients K_d and K_{d2} (L/g) are set at a value of 2. The sorption reaction rates k_1 and k_2 (L/g/s) are set at a value of 0.1. All other parameters are taken with the default values in the WAQTEL `STEERING FILE`.

Initial and Boundary Conditions

The initial water depth is 1 m with a fluid at rest. The initial values for tracers are homogeneous in each test cases:

- The first test case is a simple sorption with no sedimentation or erosion.
  $(SS, SF, C, C_{SS1}, C_{ff1}, C_{ss2}, C_{ff2})$ = (1, 0, 1, 0, 0, 0, 0) and (w, L) = (0, 0).
- Test case 2 evaluates deposition of SPM in the bassin at rest.
  $(SS, SF, C, C_{SS1}, C_{ff1}, C_{ss2}, C_{ff2})$ = (1, 0, 0, 0, 0, 0, 0) and (w, L) = (4E-7, 0).
- The third test case evaluates both sorption of micropollutants from dissolved form toward SPM, and deposition.
  $(SS, SF, C, C_{SS1}, C_{ff1}, C_{ss2}, C_{ff2})$ = (1, 0, 1, 0, 0, 0, 0) and (w, L) = (4E-7, 0).
- Test case 4 evaluates both desorption of micropollutants from SPM toward dissolved form, and deposition.
  $(SS, SF, C, C_{SS1}, C_{ff1}, C_{ss2}, C_{ff2})$ = (1, 0, 0, 1, 0, 0, 0) and (w, L) = (4E-7, 0).
- Test case 5 is equivalent to test case 4 but a law of exponential micropollutant decay is added.
  $(SS, SF, C, C_{SS1}, C_{ff1}, C_{ss2}, C_{ff2})$ = (1, 0, 0, 1, 0, 0, 0) and (w, L) = (4E-7, 1.13E-7).

There are only closed lateral boundaries with free slip condition and no friction at the bottom.

General parameters

The time step is 0.1 s for a simulated period of 125 s.

Analytical solution

An analytical solution can be calculated in the case of simple steady hydrodynamic conditions:

- In the case where the settling velocity w is nil, there is no sediment evolution and the exchanges remain exclusively in the micropollutant tracers. By setting the initial concentration of micropollutants in the water (C) at 1 Bq/m^3 and 0 otherwise, an analytical solution under these conditions is:

$$C(t) = \frac{1}{7}(1+(3+\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} + (3-\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

$$C_{ss1}(t) = \frac{1}{7}(2-(1-2\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} - (1+2\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

$$C_{ss2}(t) = \frac{1}{7}(4-(2+3\sqrt{2})e^{\frac{-3+\sqrt{2}}{10}t} - (2-3\sqrt{2})e^{-\frac{3+\sqrt{2}}{10}t})$$

16.4.4 Results

Next figures show the 5 tracers evolution at the bottom layer (z = 0 m) along time for each test case. MICROPOL module results are compared with the analytical solutions from 16.4.3.

Figure 16.20 shows the results of a simple sorption with no sedimentation or erosion.

