

Technical University of Civil Engineering of Bucharest

*Abstract of the PhD thesis*

# **Studies of the mitigation of the reservoir negative effects upon the environment**

by

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## **Abstract**

Dams and large reservoirs have a major impact on the environment and the quality of water. These effects can be positive or negative and include changes in the physical, chemical and biological properties of water quality in the reservoir and in the downstream. In this thesis, all these effects and changes, which constitute a major global problem on water resources will be studied as well as the methods of treating them. The Mike Zero simulation program developed by DHI company is also used on Lacul Morii in Bucharest. Several simulations were made on dissolved oxygen, biological oxygen demand and on some pollutants that entered into the lake, such as petroleum products and detergents, to find out the extent of its spread after a period of time and reduce their effects.

The thesis is structured in five main chapters:

**Chapter 1, Introduction:** An initial study of some of the problems caused by dams and reservoirs upon the environment and water quality. The environmental consequences of large dams are numerous and varied, and includes direct impacts to the biological, chemical and physical properties of rivers and riparian environments.

**Chapter 2, Dams and their purpose:** It represents a general study on the importance of large dams and the purpose of building them-

- **Dams and energy:** Energy is a primary requirement for economic development, as well as for civilizations to prosper. In many developing countries, hydropower is the only natural energy resource. Hydropower can play an important role in a nation's industrial development because it offers low-cost energy, In addition, it provides quality energy covering the morning and evening loads to support the growth of many basic industries, thus providing regional economic benefits. For the short- and medium-term, the three principal sources of renewable energy that will permit large-scale exploitation are wind, biomass and hydro power. Of these sources, hydropower is the most reliable, efficient and by far the most used. A 100 MW hydroelectric project, operating 50 percent of the time, saves the burning of 600,000 barrels of fuel oil annually and saves the release of  $1.95 \times 10^{12}$  BTUS into the atmosphere.
- **Water born disease:** Malaria, schistosomiasis, filariasis and viral encephalitis are some of the most important diseases borne in water. Concentrated primarily in tropical and subtropical climates, their incidence may rise significantly with the creation of a large reservoir. Long before impoundment, it is important to build a solid knowledge of the prevalence and seasonal incidence

of diseases in exposed neighboring populations. Health maintenance and sickness prevention planning should be secured during pre-project planning. An evaluation of the strengths and weaknesses of the local and regional health services will allow for planning of any necessary improvements. These may include a task force approach, on-going monitoring, preventive and supportive measures and emergency facilities. As with other types of impact, it is important to inform the population concerned so that they themselves can take particular care of their health.

- **The need of water:** The greatest need for water occurs in the arid regions of the world during the warm, dry seasons. Further, demands on water supplies worldwide are increasing rapidly due to unprecedented growth in population, increased economic development and higher standards of living prompted by industrialization. World population has been 7.8 billion people as of March 2020. The global population is still increasing and is projected to reach about 10 billion in 2050 and more than 11 billion in 2100. The demand for water has quadrupled. A tremendous demand for water supply is created by vast increases in irrigated agriculture necessary to support the population with food, and a desire for improved living standards through economic development.
- **Management of water resources:** Management of our global water resources is a critical step toward meeting the water supply needs of both the present and projected global populations. Such a plan should consider the following measures: a) Maximize use of renewable water resources from precipitation. B) Limit use of nonrenewable aquifers and fossil water. C) Counter the adverse effects of using water as a transport medium for sewage and other waste, which eventually turns water into a conduit for disease and poisonous materials. D) Reduce flooding, which destroys life and property. e) Balance human needs and wildlife preservation.

**Chapter 3, Dams and environment:** Consists in a detailed study of the effects of the dams and reservoirs on the environment.

- **Contribution of dams to global warming:** The large dams emit approximately 1.4 million tons of methane annually, which is responsible for 4% of the total warming impact of human activities, and approximately 23% of all emitted methane due to human activities. These emissions come from reservoir surfaces, waterways and turbines. Methane is more effective than carbon dioxide in absorbing heat, although it does not last long in the atmosphere. The fuel for methane and carbon dioxide emitted comes through the decomposition of organic materials such as plants and algae, the decomposition of soil immersed in water, as well as through fossil fuels and building materials used during the dam construction.
- **Dams cause earthquakes** due to the pressure of excess weight of water in the reservoir, which leads to cracking the ground under or near the reservoir. One of the most known earthquakes with power of 7.9- magnitude happened in May 2008 in Sichuan, in which nearly 80,000 persons died.

There are more than 100 recorded cases around the world of earthquakes caused by large reservoirs. Like, Koyna, India in 1967 with magnitude 6.3, Hsingfengkiang dam in China, Kariba dam in Zimbabwe and Kremasta dam in Greece. .

- **Dams and environment Geophysical impact:** The construction of dams and the formation of reservoirs can significantly affect existing environmental and social values. The effect can be both short and long-term, and can extend well beyond the physical boundary. Geophysical processes include: reclamation and drainage, slope stability, water flow and sediment transport and seismicity.
- **A reservoir induces effects on water quality** at each stage of its development. The flooding of the impoundment triggers possible leaching of the flooded soil and decomposition of organic residues, with subsequent effects on physical and chemical properties of the water. In addition, the method of operation of major reservoir entails a change in thermal stratification and distribution of dissolved oxygen which also acts on the chemical properties of water and sediment.
- **Thermal stratification:** In general reservoirs with long water residence time (full season's cycle) and water depth of more than 10 meters will frequently have thermal stratification. Reservoir operation and morphology will have an important influence on stratification. Thermal stratification is the result, generally temporary, of a dynamic physical process, where two forces are counteracting: warming up at the water surface by radiation reduces vertical mixing and vertical mixing can be induced at the water by wind and wave forces (entrainment). Water mixing following a seasonal temperature change can eventually be positive or negative for fish and aquatic life since the levels of DO can be increased or decreased at all depths of the water column. These thermal characteristics and thermal stability for a reservoir can be predicted by models. If any problems are anticipated, mitigation measures can be considered. These include : 1) Changes in inlet structure configuration, 2) In-reservoir desertification, 3) Multilevel outlet works for mitigation of downstream effects, 4) Positive mixing and aeration by fountain jets or compressed air.
- **Sediments:** All rivers contain sediments that come from many sources. If water remains in the reservoir for extended periods of time, the sediments drop to the bottom. One of the most important problems caused by sediments is to reduce the capacity of the reservoir to water, so the reservoir loses the purpose for which it is built for. The most significant positive impact of the reservoir sedimentation process is the increased clarity of the stored water due to the removal or settling of suspended solids in the reservoir. Water released from a reservoir will require much less treatment for use as a domestic or industrial water supply due to its increased clarity. Other

