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Modelling Water Quality with Iber

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WP4: Accidental water pollution
Practical exercise II

Sewage spill in an estuary (Iber)

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1 Practical Example II: Sewage spill in an estuary

1.1 Objectives

In this example, Iber is used to model faecal coliform contamination. We will look at the impact of **wastewater** discharges on an **estuary** (the receiving water body), analysing the evolution of bacterial concentration over two days. Based on the results, we can analyse compliance with regulations regarding concentrations of faecal indicator bacteria.

We will define the decay rate of bacteria by introducing a time series of **T90**, this being the time required to reach a 90% reduction in concentration. Alternatively, we can also use the empirical formulations proposed by Mancini (1978) or Canteras et al. (1995) to compute the bacterial decay rate, based on temperature, salinity, turbidity and solar radiation levels.

1.2 Description of the case study and input data

The case study site is the estuary of Ferrol, in northwest Spain. The total surface of this estuary is approximately 25 Km^2, with a length of 16 km and a width of around 350 m (Figure 1). The estuary is connected to the sea by a narrow channel, 400 m wide. The volume of water in the estuary varies between 0.21 km^3 at low tide and 0.29 km^3 at high tide. The discharge of local rivers is very low and is not significant compared to the tidal flow, the water in the estuary being mainly of marine origin.

The port of the city of Ferrol is located on the northern shore of the estuary. In the inner part of the estuary, a bridge connects the northern and southern shores (marked with an orange circle in Figure 126). In this example we will ignore the effect of the bridge piers on the flow, due to their small dimensions.

Figure 1. Aerial image and dimensions of the estuary. The location of the bridge that connects the two shores is circled in orange.

We will consider two sewage spills with a constant flow discharge of **0.1 m^3/s** and a **coliform** concentration of **107 cfu/100 ml**. These inflows **do not** correspond to real flows from sewage treatment works in this estuary, and are used only as simplified examples. These two inflows will be the only sources of coliform contamination.

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The tidal level in the open sea varies from **0.42 m to 5.06 m**, while the maximum water depth at the mouth of the estuary is approximately **25 m** (Figure 2). The river that flows into the estuary has an average discharge of about **3 m³/s**, which is **negligible** with respect to the flow generated by the tide, thus we will not take it into account in the calculation.

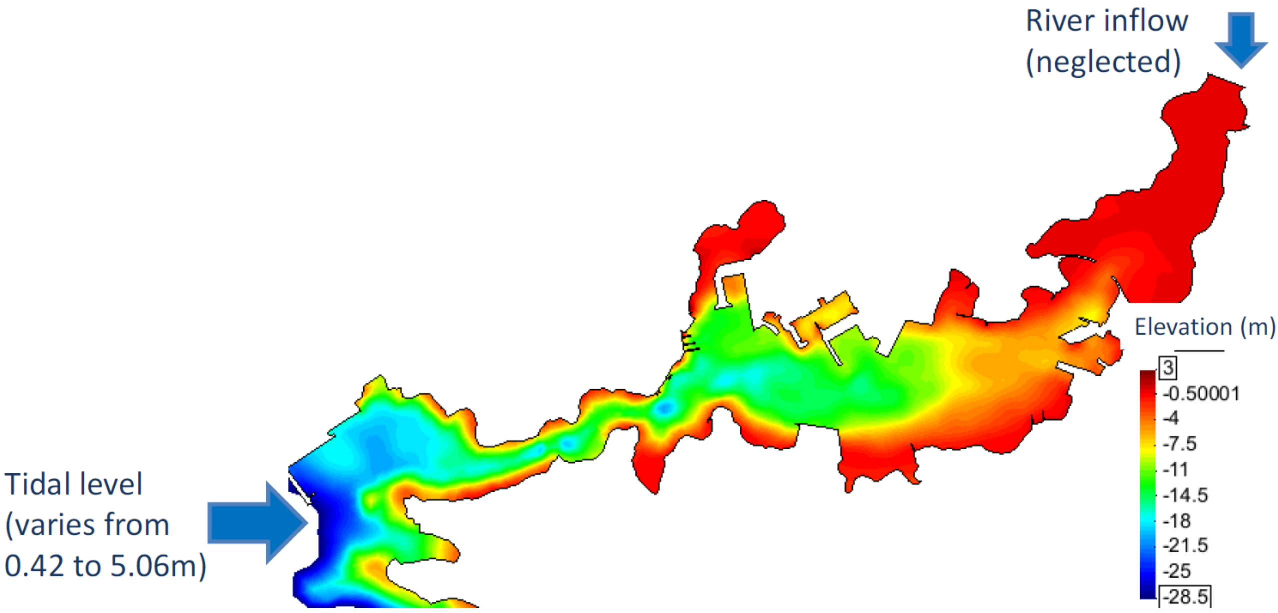

Figure 2. Bathymetry of the estuary used in the numerical model, relative to mean sea level in Alicante.

