Project Assignment

Computational methods and tools

ENG-270

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December 20, 2024

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1 Deviations from project proposal

Our final code strayed a little from the objective of the project proposal. In general, we have simplified the inputs and outputs, while keeping the basic objective in mind. The main objective of our project was and still is to show the impact of oxygen-demanding waste on dissolved oxygen and thus on aquatic life. However, in the beginning, we wanted to create a user interface for the user to enter values such as waste amount, temperature, or flow rate. In the end, we thought it would be clearer and easier to set some defined values and to observe the results depending on specific variables in order to answer our own question rather than doing a more general code, which would have been useful if the goal of the project was to provide a tool for other users. So, we decided to incorporate several scenarios to demonstrate the impact of temperature, flow rate, and waste amount. Instead of allowing the user to select the values, we predefined or assumed them ourselves. The scenarios are : a sharp rise in temperature, a constant flow rate, an unpolluted river, and a large waste spill. Those are compared with a base scenario containing values closest to reality. For even more visualization, we have chosen to create these scenarios for each season (Winter, Spring, Summer, Autumn). We also wanted to return which aquatic species would be threatened. Nevertheless, this required a lot of precise data, which we were unable to obtain. We asked two teachers (one in biology and one in ecology) and only one responded but unfortunately did not have the data we were looking for. We did some research ourselves, but finding precise dissolved oxygen values for the survival of each species in the Rhone River proved more difficult than we thought. We have though found valid stress and mortality thresholds for fish in order to show the impact of waste discharge on aquatic life [2] [4] [3]. For the outputs, we stuck to the basic idea of creating graphs. We believe that graphs are a good way of visualizing variations over time and make it easy to compare several cases. Instead of printing a message to indicate which species would have been threatened we add threshold to the finals graphs to show the impact on fish in general.

2 Introduction to the problem

Many rivers are affected by anthropic pollution. One type of waste that has a huge impact on water quality are the oxygen-demanding wastes. Often coming from municipal wastewater or industrial effluents, those wastes especially affect the amount of dissolved oxygen in water which is a key parameter for assessing the water quality of a river and, consequently, the health of its ecosystem. Indeed, oxygen-demanding wastes are biodegradable organic substances decomposed by bacteria and during the decomposition process, these bacteria consume dissolved oxygen, leading to a reduction in its concentration.

To understand the impact of organic pollution, the biochemical oxygen demand (BOD) is an essential parameter. It represents the amount of oxygen required by microorganisms to biologically degrade organic waste. When waste with a high BOD is discharged into a river, it leaves less oxygen available for aquatic species. Insufficient oxygen levels can stress aquatic organisms, causing an increase in their heart rate, blood pressure, and respiration. In more severe cases, when anaerobic conditions are present, it can lead to their death.

Pollution of rivers can pose a serious threat to many species, hence it is essential to provide a clear representation of its effects on aquatic biodiversity. In order to raise awareness about organic pollution we must understand its impact on rivers' health.

3 Approach used

Our code is based on the formulas provided by the *point-source, plug flow* model. This model of the oxygen resources in a river focuses on two key processes: the removal of oxygen by microorganisms during biodegradation, and the replenishment of oxygen through reaeration at the interface between the river and the atmosphere. In this simple model, it is assumed that there is a continuous discharge of waste at a given location on the river. As the water and wastes flow downriver, it is assumed that they are uniformly mixed at any given cross section of river, and it is assumed that there is no dispersion of wastes in the direction of flow [5]. Several processes are not taken into account in this simplified model, such as photosynthesis and nitrification.

Our code calculated the deoxygenation rate constant, the BOD of the mixture of streamwater and wastewater at the point of discharge (L_0), the reaeration rate constant, the initial oxygen deficit of the mixture of river and wastewater (D_0), the deficit (D) and finally the dissolved oxygen (DO).

$$DO = DO_s - \left[\frac{k_d L_0}{k_r - k_d}\left(\exp(-k_d t) - \exp(-k_r t)\right) + D_0 \exp(-k_r t)\right]$$

where:

- DO is the actual dissolved oxygen at a given location downstream (mg/L),
- DOs is the saturated value of dissolved oxygen (mg/L),
- k_d is the deoxygenation rate constant (time^{-1}),
- k_r is the reaeration constant (time^{-1}),
- L_0 is the ultimate BOD of the mixture of streamwater and wastewater (mg/L),
- D_0 is the initial oxygen deficit of the mixture of river and wastewater (mg/L)