benefits include: a) the high clarity of the stored water also becomes a much more appealing recreational attraction than the turbid waters of a following stream; b) the deposited sediments serve as a sink for capturing heavy metal ions and pesticides which would otherwise be carried via the flowing water as has been observed in many reservoirs; however, the trade-off is that the sediment material may now be contaminated; c) valuable sport fisheries have developed downstream of many dams where none existed naturally, because the water released from the dam has a significantly reduced suspended solids load and, in the case of deeper reservoirs, is most probably colder than the natural stream flow in temperate climates; d) the deposits in the entry zone of the reservoir, usually termed the “delta”, provide ideal biological growing condition, particularly for phreatophytes. Although this vegetative growth increases the evapotranspiration from the reservoir it provides excellent riparian and wetland wild-life habitat. Several mitigating measures can be used like: reservoir bypassing, flushing and sluicing.

- **Dissolved oxygen:** A high dissolved oxygen content of water is very important to the life. If low oxygen concentration is anticipated in reservoir with heavy metals in the sediment, these toxic substances may be released as a result of anoxic chemical reaction. The dissolved oxygen content of a reservoir largely depends on: the decomposition of organic matter from the soil and from submerged vegetation, seasonal changes in temperature of water, concentration of algae, etc. If mitigation is necessary the following different actions can be considered :1) in-reservoir re-aeration, 2) injection of oxygen, 3) turbine venting, 4) outlet works aeration, 5) reservoir cleaning, 6) river basin management, 7) spillway level and use. Dissolved oxygen is a test for the surface water quality of the reservoir.
- **Toxic substances:** The extent to which a reservoir is contaminated by nuisance and toxic compounds depend on several factors, including the submersion of land, the inflow, the balance between adsorption and adsorption of pollutants associated with sediment, and their deposition through these sediment. The submersion of soil and its vegetation is a potential source of heavy metal, pesticides and other pollutants. These substances enter the water column through leaching or through release from the decomposition of organic matter in the soil and plant life. Their release and transport is strongly affected by the dissolved oxygen concentration. Action for mitigation of nuisance and toxic substance effects can be considered to be divided into two approaches: 1) minimizing or eliminating the source of these substances, 2) actions to change the reservoir conditions to change the chemical end state of the substance.
- **Nutrients and algae:** Algae need an abundance of nutrients for growth, which forms the base of a large and complex food web that supports the entire aquatic ecosystem. In the right conditions, with abundant amounts of nutrients, algae continue to grow and support the food chain. With a

high temperature and abundance of nutrients, algae grows to the highest level and then explodes and sink into the bottom of the reservoir, and then the oxygen is used for its decomposition. This process is called Eutrophication. The most important negative effects of this phenomenon are: the presence of large and thick quantities of algae near the surface, a large decrease in oxygen concentrations, color and odor problems of water, the death of large quantities of fish and other aquatic organisms due to a lack of oxygen. Control of residence time by operational procedures (at the dam or at the spillway), regulation and positioning of the outlet level are reliable techniques to be used for mitigation measures to prevent eutrophication and algal blooms. When the major source of nutrients into a reservoir comes from agricultural activities in the watershed, the use of best management practices can drastically decrease the nutrient load.

- **Chlorophyll and phytoplankton:** The concentration of chlorophyll gives us information about the state of water and its quality due to its relationship with algae, as chlorophyll is a measure of the amount of algae in the reservoir. Typical problems associated with the deterioration of water quality are decrease in transparency, colored water, clogging of sand filters in water treatment plants, taste and odor in finished water, and fish kills. All of these problems are originated from massive growth of phytoplankton in lakes and the growth is known to be controlled by nitrogen and phosphorus concentrations. Thus, nitrogen and phosphorus standards for phosphorus were legislated in 1982 as one of the environmental water quality standards to maintain living environment. The changes in water quality by eutrophication are caused by the increase in organic substances originated from primary production of phytoplankton. Primary production is controlled not only by chemical parameters like nutrients but also by physical factors like light intensity, water temperature, mixing of water, hydraulic retention time and shape of lake basin. It is impossible to take all of these parameters into consideration into the expected water quality. The biomass of phytoplankton in lakes and reservoirs is often estimated by measuring the amount of chlorophyll-*a* (Chl-*a*), the predominant green pigment used in photosynthesis. Chl-*a* can be determined from a sample of phytoplankton collected from the water column. To determine the amount of Chl-*a*, the chlorophyll is extracted from the cells with a solvent such as acetone. The Chl-*a* value is then measured by such means as spectrophotometry, fluorometry, or high pressure liquid chromatography (HPLC) (APHA 1998). Phytoplankton forms the basis of the oceanic food web, the food web being a complex web of organisms and food chains. In general, phytoplankton is consumed by zooplankton and then is consumed by larger creatures down to sharks. Phytoplankton has the ability to use sunlight to convert carbon dioxide and water into energy.