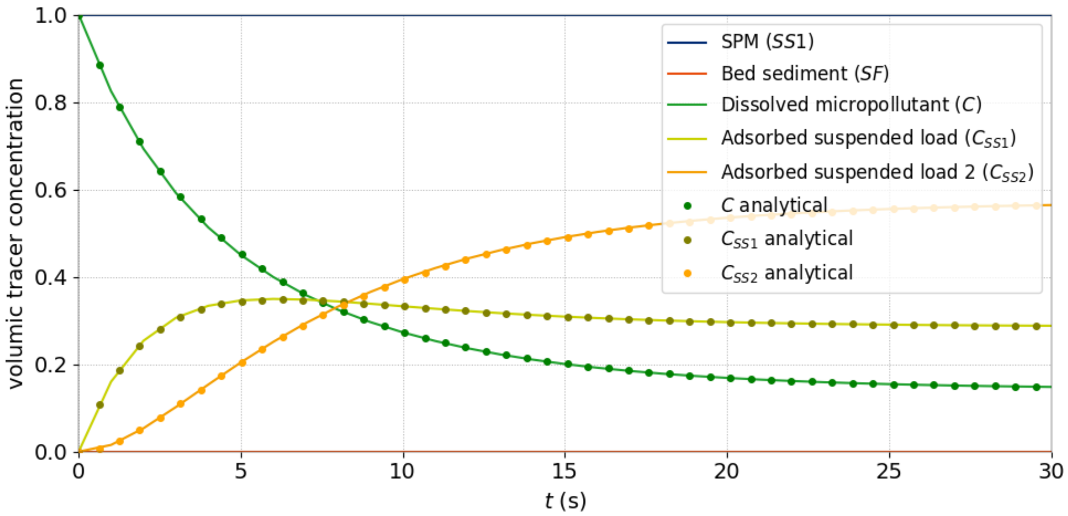

Figure 16.20: Tracers evolution for test case 1

Figure 16.21 evaluates deposition of SPM in the basin at rest. Depending on the bottom layer thickness, suspended sediments concentration accumulates before reaching the bed sediment layer.

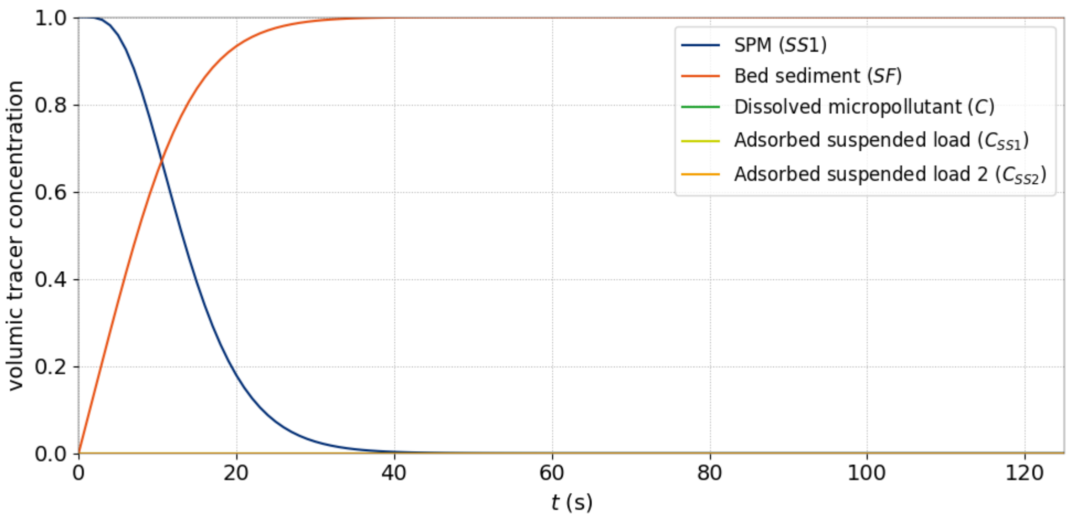

Figure 16.21: Tracers evolution for test case 2

Figure 16.22 displays both sorption of micropollutants from dissolved form toward SPM, and deposition results.