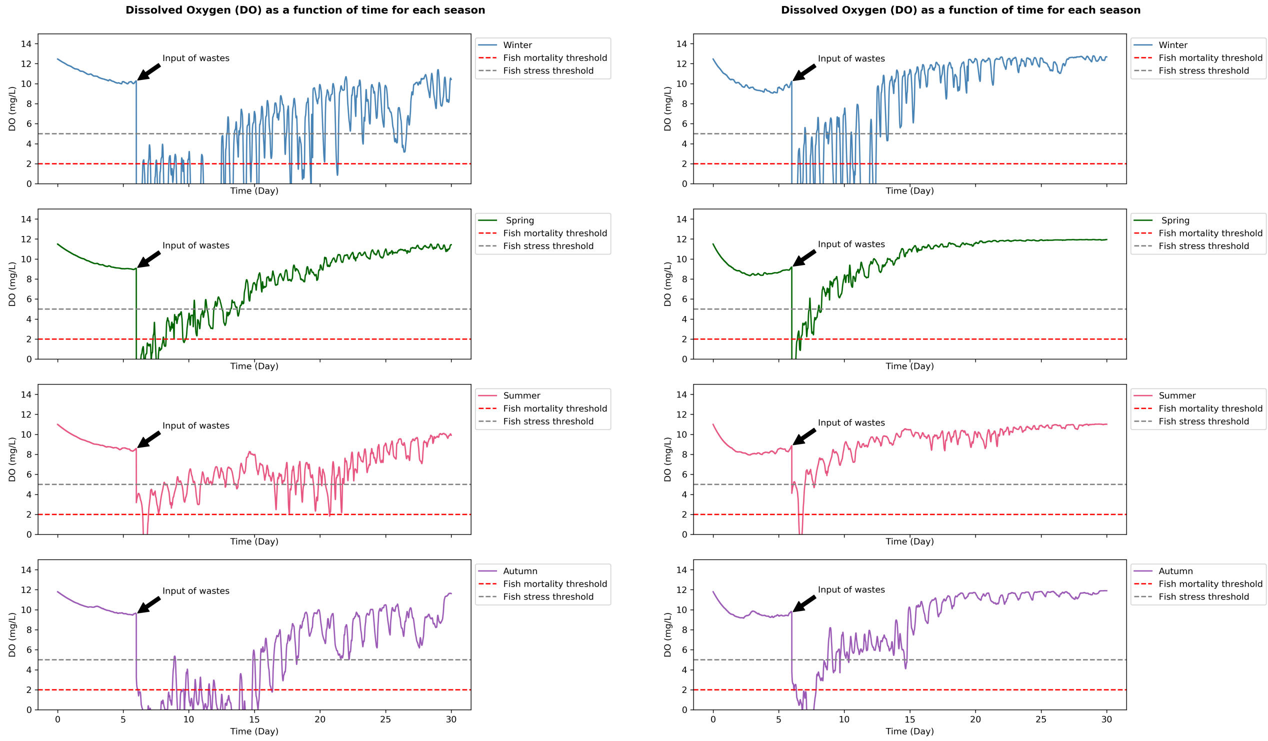
To carry out these calculations, we had to obtain a large amount of data. To do this purpose we ordered data from the 2009 station, Rhone Porte du Scex on the website of the Swiss Federal bureau of the Environment in the Hydrology division. We therefore received csv files for: water temperature, water level, river dissolved oxygen and saturated dissolved oxygen value. All these values were ordered as monthly averages over the year 2023. We therefore chose one value per season that we felt best represented reality and seasonal changes (in general, we based our work on the months of February, May, August and November). Regarding river flow, we have obtained data for the entire year of 2023, averaged at 5-minute intervals. Our simulation takes place over 1 month (30 days) and we use the code to collect river flows over 1 month for each season. For the other variables, such as wastewater flow (Q_w), wastewater DO (DO_w) and river BOD (L_r), we drew inspiration from examples 6 and 7 in the book [5]. In addition, for the BOD of waste (L_w), we identified a typical value for organic pollution found in most Swiss wastewater treatment plants in the "Traitement et valorisation des eaux et des déchets" ENV304 course. To find the depth we used the water level data ordered, from which we subtracted the level indicated on the layout plan [1]. As seen on the layout plan, the Rhone River in Valais at the station "Porte du Scex" is considered as canal. Finally, to determine the speed of the water, we calculated the area for each season as a function of the depth of each season. We found our formula in the "Fluid mechanics (for SIE)" ENG-272 course. We used the one for an open channel flow with a trapezoidal cross-section. From the same course, by considering a fixed control volume in the canal and making several assumptions—such as steady flow, uniform velocity, incompressibility, and uniform density distribution—we determined the velocity by dividing the flow rate by the cross-sectional area.