The temperature also directly affects photosynthesis, where an increase in temperature increases the productivity of this process and thus increases the number of phytoplankton. All kinds of phytoplankton that cling to the green patch will benefit from high temperatures to increase productivity.

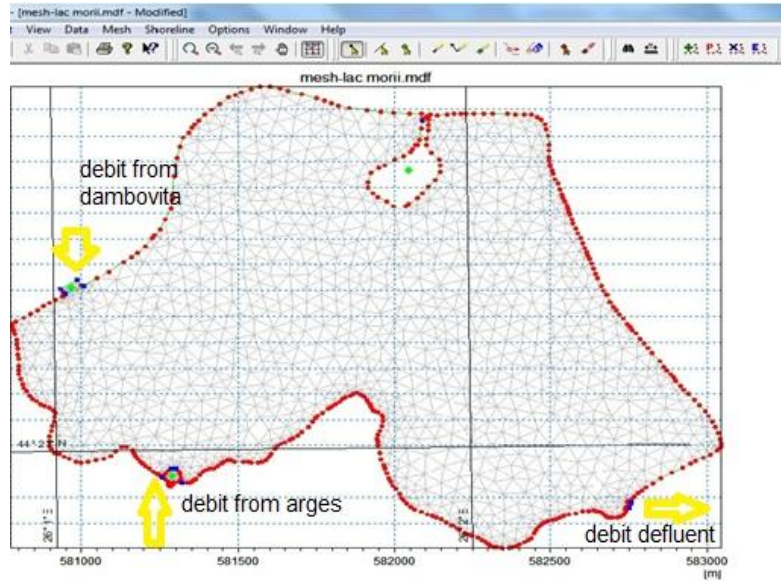
- **Water quality in the downstream** The water quality below the reservoir depends directly on the physical and chemical properties of the water in the reservoir, the level of its penstocks, water uses, flow regime, river recovery capacity. For example the settling out of suspended particles in the reservoir contribute to lowering the turbidity of the water and enhancing its transparency in downstream, entailing a beneficial effect particularly for domestic intakes. This decrease in transported suspended particles may have negative effects for some of the organisms living downstream. The water released downstream is hungry for sediment and this results in some scouring of the bed and banks.

**Chapter 4, Using mike zero software on the Lacul Morii:** A detailed explanation of the Mike Zero simulation program, the models that were used, and the most important information we obtained from each model are presented. This chapter contains also explanations on the Lacul Morii mesh and how it was created.

- **Lacul Morii:** The reservoir is located in Bucharest approximately 6 km from the center, with an area of 246 ha and volume 14.7 million m<sup>3</sup>. The reservoir was created by a dam with 15m high. The reservoir was put into operation in 1986 mainly to protect the city against floods. It is also a recreation area.

Setting up a mesh includes appropriate selection of the area to be modelled, adequate resolution of the bathymetry, flow, wind and wave fields under consideration and definition of codes for open and land boundaries. Mesh of Lacul Morii was created by Mike Zero and by using coordinate stereo 70.

The boundary and the incoming sources (from Dambovită și Argeș) and the effluent discharge were identified as shown in the following figure.



Mesh of Lacul Morii reservoir with two sources of discharge inflow and one outflow.

- **MIKE Zero** is the common name of DHI's fully Windows integrated graphical user interface for setting up simulations, pre- and post-processing analysis, presentation and visualisation within a project oriented environment. The Mesh Generator provides a work environment for creating detailed digital mesh for use in the MIKE Zero flexible mesh (FM) models. Providing these new generation models with a suitable mesh is essential for obtaining reliable results from the model simulations. In this program we used three models for simulation, and each model requires specific information.
- a) **Hydrodynamic Module:** The period to be covered by the simulation is specified in the dialog box. Must to specify the simulation start date, the overall number of time steps and the overall time step interval. The overall discrete time steps are used to determine the frequency for which output can be obtained from the different modules and to synchronize the coupling between the different modules. To determine the period of simulation we must determine the number of time steps. For example, for a simulation of 11 days and time steps interval 120 s ( time steps interval means that mike zero will calculates equations every 120s), the number of time steps will be 7920 ( $86400 \text{ s per day} / 120\text{s/time step} = 720 \text{ number of time steps per day}$  and  $720 \text{ time steps/day} * 11 \text{ days} = 7920 \text{ time steps}$ ). The simulation always starts with time step number 0, while the simulation start date is the historical data and time corresponding to time step 0. The simulation end date is presented for reference. By using simulation in hydrodynamic modules we can get information like Surface elevation, Total water depth, U velocity and V velocity.



- b) **Transport module:** The transport module calculates the resulting transport of materials based on the flow conditions found in the hydrodynamic calculations. On the dialog box we specify the number of components and the name of the components that should be solved for. Each component defines a separate transport equation (in this simulation we used three components: petroleum products, detergent and fixed residue). By using simulation in transport modules we can get information like : U velocity, V velocity and the concentration for each component and their dispersion after a period of time. The concentrations of each component are obtained in each node of the network mesh. By clicking on any point of the mesh of the lake, we can know the coordinates of the point as well as the concentration in it.
- c) **Mike eco lab module :** is a numerical lab for ecological modelling. It is an open and generic tool for customizing aquatic ecosystem models to describe water quality, eutrophication, heavy metals and ecology using process oriented for mutations.