We will use the following input data files:

- Georeferenced orthophoto (Ferrol.jpg and Ferrol.jgw)
- Boundary of the estuary in CAD format (Boundary_Ferrol.dxf)
- Bathymetry of the estuary in raster format (DTM_Ferrol.asc)
- Time series of tidal levels at the mouth of the estuary (Tide_Ferrol.txt)

1.3 **Model set-up**

1.3.1 Geometry

After launching the model and creating a new project (**Files>>Save**), we are ready to define the geometry of the model. We start by loading the orthophoto Ferrol.jpg using the menu **View>>Background Image>>Real size**.

The boundary of the estuary is provided in CAD format (**Boundary_Ferrol.dxf**). We import this file (**Files>>Import>>DXF**). Whenever we import a geometry file, it is advisable to collapse the geometry (**Geometry>>Edit>>Collapse>>Model),** but in this case we enable the option "**Collapse allow more tasks**" available when enable the automatic collapse options.

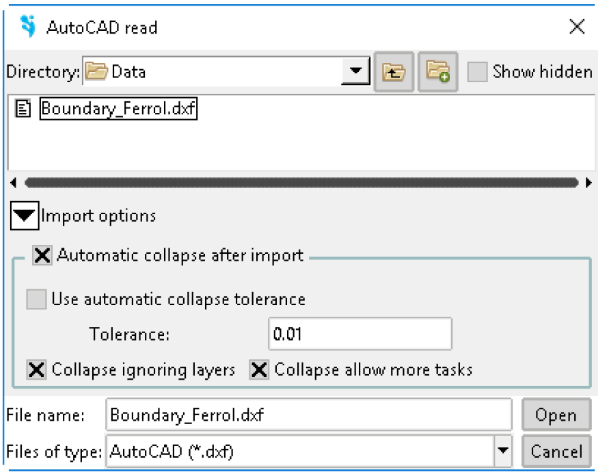

Figure 3. DXF file import options.

The next step is to create the three lines shown in Figure 4, and then to generate the four **NURBS** surfaces that define our model domain.

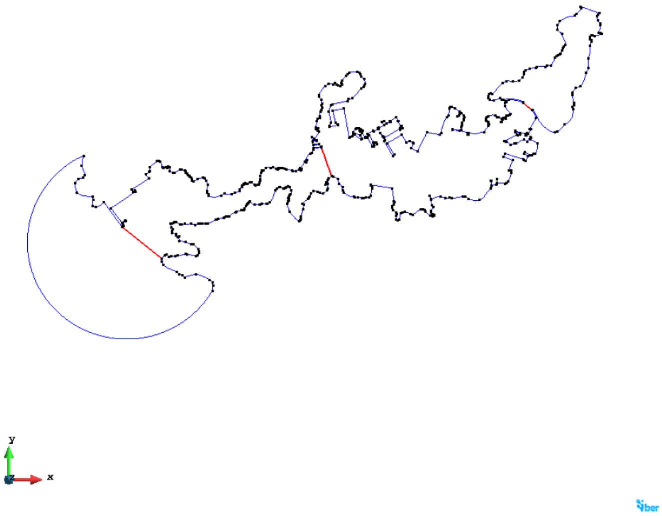

Figure 4. Lines to be created in Iber.

The easiest way of creating the **NURBS surfaces** is to use the search tool (**Geometry>>Create>>NURBS surface>>Search**). After completing this step, the geometry should look like Figure 5.

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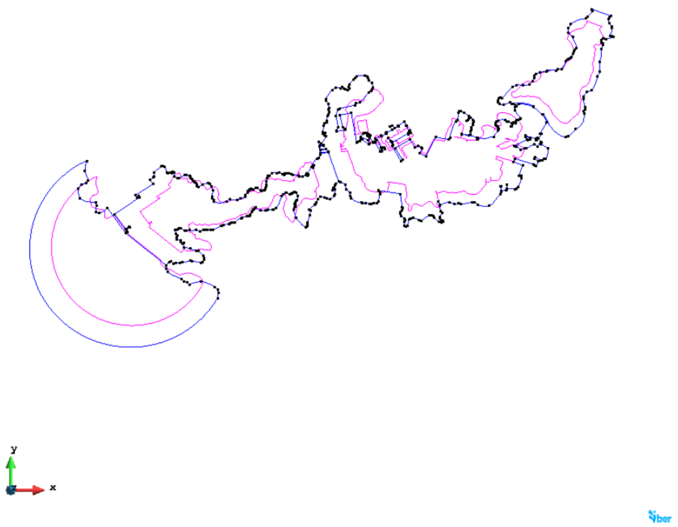

Figure 5. Geometry of the model once the NURBS surfaces have been created.