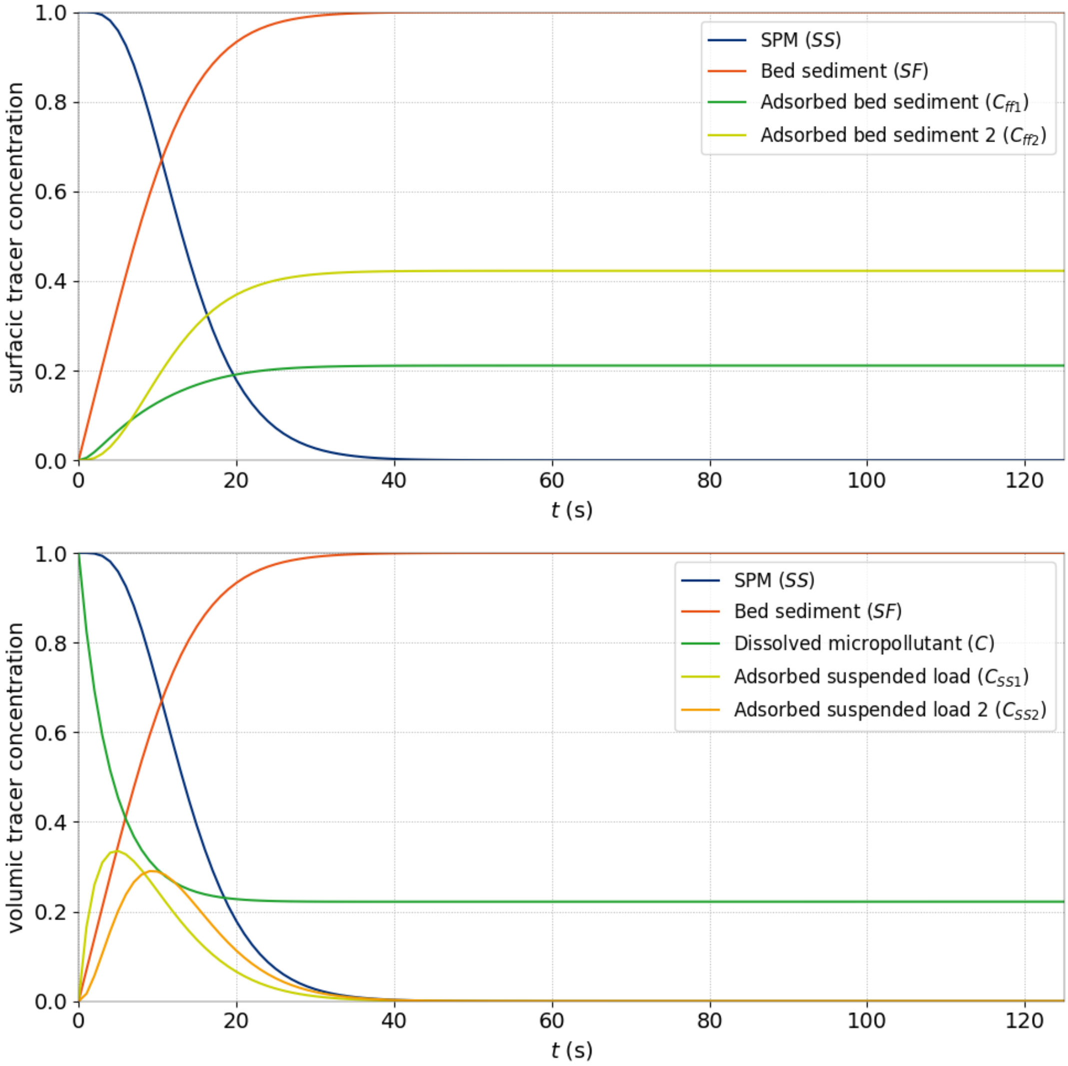

Figure 16.22: Tracers evolution for test case 3

In Figure 16.23 are shown both desorption of micropollutants from SPM toward dissolved form, and deposition.