**Chapter 5, Result and discussion:** Many simulations were done in the Mike Zero program by using the information that we obtained from the Administratia Nationala Apele Romane (ANAR). Simulations were made for dissolved oxygen and the BOD of Lacul Morii after entering the concentrations from Dambovită and Argeș rivers to know the spread and values of these concentrations after a certain period of time as well as their conformity to the water quality standards. Simulations were also made for some pollutants that entered to the lake, such as petroleum products and detergents, to find out the concentrations of these products at a specific point in the lake. Evacuation and dilution methods were used to reduce the pollutants. As well simulations were made for chlorophyll and phytoplankton concentrations to explain the relation between dissolved oxygen and temperature with these concentrations.

#### 1) Simulation for 2013

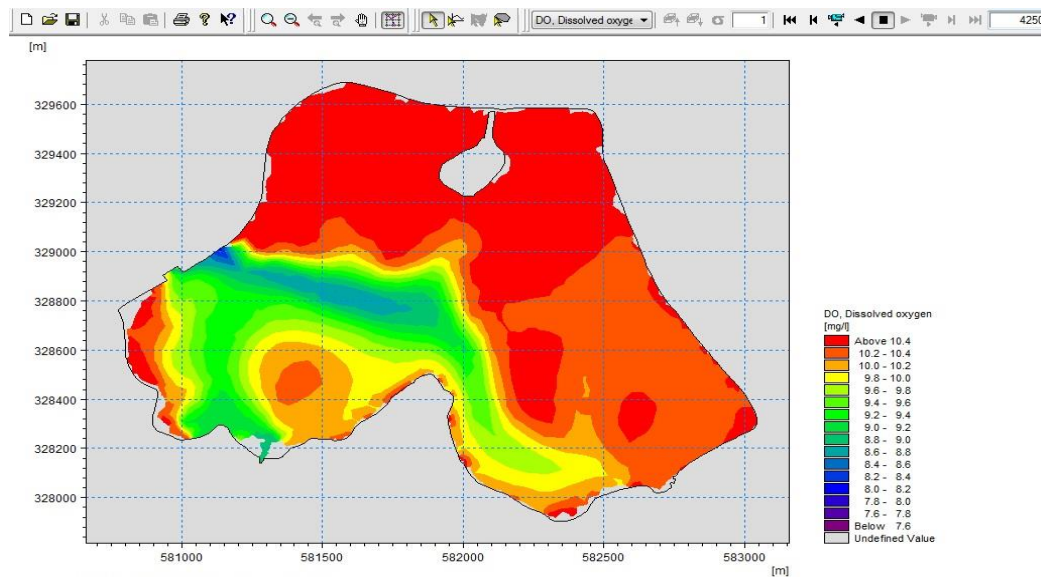
Table 1 : The data received from Administrația Națională Apele Române (ANAR) for 2013

|                   | DO (mg/l) | BOD(mg/l) | Q (m <sup>3</sup> /s) |
|-------------------|-----------|-----------|-----------------------|
| Dambovită         | 8.6       | 7.2       | 7                     |
| Argeș             | 9         | 1.3       | 3                     |
| Defluent          | 10.3      | 4.2       | 10                    |
| Initial condition | 10.1      | 5.2       | -                     |

- The period of simulation 01/10/2013 – 30/10/2013.
- Temperature 13C<sup>0</sup> (constant)
- Water elevation 82m (constant)
- Bod decay rate : 0.477
- Reaeration rate : 0.35

a) Simulation of dissolved oxygen concentration

On the first day of the simulation, we already have good concentrations of dissolved oxygen in the lake (10.1 mg/l), as well as coming from the Dambovită source before mixing process, and assuming that the Argeș source is unpolluted source and contains good concentrations of dissolved oxygen and BOD and compliant with water quality standards.



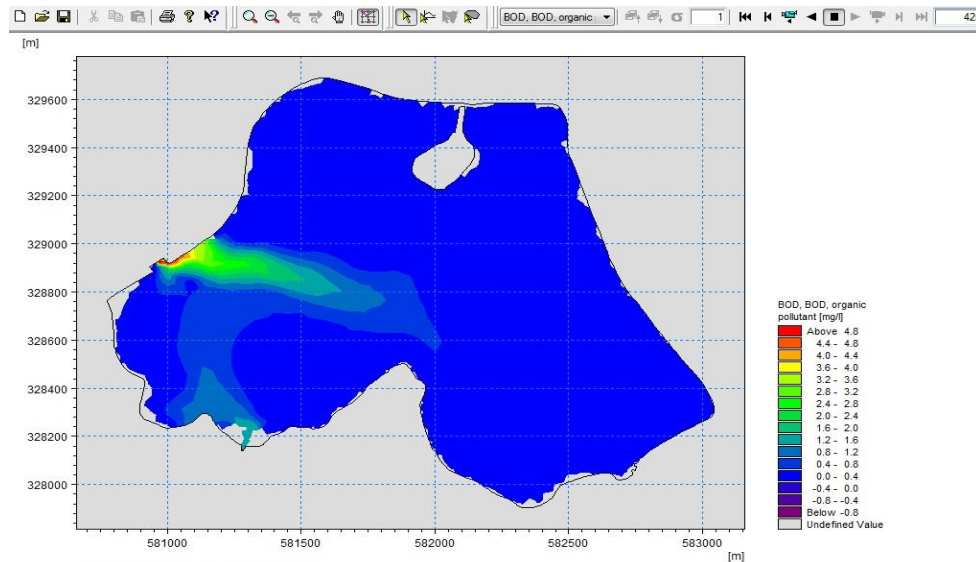
The concentration of DO after 30 days showing the concentrations of dissolved oxygen in reservoir after the mixing process.