1.3.2 Hydrodynamics

The **only boundary condition** to be imposed in this case is the tidal level at the mouth of the estuary (Figure 6). The remaining boundaries are **closed**, since the runoff inflows are negligible. To assign this boundary condition we go to **Data>>Hydrodynamics>>Boundary conditions>>2D Outlet** and we choose a **Subcritical flow** condition of the type **Given Level**. We introduce the **tide level series** (**Tide_Ferrol.txt file**) and assign it to the sea boundary of the model. We can **copy** all the values directly from the **text file** and paste them into the Iber window.

Although we have set the **tidal condition** as a given level at an **outlet boundary**, the water can enter or exit the domain through that boundary, depending on the **water level** at the mouth of the estuary and the tidal level imposed at each time step. Iber will automatically detect at each time step whether the water level at the boundary is higher or lower than the water level at the mouth of the estuary and, as a function of this, it will correctly calculate the inflow or outflow through that boundary.

As an **initial condition** we set a water level for the whole estuary **equal** to the tide level at time **t = 0 s**, that is, **2.72 metres** (**Data>>Hydrodynamics>>Initial conditions**). We impose a Manning coefficient of **0.025 s·m-$^{1/3}$** throughout the estuary (**Data>>Roughness>>Land use**).

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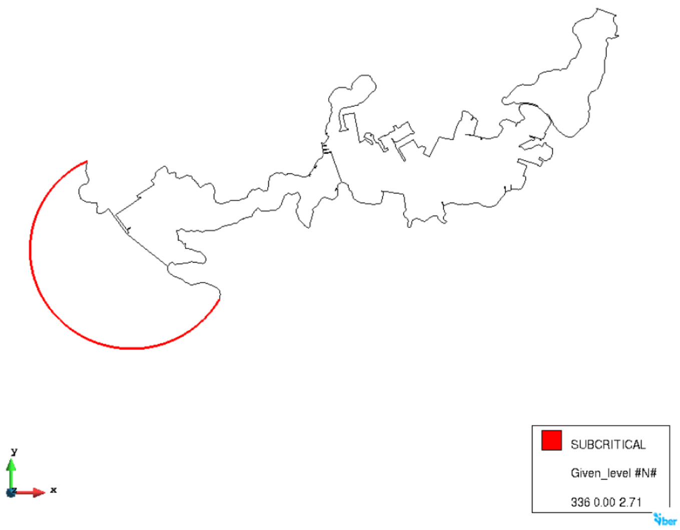

Figure 6. Location of the open boundary of the model.

1.3.3 Water quality

We now define the water quality initial conditions. In this case, we define the initial concentration of coliforms in the estuary, which we set to zero for the entire domain, using **Data>>Water Quality>>Initial Conditions>>Coliforms Initial Cond**, as shown in Figure 7. We assign a value of **0 cfu/100 ml** to the four **NURBS** surfaces.

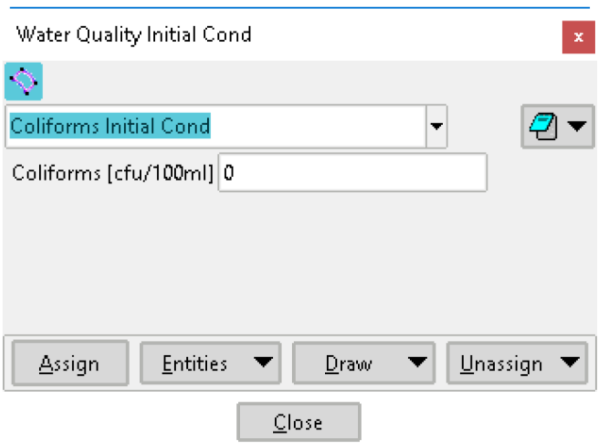

Figure 7. Water quality initial conditions window.

The water quality boundary conditions of the model are now defined, using **Data>>Water Quality>>Boundary Conditions**. In this case there is **only one open boundary**, to which we assign a concentration of **coliforms** equal to **0 cfu/100 ml** (Figure 8).

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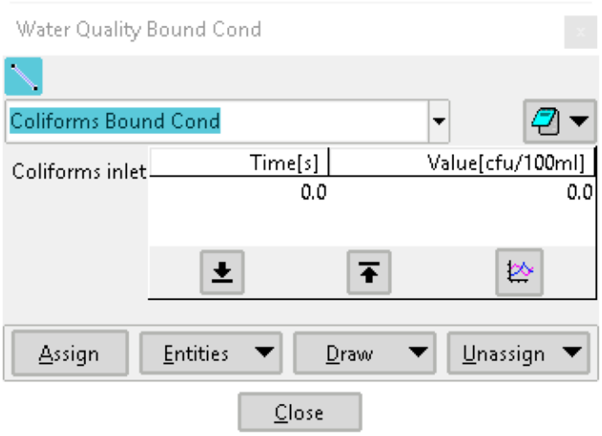

Figure 8. Water quality boundary conditions window.