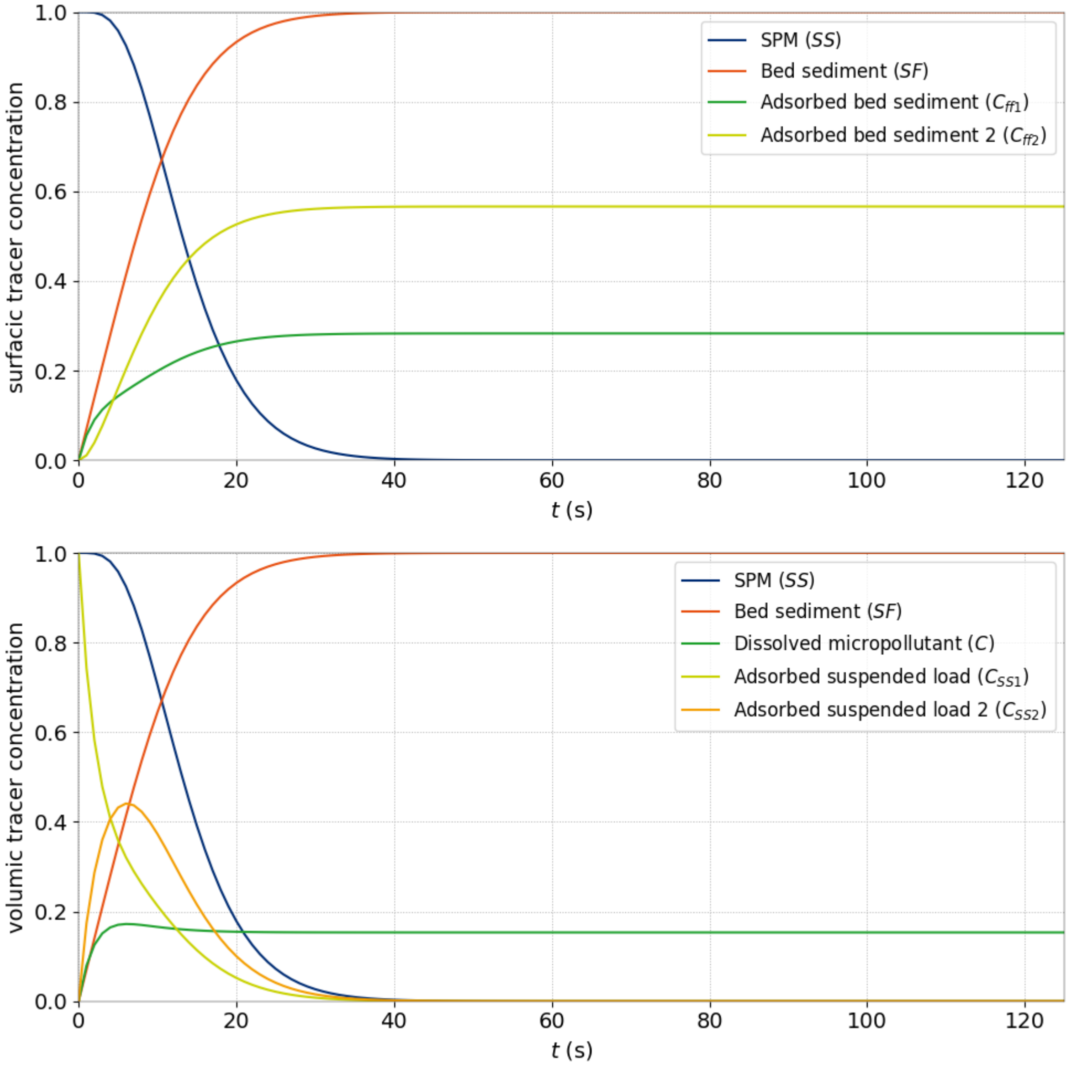

Figure 16.23: Tracers evolution for test case 4

Results of Figure 16.24 are equivalent to test case 4 but a law of exponential micropollutant decay is added.