After 30 days, we notice that the dissolved oxygen concentrations in the reservoir are very good. There are changes in the concentrations in the middle of the lake (the flow line of the currents are oriented between the sources entering into the lake towards the dam) as well as good concentrations in the areas surrounding the island (at the top of the figure); the concentrations are in the range (10-11.5 mg/l) which can be explained by a low water speed in these areas. In the center of the lake, the concentrations range (8-10 mg/l), while the dam area ranges (10.1-10.4 mg/l). All concentrations are meeting the required standards. It is considered the entry of suitable concentrations from Dambovită and Argeș, as well as the abundance of pre-dissolved oxygen in the lake, as well as the moderate temperature, which is the reason to obtain these concentrations.

### b) Simulation of Biochemical Oxygen Demand concentration

BOD represent the amount of DO necessary for aerobic organisms to decompose organic matter in the water, a high level of BOD may indicate high organic carbon contents from natural sources and contamination with waste water from anthropic sources.

The BOD concentrations found in the lake, as well as those entering by Dambovită river are relatively large concentrations and affect negatively the water quality.



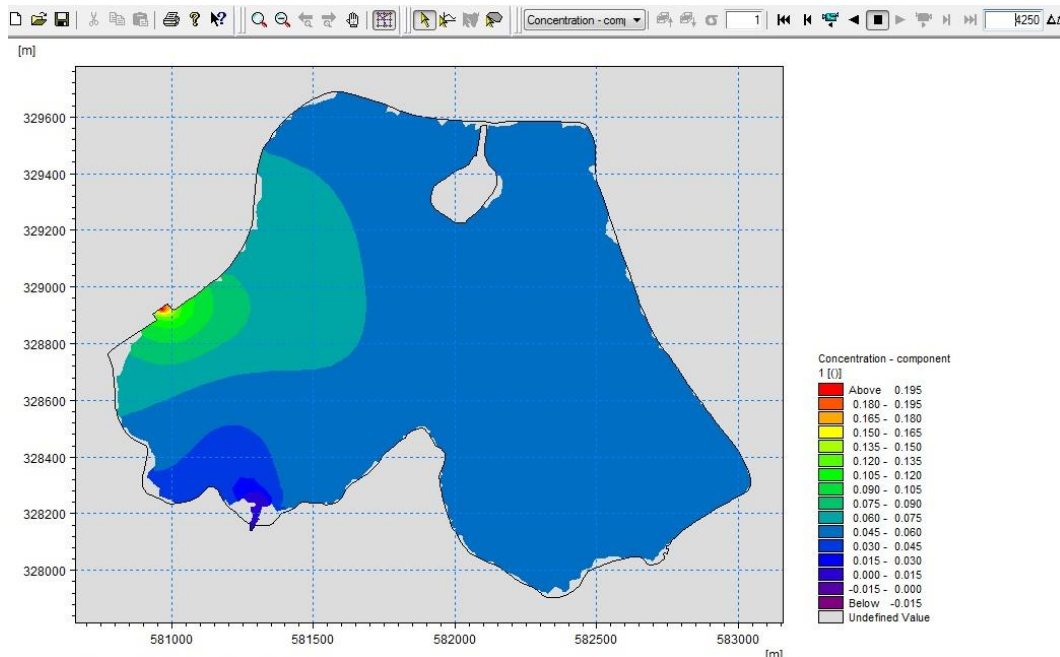
The concentration of BOD in the reservoir after 30 days.

After 30 days (at the end of simulation), the concentrations of BOD in the reservoir (in most areas of the reservoir) have decreased from 5.2 mg/l to 1.2 mg/l as showing in the figure. The reason is the entry of a pure water source from Arges (with BOD 1.3 mg/l) and the exit of large quantities of BOD outside the reservoir, as well as the initial presence of dissolved oxygen in high concentrations in the reservoir strongly influenced by the input of Dambovită and Arges sources (8.6 respectively 9 mg/l). The value of the BOD meets the water quality standards. I assume that the quality improvement was also due to the effect of the rearetion by wind.

### c) simulation in case of detergents concentration

A pollutant (detergent in this simulation) entered to the reservoir for a month by Dambovită river with a concentration of (3.424 mg/l) and a flow ( $7\text{ m}^3/\text{s}$ ). We assumed that a water source contained pure water

entered from Arges river (0mg/l of detergent with 3 m<sup>3</sup>/s), The outflow (10m<sup>3</sup>/s). Water elevation constant (82m) and the temprature constant (13C<sup>0</sup>).

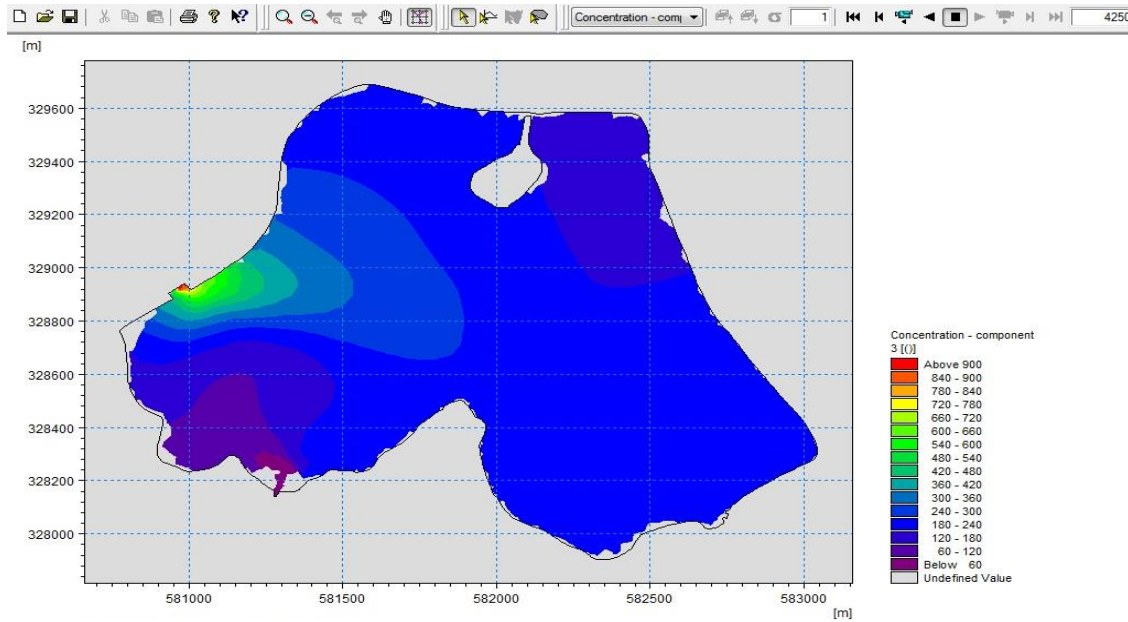


Dispersion of detergent after 30 days with a value of dispersion in the reservoir.