Finally, we introduce the two sewage spills in the model in the positions indicated in Figure 9. To do this, we create a new discharge (**Data>>Water Quality>>Discharges**) and manually specify its location through the button . We must make sure that we place the **spills inside the model domain**, and not on the outer boundaries. We define a water temperature (Temp) of **20 °C**, a flow discharge **(Q) of 0.1 m^3/s** and a coliform concentration (CF) of **10000000 cfu/100 ml** (Figure 10), and keep the default values for the rest of the parameters, since they will **not be included** in the calculation. Once the discharge data has been introduced, its location will be displayed in the model geometry (**with a point at the corresponding location**).

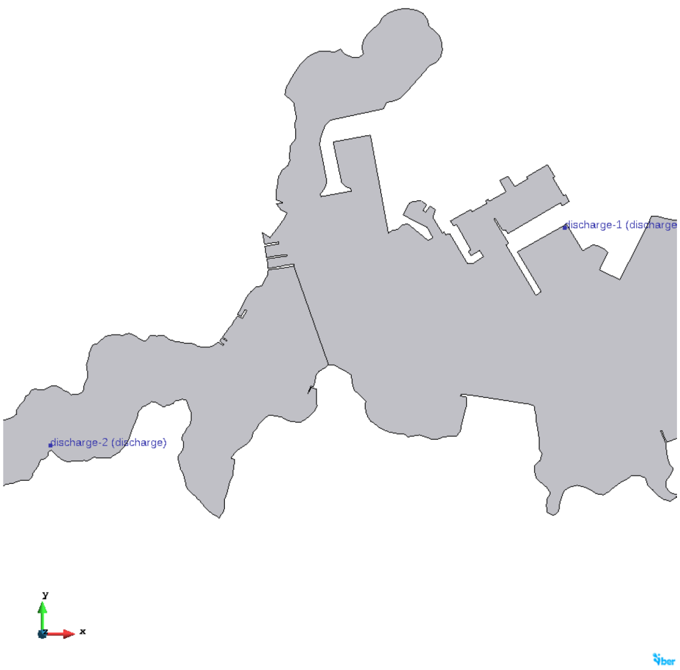

Figure 9. Location of sewage spills in the model.

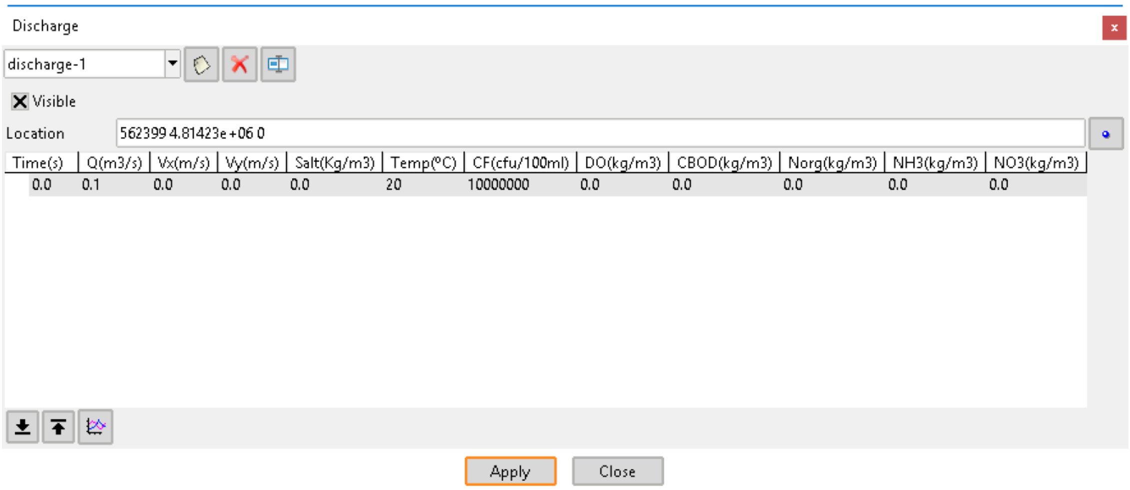

Figure 10. Discharge tab to introduce the location and water quality characteristics of the spill.

1.3.4 Mesh

The next step is to create a computational mesh to spatially discretize the domain. We generate an **unstructured** mesh made of **triangular elements**, with a mesh size of **250** m in the outer part of the estuary and **100 m** in the inner part, as shown in Figure 11. Mesh sizes can be defined in **Mesh>>Unstructured>>Assign sizes on surfaces**.