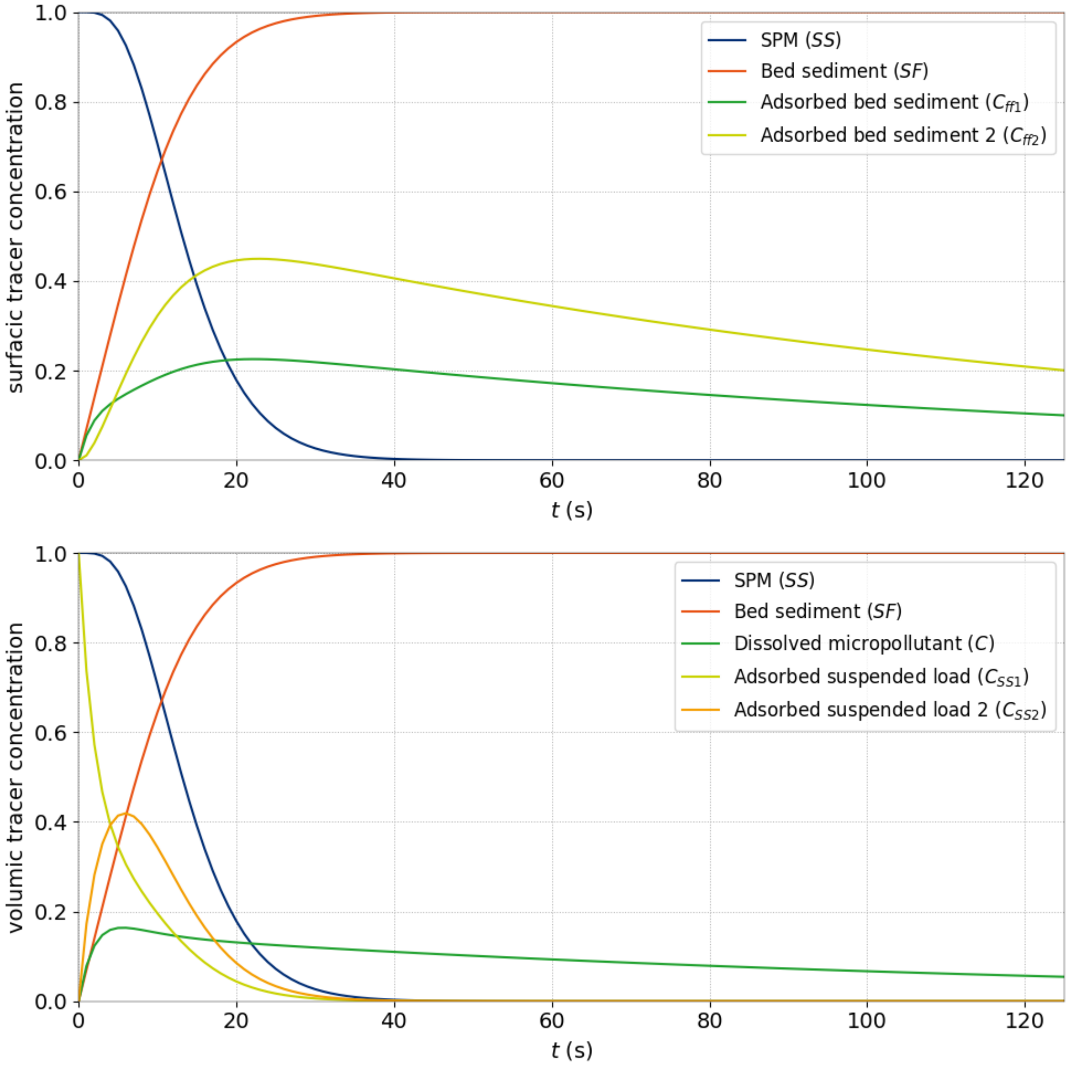

Figure 16.24: Tracers evolution for test case 5

16.4.5 Conclusion

The MICROPOL module of WAQTEL can be coupled with TELEMAC-3D for micropollutant and sediment interactions.

17. waq3d_o2

17.1 Purpose

This case is an example of the use of the O_2 module of WAQTEL coupled with TELEMAC-3D.

17.2 Description

A square basin at rest is considered (length and width = 10 m) with flat bathymetry and elevation at 0 m.

17.3 Computational options

17.3.1 Mesh

The triangular mesh is composed of 272 triangular elements and 159 nodes (see Figure 17.1).

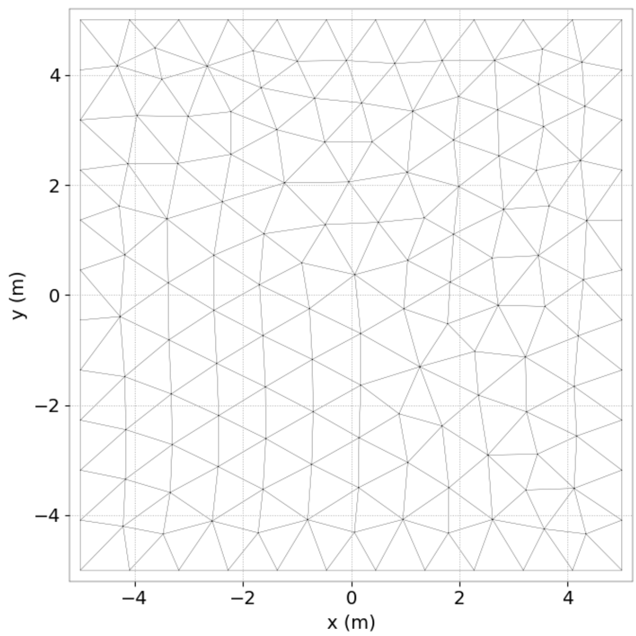

Figure 17.1: Mesh

To build the 3D mesh of prisms, 5 planes are regularly spaced over the vertical. The vertical mesh between nodes of coordinates (-5 ; 0) to (5 ; 0) can be seen on Figure 17.2.

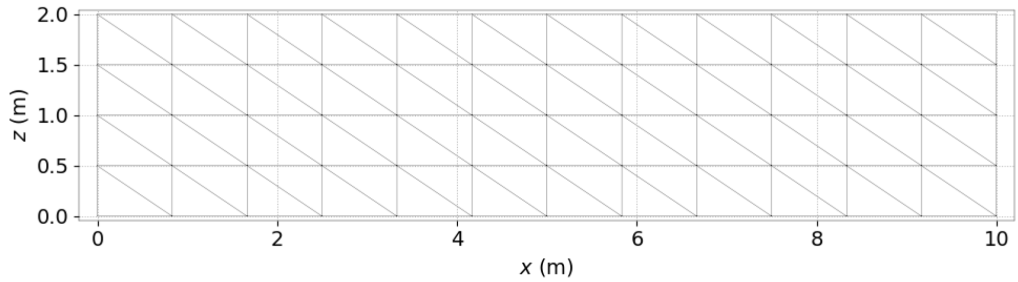

Figure 17.2: Vertical mesh

5 (at least) are needed to see variations of dissolved O_2 over the vertical.