We did our program in python and C languages. C was used for the mathematical part : the writing of every function from the *plug flow* model needed to calculate the dissolved oxygen. Python was used for the visualization of the results generated by the functions in the C code. We plotted five graphs illustrating the evolution of the dissolved oxygen as a function of time for different scenario.

4 Results

Near the outlet, the degradation of organic matter is such that the rate of oxygen removal from the water is higher than the rate of restitution by reaeration, so that dissolved oxygen decreases. As time goes by, less and less organic matter remains, so the rate of oxygen elimination continues to fall. There is a critical point where the rate of oxygen removal is equal to the rate of oxygen addition by reaeration. Beyond this critical point, reaeration begins to dominate, returning oxygen to the river faster than the bacteria remove it, so that dissolved oxygen begins to rise to the saturation value. In our case, with a non-constant river flow, there are always fluctuations after the critical point, and in extreme cases, there can be several critical points.

If the amount of waste added to the river is excessive, the oxygen curve may drop below a minimum acceptable level, leading to a stretch of river with unhealthful conditions. Fish that cannot tolerate water with such low oxygen will be driven elsewhere, or they will die.



(a) Scenario 1 : Values closest to reality.

(b) Scenario 3 : 20°C increase in water temperature.

Figure 1: Comparison of different scenarios.

In the Figure 1, the comparison between scenario 1 and 3 shows the impact of the increase in temperature. In the Figure 1.a) the temperature of the river are the true values measured in the Rhone River. We can see that winter has the lowest DO values over the longest period, resulting in the greatest loss of aquatic species. As illustrated in the graph, the river experiences anoxic conditions for about 10 days. In autumn, we also have many low oxygen values. The low DO values in winter and autumn on the Rhone (Porte du Scex station) are mainly the result of reduced flows during these seasons, which limit the dilution of pollutants and natural re-oxygenation. However, it is during these seasons that we have the greatest fluctuations, which can also be explained by the low flow rate. Indeed, low flow accentuates the appearance of DO variations, as the water is more sensitive to local disturbances. In summer and spring we have more reasonable DO values. Anoxic conditions do occur, but on fewer days than in other seasons. This can be explained by the fact that snowmelt plays a key role in spring and summer, which increases the Rhone's flow, contributing to pollutant dilution and facilitating oxygenation. Moreover, dissolved oxygen increases and returns to its initial value more rapidly in spring than in summer, which may be caused by the greater variability in our flow values during the summer. In fact, summer shows the highest variability, likely due to irregular summer storms and varying contributions from glacier melt.

In Figure 1.b), we observe that the curves generally follow a similar pattern across all seasons. In comparison to the Figure 1.a), the DO values increase and appear to return to their initial levels more rapidly for each season. The effect of temperature on the oxygen curve is important. As temperatures rise, wastes decompose faster. In spring, we can even see a return to saturated dissolved oxygen levels, with a constant plateau at the end of the month. Overall, the increase in temperature has smoothed out fluctuations across all seasons. It is also important to highlight that, in all seasons and regardless of temperature, DO values drop at certain points below the stress and mortality thresholds for fish, illustrating the significant impact of waste on aquatic life.