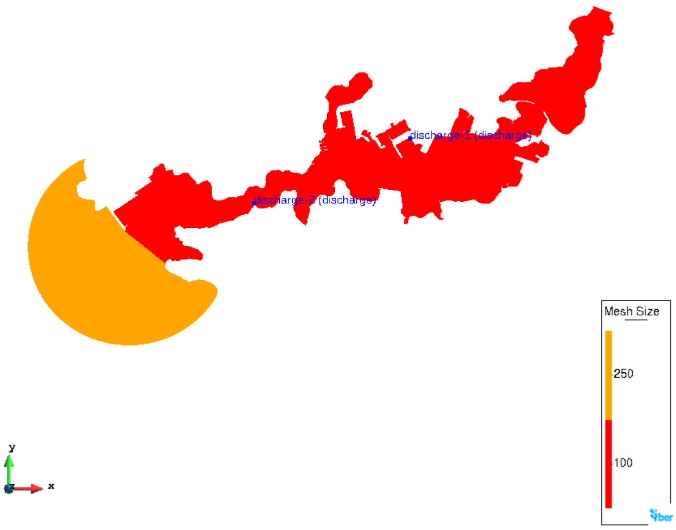

Figure 11. Mesh sizes defined.

We set the following meshing preferences in **Utilities>>Preferences>>Meshing**:

- Automatic correct sizes: **Normal**
- Unstructured size transitions: **0.7**
- Regular transition near boundary: **Disabled**

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With these options, we generate a mesh (set **250 m** as mesh value for mesh generation) of approximately **8,000 elements** (**Mesh>>Generate mesh**) (Figure 12).

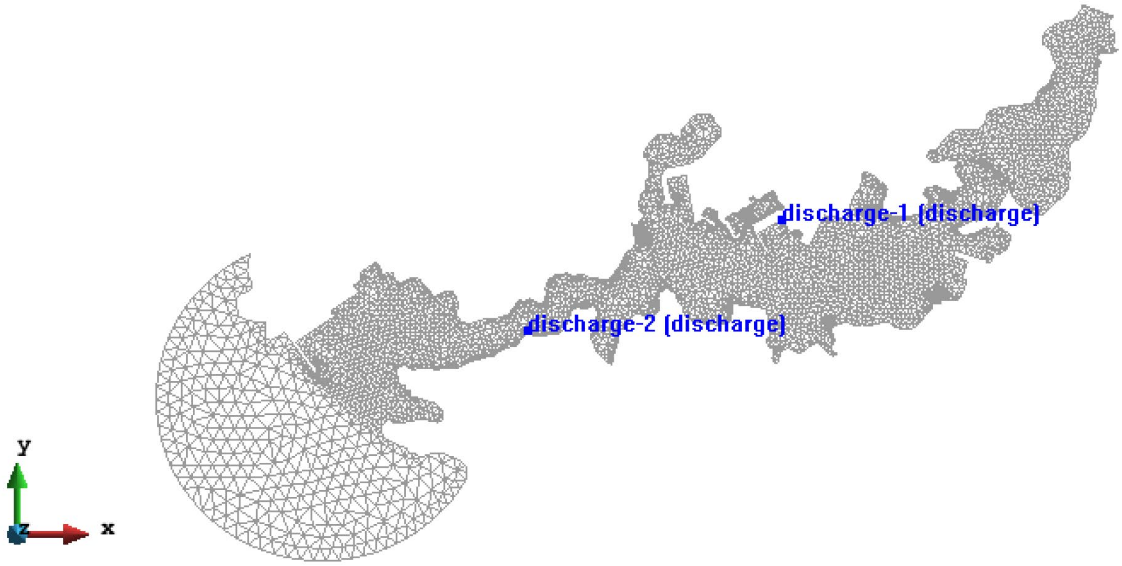

Figure 12. View of the mesh of the model.

Finally, we interpolate the **bathymetry** in **DTM_Ferrol.asc** using Iber **Tools>>Mesh>>Edit>>Set Elevation From File**.

1.3.5 Calculation data

Before running the model, we need to set the computation parameters (Data>>Problem Data). First, we choose a maximum simulation time of 172,800 s (approximately 4 tidal cycles) and a time interval of 900 s to analyse the results in sufficient detail.

We define the following parameters in the Data>>Problem Data>>General tab, so that the calculation time is not too long:

- Numerical scheme: First Order
- CFL: o.6
- Wet-dry limit: 0.01 m
- Friction on walls (Show General Options): No Friction

In the **Water Quality** tab (**Data>>Problem Data**), we activate the calculation of coliforms. We choose the **T90 decay** model for faecal coliforms (Figure 13). As noted previously, **T90** is the time required to reach a **90 % reduction** in bacterial concentration. We impose a constant **T90** value of **10 hours** during the entire simulation (**T90 Time Series**). The value of **T90** actually varies with variables such as solar **radiation** and water **temperature**, but we will assume a **constant** value in this simplified example. We select the **default** options for the remaining parameters.