After the simulation is over, we notice that the pollutant has spread from the source of Dambovită to the rest of the reservoir. As after 30 days after the polluter entered, the concentration at the dam area reached to 0.064 mg/l, but at the center of the reservoir reached to 0.08 mg/l. The reason for this rapid spread is the high flow of dambovită as well as the high concentration of the pollutant. Arges flow can be increased by assuming a clean source to reduce the pollutant's impact on the reservoir's water quality. See a decrease of the pollutants in the reservoir at Simulation for petroleum products.

#### d) Simulation of the concentration in case of fixed residue

A pollutant (fixed residue in this case) entered to the reservoir for a month by Dambovită river with a concentration of (1155.17mg/l) and the flow (7m<sup>3</sup>/s). We assumed that a water source contained pure water entered from Arges river (0mg/l with 3 m<sup>3</sup>/s), The outflow (10m<sup>3</sup>/s). Water elevation constant (82m) and the temperature constant (13C<sup>0</sup>).



Dispersion of fixed residue after 30 days.

At the end of simulation we notice that the pollutant has spread from the source of Dambovita to the rest of the reservoir. As after 30 days after the pollutant entered, the concentration at the dam area reached approximately to 120 mg/l, but at the center of the reservoir reached to 300 mg/l, that mean increasing in pollutant concentration 4% every day until reaching the dam area. The reason for this rapid spread is the high flow of Dambovita as well as the high concentration of the pollutant. Arges flow can be increased by assuming a clean source to reduce the pollutant's impact on the reservoirs water quality.

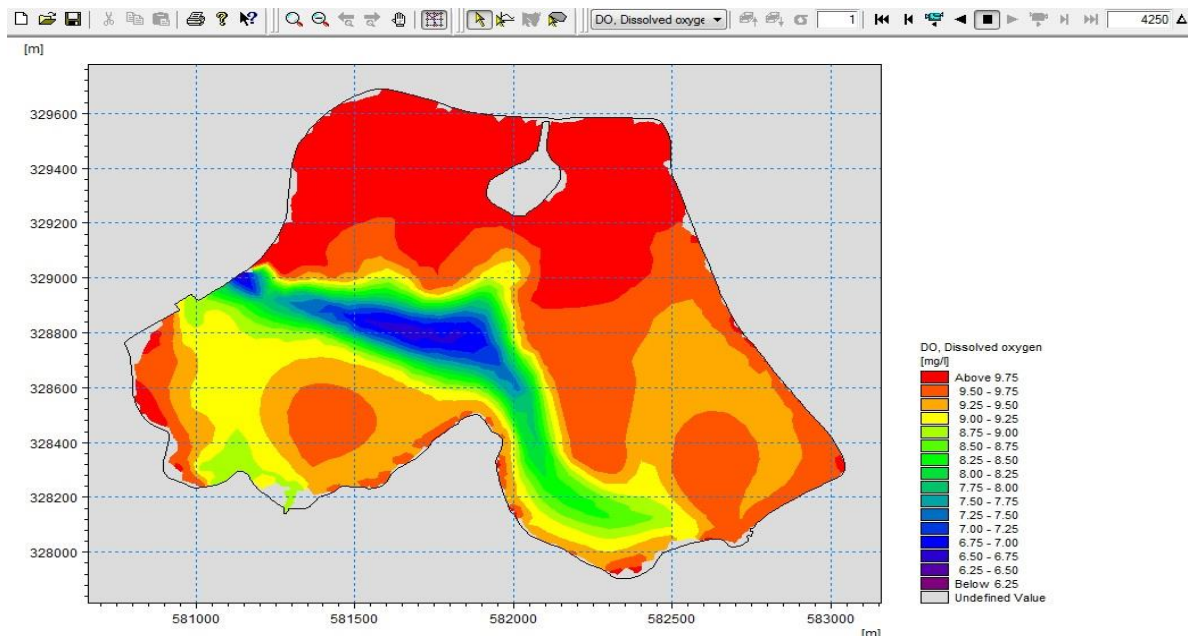
## 2) Simulation for 2014

Table 2 : The data received from Administrația Națională Apele Române(ANAR) for 2014

|                   | DO (mg/l) | BOD(mg/l) | Q (m <sup>3</sup> /s) |
|-------------------|-----------|-----------|-----------------------|
| Dambovita         | 8.9       | 17        | 7                     |
| Arges             | 9         | 1.3       | 3                     |
| Defluent          | 9.1       | 8.2       | 10                    |
| Initial condition | 8.8       | 5         | -                     |

- The period of simulation 15/09/2014 – 15/10/2014.
- Temperature 16C<sup>0</sup> (constant)
- Water elevation 82m (constant)
- Bod decay rate : 0.477 ,
- Reaeration rate : 0.35