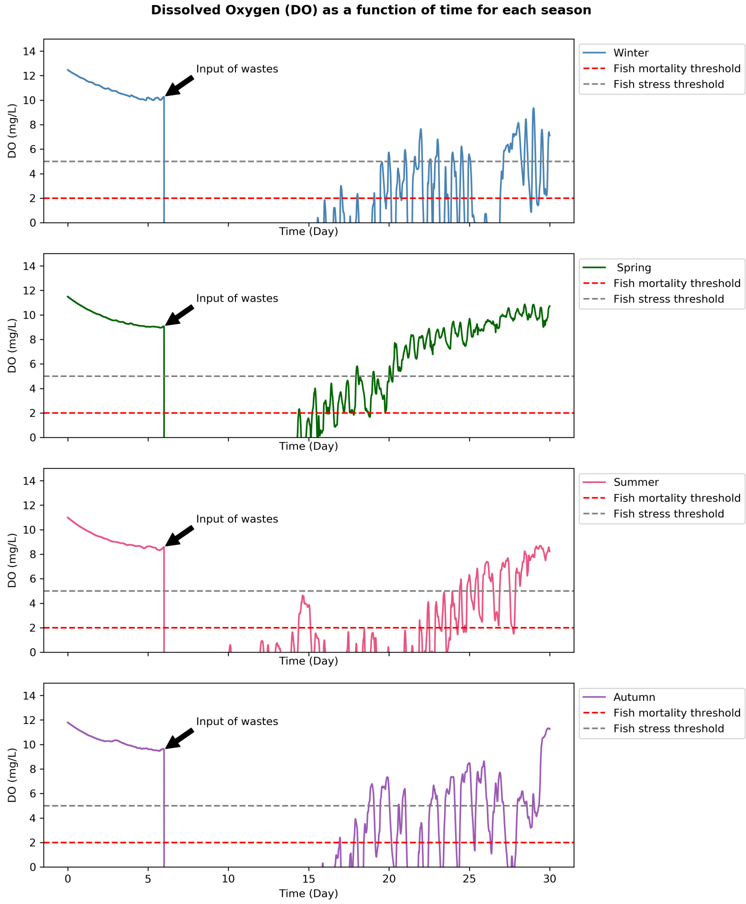


Figure 2: Scenario 5 : Extreme discharge of waste

Figure 2 depicts a significant waste spill. The waste flow in Figure 1.a), representing the scenario closest to reality, increased from 20(m^3/s) to 70(m^3/s). We can clearly see that for all seasons immediately after the spill, DO values are extremely negative for a certain period of time. Taking into account that we are using a simplified model and non-constant flow values, our simulation is not perfect, as in reality a river could not have a negative DO. The extreme case of excessive pollution is one in which the dissolved oxygen is driven to zero, creating a nearly lifeless anearobic stretch of river. The decomposition continues at a much slower rate by anaerobic microbes, releasing noxious and toxic gase such as hydrogen sulfide and ammonia. Furthermore, the rise in DO levels is delayed in all seasons compared to Scenario 1. Only in spring does the river appear capable of handling waste input, allowing it to become habitable again for fish. In the other seasons, fluctuations persist towards the end of the month, causing the stress and mortality thresholds to be surpassed.

The Figure 3 shows the evolution of dissolved oxygen (DO) in the river when there is no input of wastes. We can see that, across all seasons, the DO remains in a reasonable interval, approximately between 8 and 12.5 mg/L, and stays well above the critical threshold for fish stress and fish mortality. These values are conducive to fish growth and reproduction. Under natural conditions, with respect to oxygen levels, the quality of the water is optimal and the ecosystem of the river remains healthy.

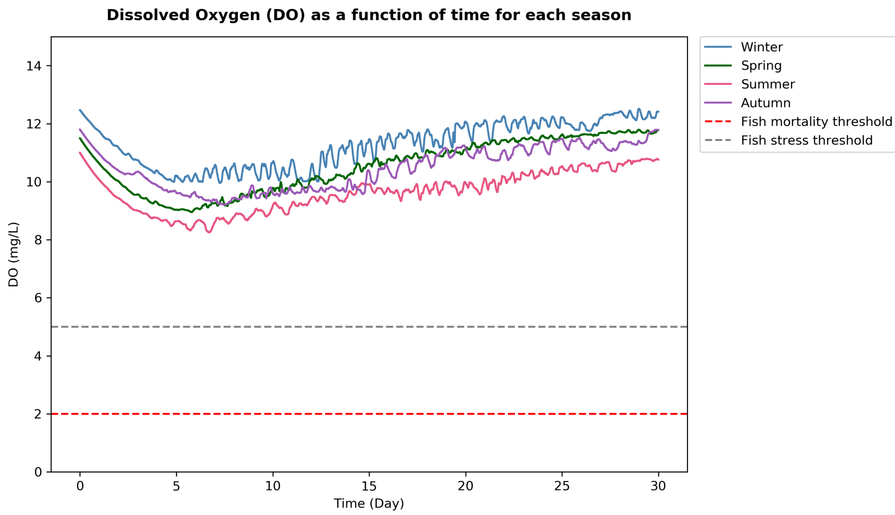


Figure 3: Scenario 2: Unpolluted river

However, seasonal variation can still be observed. DO values are the highest in winter and the lowest in summer. This can be due to water temperature variation (+4.5°C between winter and summer). Indeed, there is a correlation between temperature and dissolved oxygen solubility: as the temperature increases, DO solubility decreases, leading to lower DO values in summer.