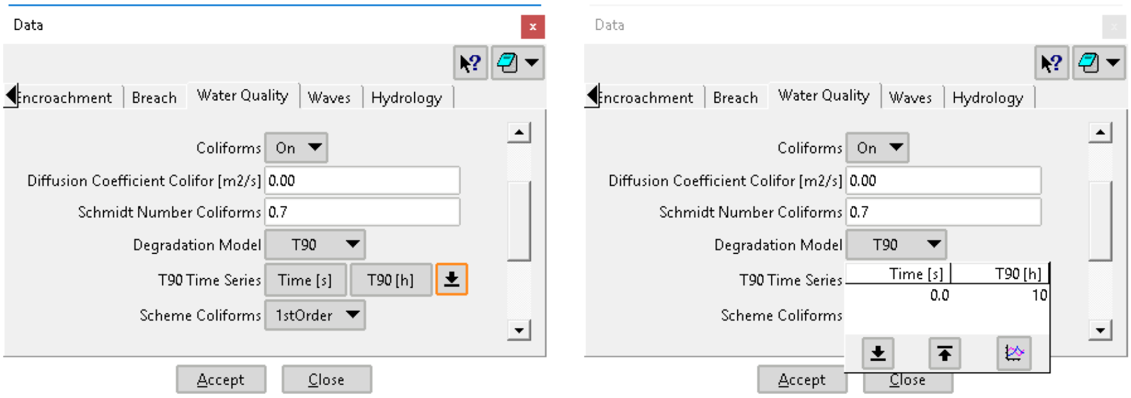

Figure 13. Definition of T90 values.

Finally the **calculation** is launched (**Calculate>>Calculate**).

1.4 Analysis of the results

Once the calculation has finished, we plot the concentration of coliforms in the final time step (**172,800 s**), using the **View Results** window (**Window>>View Results**). The results should look like the following image (Figure 139). We can set the range of values represented (**maximum** and **minimum** coliform concentration).

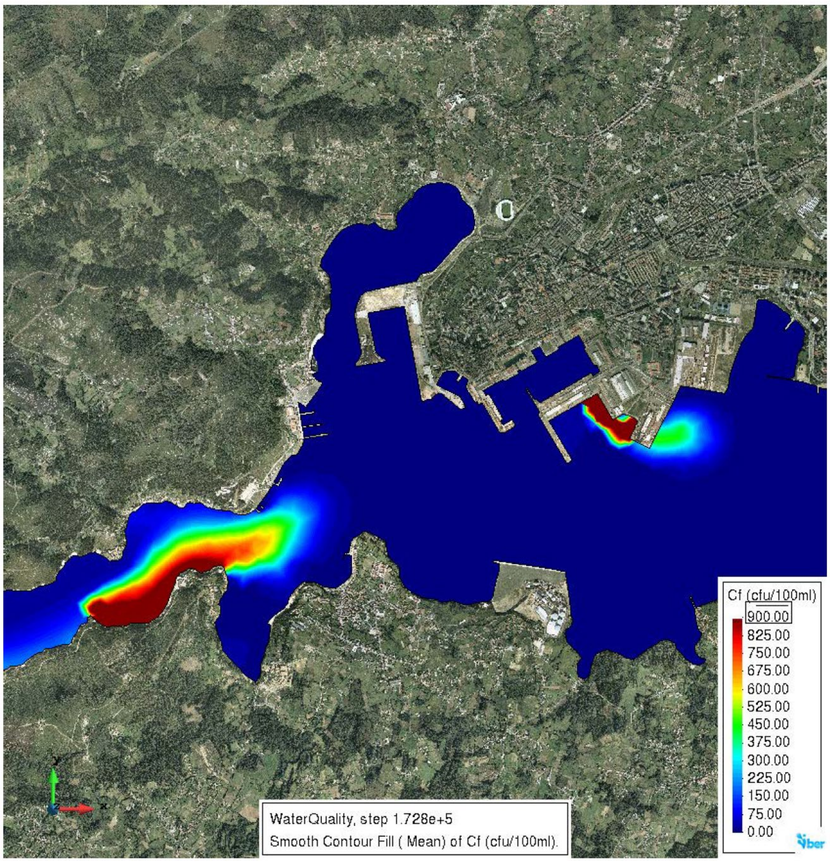

Figure 14. Concentration of coliforms in the estuary in the last time step.

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We will now plot the temporal evolution of the coliform concentration at two specific points. Open the **View graphs** window and **click** on the **Create tab**. We select **View: Point Evolution**, **Analysis: Water Quality** and the concentration of faecal coliforms as the variable to plot (**Y-axis**). Press **Apply** and choose **two points** within the **model domain** (see Figure 15). We should obtain results similar to those shown in Figure 16.