17.3.2 Physical parameters

The O_2 module is activated by setting `WATER QUALITY PROCESS` = 2 in the TELEMAC-3D `STEERING FILE`.

3 tracers are considered:

- dissolved O_2,
- NH_4 load,
- organic load.

Only the following water quality parameters have been changed in the WAQTEL `STEERING FILE` compared to the default values:

- `K2 REAERATION COEFFICIENT` = 0.3,
- `FORMULA FOR COMPUTING K2` = 0 (i.e. k_2 is constant),
- `O2 SATURATION DENSITY OF WATER (CS)` = 9 mgO_2/l (C_s is constant),
- `WATER TEMPERATURE` = 20°C (which is the mean temperature of water).

17.3.3 Initial and Boundary Conditions

The initial water depth is 2 m with a fluid at rest.
The initial values for tracers are homogeneous:
([O_2], [L], [NH_4]) = (50 mgO_2/l, 3 mgO_2/l, 0.01 mgNH_4/l).
There are only closed lateral boundaries with free slip condition and no friction at the bottom.

17.3.4 General parameters

The time step is 4 s for a simulated period of 40,000 s.

17.3.5 Numerical parameters

Basin at rest (no advection nor diffusion for hydrodynamics).

2 new default values since release 8.1 for the advection and diffusion of the tracers are taken in the TELEMAC-3D `STEERING FILE` :

- `ACCURACY FOR DIFFUSION OF TRACERS` = 10^{-8},
- `SCHEME OPTION FOR ADVECTION OF TRACERS` = 4 (combined with `SCHEME FOR ADVECTION OF TRACERS` = 5 leads to LIPS use).

17.4 Results

Figure 17.3 shows the 3 tracers evolution along time.

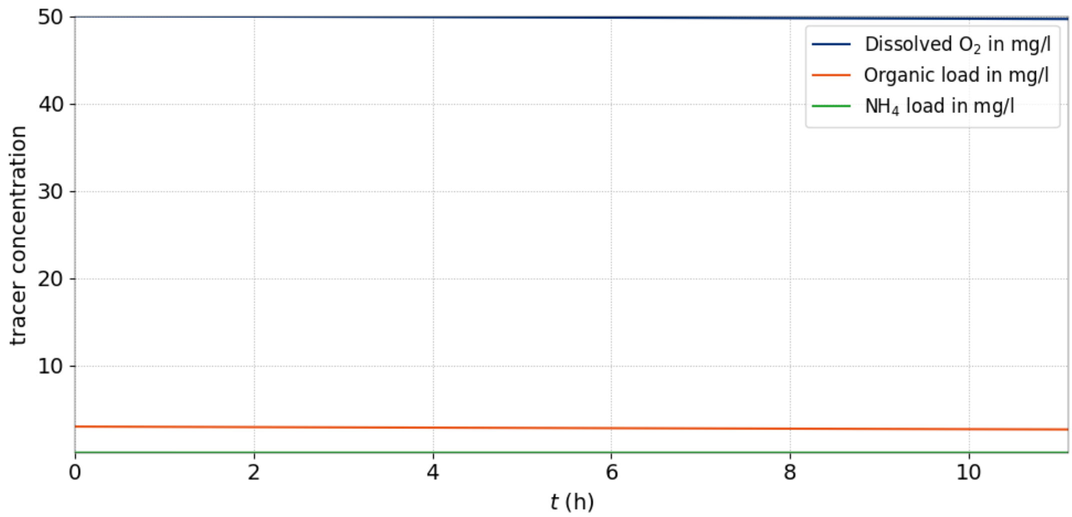

Figure 17.3: Tracers evolution for different tracers of the O_2 module

17.5 Conclusion

The O_2 module of WAQTEL can be coupled with TELEMAC-3D.

[1]

[1] J-M. HERVOUET. *Hydrodynamics of free surface flows. Modelling with the finite element method.* John Wiley & Sons, Ltd, Paris, 2007.