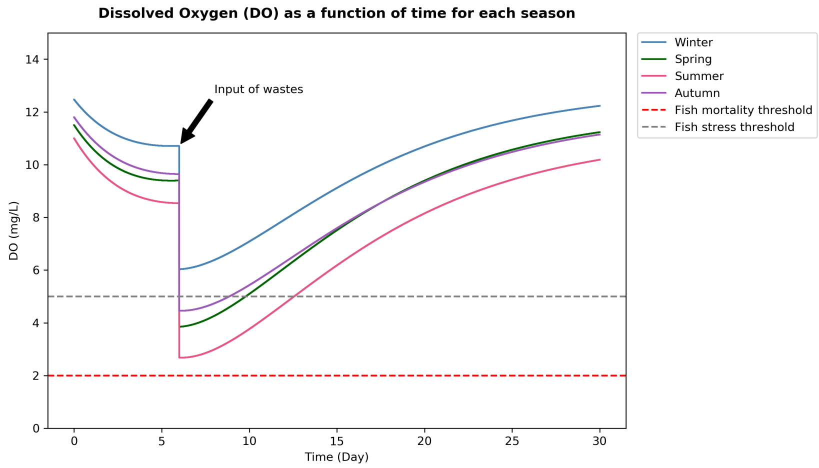


Figure 4: Scenario 4: Constant flow of the river

Figure 4 represents the evolution of DO for a constant flow of the river of 300 m^3/s. We can see the curves are much smoother, highlighting the fact that the fluctuations seen on the other figures are due to the inconstancy of river's flow during each month. This graph is way more similar to the usual representation of the *plug flow* model.

This is because the *plug-flow* model is normally used with a constant river flow. This really simplified simulation of the river allows us to give a clearer representation of the DO deficit caused by the input of waste. We notice the same type of seasonal variation than in Figure 3 (Scenario2): DO values are the highest in winter and the lowest in summer. This can again be explained by the temperature variation: oxygen has a higher solubility at lower temperatures. Thanks to its fast recovery, the dissolved oxygen amount in winter, doesn't reach fish stress threshold, it remains above 6 mg/L, therefore the fish should not be impacted by input of waste. However, the recovery is slower for the other season, especially for summer that presents the slowest recovery out of the four seasons. The fish stress threshold is thus passed during around four days in spring and autumn and during around seven days during summer. The fish mortality threshold is approach but not passed, meaning that anaerobic conditions are not reached. By comparing with the results of the other Figures that use real flow data, we can see that the natural fluctuation of the river flow increases the impact of waste. Its variation seems to enhance the decrease of dissolved oxygen, putting in risk aquatic life in the river.

5 Conclusion and outlook

In this project, we successfully demonstrated the significant impact of oxygen-demanding waste on dissolved oxygen levels and, by extension, on aquatic life. By utilizing a simplified model of river flow and waste discharge, we were able to visualize how changes in factors such as temperature, river flow, and waste input affect the oxygen levels in the water. Through the various scenarios we modeled, we observed how the input of waste can lead to conditions where dissolved oxygen levels fall below thresholds necessary for the survival of fish, ultimately threatening biodiversity.

The use of graphical representations was an effective way to highlight the variations in dissolved oxygen over time, providing a clear comparison between different seasons and scenarios. Despite simplifying the input parameters, we were able to address the main objective of the project: to explore how organic pollution influences dissolved oxygen concentrations and the overall health of the river ecosystem.

Although we had to adjust our initial goal of creating a user interface for entering data, the decision to focus on predefined scenarios allowed us a better understanding of the dynamics between temperature, flow rate, and waste discharge, and how these elements interplay to influence oxygen levels in rivers. However, we were unable to incorporate detailed data on the impact of oxygen levels on specific aquatic species. Although we were still able to illustrate the general effect of waste discharge on aquatic life using general stress and mortality thresholds for fish, the project would be more complete if we added thresholds for various species.

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