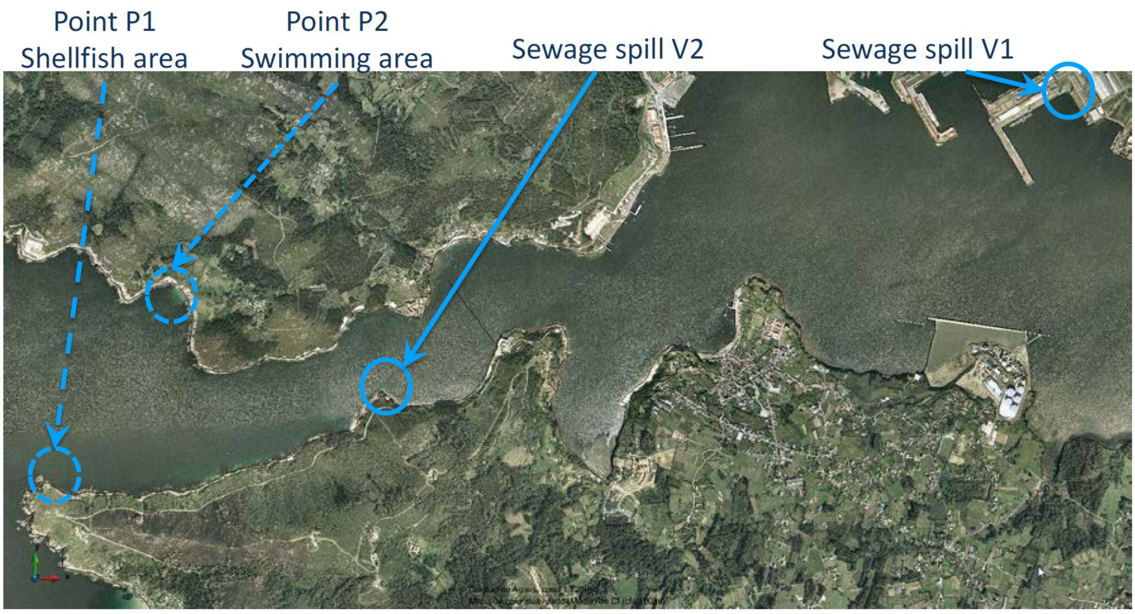

Figure 15. Location of control points and sewage spills.

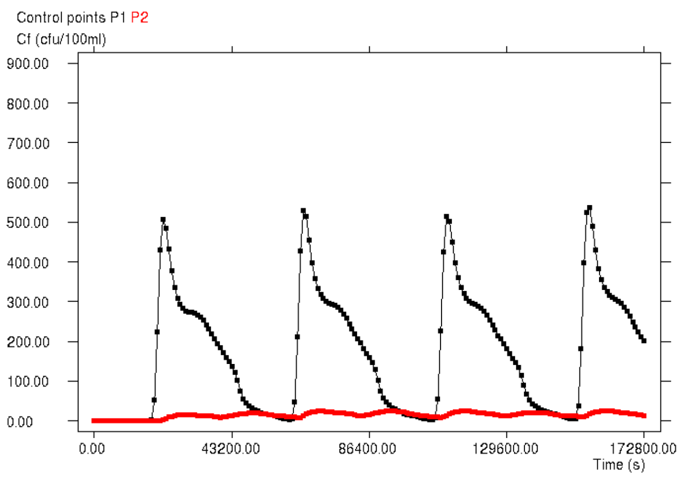

Figure 16. Time series of coliform concentration at the two control points.

We can export the **time series** to analyse them with other software, using **Show table** in the **Options** tab (Figure 17). A table with the results for each time step will appear. We can simply **copy** and **paste** these results into a **spreadsheet**, for example, to analyse them in more detail. Please note that in these data the decimal separator is the period **"." symbol**.

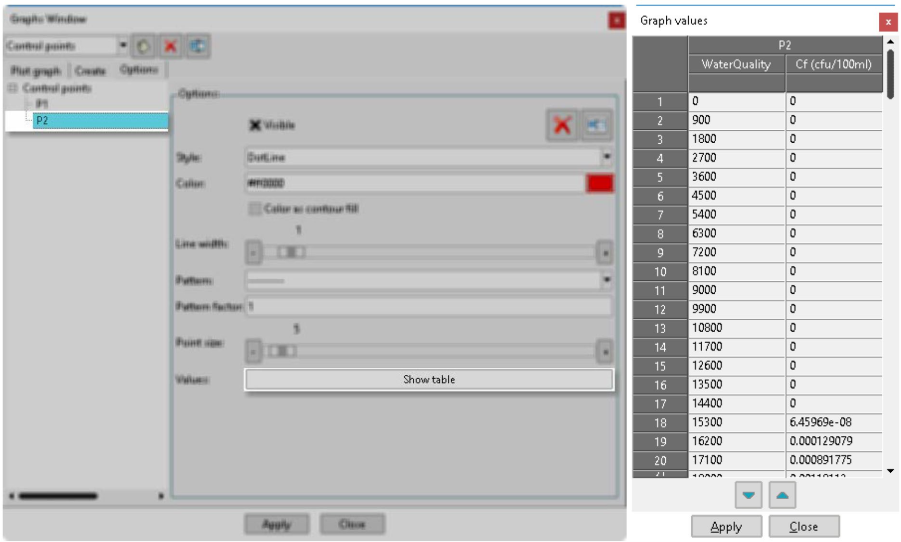

Figure 17. Time series of coliform concentration P2 (table of values).