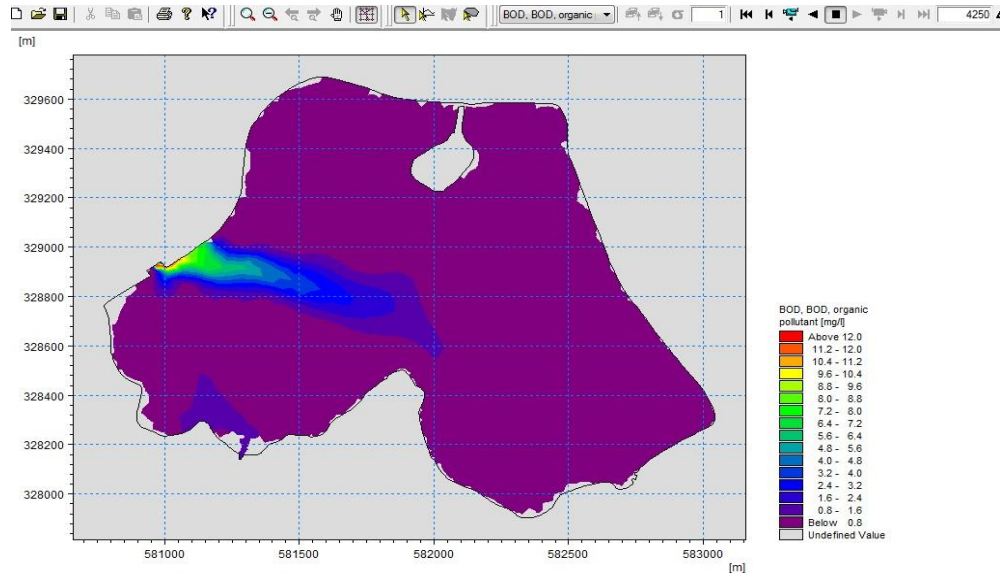
#### a) Simulation of dissolved oxygen concentration



The concentration of DO after 30.

After the simulation is over, we notice that the dissolved oxygen concentrations in the reservoir are very good. There are changes in the concentrations in the middle of the lake (the flow line of the currents are between the sources entering into the lake to the dam area) as well as good concentrations in the areas surrounding the island. The concentrations are approximate (8-10 mg/l). In the center of the lake, the concentrations range (7- 9.5 mg/l), at the dam area ranges (9 - 9.75 mg/l). All concentrations are considered to meet the required standards. It is considered the entry of suitable concentrations from Dambovită and Argeș, as well as the abundance of pre-dissolved oxygen in the lake, as well as the moderate temperature, which is the reason to obtain these concentrations.

### b) Simulation of Biochemical Oxygen Demand concentration



BOD after 30 days showing the decrease in the value because the mixing proces with the rezidual BOD in the lake, and high value of dissolved oxygen in the lake.

After the simulation is over, we notice the spread of a high value of BOD in the reservoir due to the great biological demand coming from Dambovita river. The concentrations decreased from 4.8 mg/l to 2.4mg/l (at the end of this simulation). The contribution of Arges river is very important to reduce the impact of the BOD due to the good water quality it carries (as happened in the 2013 simulation). Also, the high concentrations of DO existing in the reservoir will reduce this effect of bad quality water of Dambovita river.

### 3) Simulation for 2015

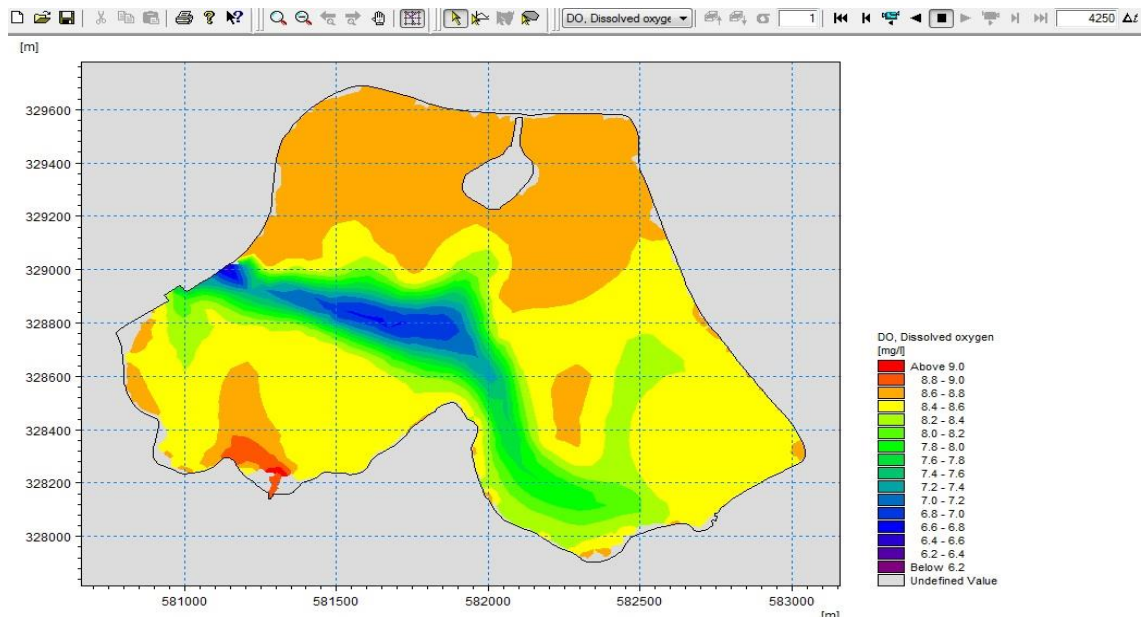
Table 3 : The data received from Administrația Națională Apele Române(ANAR) for 2015

|                   | DO (mg/l) | BOD(mg/l) | Q (m <sup>3</sup> /s) |
|-------------------|-----------|-----------|-----------------------|
| Dambovita         | 7.4       | 9.2       | 7                     |
| Arges             | 9         | 1.3       | 3                     |
| Defluent          | 11.5      | 4.9       | 10                    |
| Initial condition | 11.3      | 5.3       | -                     |