Once we have copied the two time series of concentrations in a spreadsheet, we can sort the values from **highest** to **lowest**, as shown in Figure 18. In this way we can **see** the number of time steps in which the coliform **concentration exceeds** the threshold value. At point **P1**, the threshold of **300 cfu/100 ml** is exceeded for **34%** of the time. At point **P2**, the coliform concentration is always **below 100 cfu/100 ml**.

	A	B	C	D	E	F
1						
2						
3		Shellfish area			Swimming area	
4		% >300:	34%		% >100:	0%
5		FC	Time		FC	Time
6		931.259	110700		49.1999	113400
7		819.177	153900		48.885	114300
8		817.818	65700		47.0956	156600
9		749.325	111600		46.4377	68400
10		704.152	153000		45.9169	115200
11		702.791	64800		45.7897	155700
12		650.08	109800		45.0932	67500
13		593.174	154800		44.8389	157500
14		591.56	66600		44.2159	69300
15		567.577	23400		43.6859	116100
16		491.637	24300		41.2328	112500
17		455.297	112500		40.3257	158400

Figure 18. Analysis of the time series in a spreadsheet.

If we repeat the same process for the water surface **elevation**, we can add the corresponding time series to the spreadsheet. This allows us to analyse **how** the concentration of coliforms **varies** with the **tidal level**, by plotting the two time series in the same figure (Figure 19).

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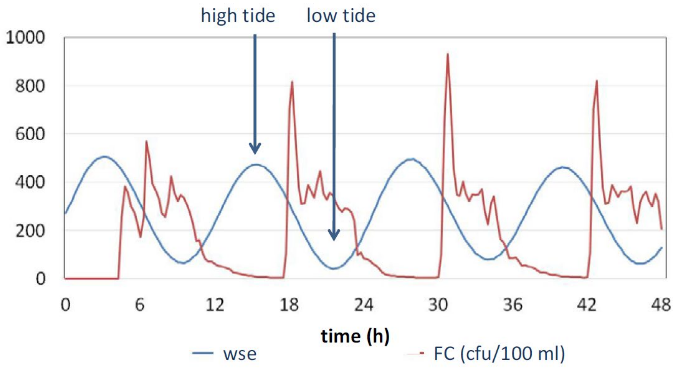

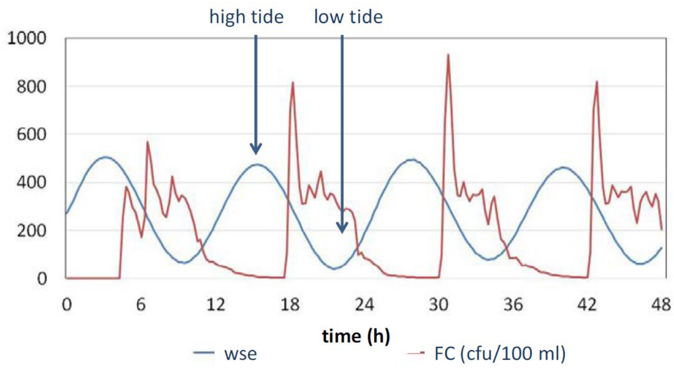

Figure 19. Coliform concentrations and tidal levels at control point P1 (up) and point P2 (down).

1.5 Conclusions

In this example we have seen how to **simulate faecal coliform** contamination in **Iber**. We have used the simplest approach to define the **bacterial decay rate**, which consists of **directly defining a value of T90**. The bacterial decay models of Macinin (1978) and Canteras (1995), which depend on meteorological and oceanographic variables, are also implemented in Iber and could be used as an alternative. Based on the results obtained, we can analyse compliance with the regulations regarding faecal coliform concentrations.

1.6 Data

Data for the exercise can be downloaded from this link: **https://hydroeurope.upc.edu/wp-content/uploads/2024/10/Data_WQ_E2.zip**

1.7 References

Bladé, E., Cea, L., Corestein, G., Escolano, E., Puertas, J., Vázquez-Cendón, E., Dolz, J., Coll, A. (2014a). Iber: herramienta de simulación numérica del flujo en ríos. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería, Volume 30, Issue 1, 2014, Pages 1-10, ISSN 0213-1315, DOI: 10.1016/j.rimni.2012.07.004.

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Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. Journal of Water Pollution Control Federation 50(11), 2477-2484.

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