- The period of simulation 01/06/2015 – 30/06/2015.
- Temperature 22C<sup>0</sup> (constant)
- Water elevation 82m (constant)
- Bod decay rate : 0.477 ,
- Reaeration rate : 0.35

a) Simulation of dissolved oxygen concentration



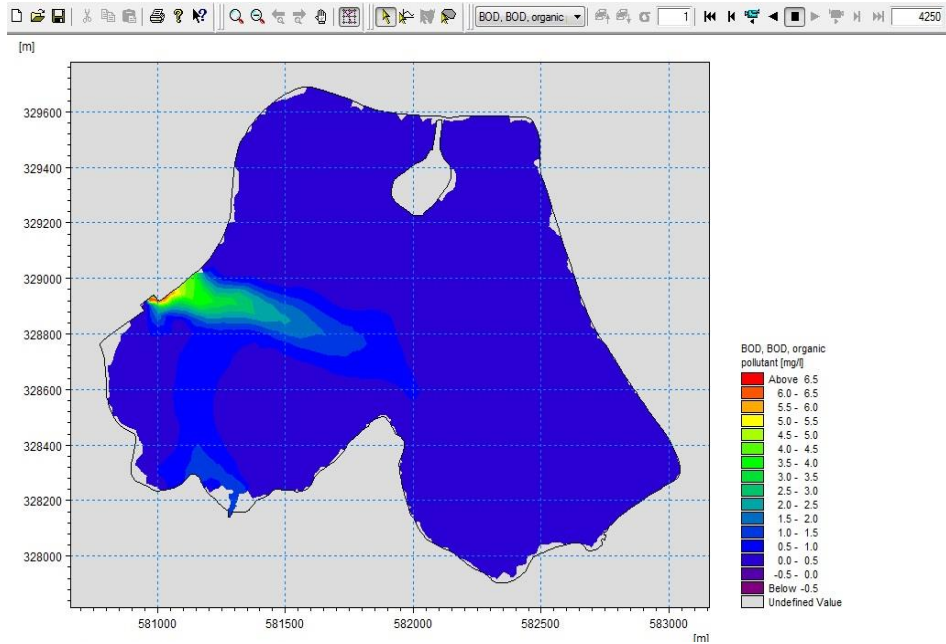
Concentration of DO after 30 days.

At the end of the simulation the oxygen concentrations in the lake are very good as the concentrations arrived in the middle of the reservoir (7-8.8mg/l); concentrations are also good at the dam area (8-9.3 mg/l).

b) Simulation of Biochemical Oxygen Demand concentration

At the end of the simulation, we notice a decrease in the value of the BOD in the middle of the reservoir from 5.3 to 1.8 mg/l due to the hypothesis of entering a pure water source from Arges, which is more likely to help reduce the effect of the large BOD. Also, the presence of BOD decay rate which is considered good (0.477).





Concentration of BOD in reservoir after 30 days.

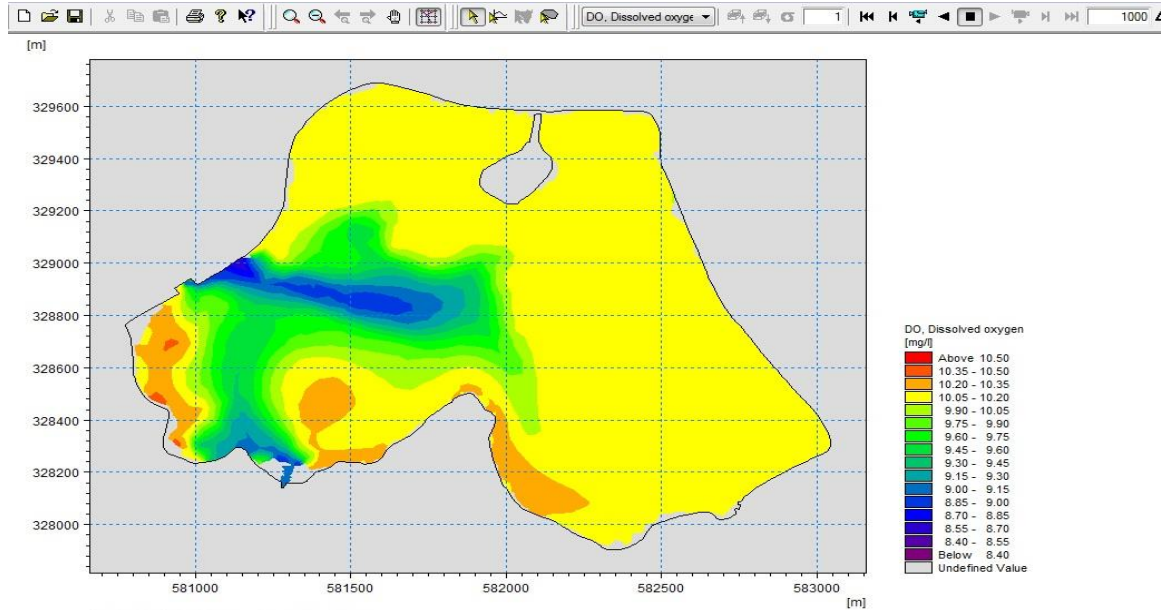
#### 4) Sensitivity analysis of BOD decay rate and aeration rate

In this simulation we will find the variation effects of BOD decay rate and reaeration rate on the concentration of DO for period of one week. The discharges will be constant for these three simulations, and the reaeration rates will be variable.

- Discharge of Arges river : DO : 9mg/l BOD :1.3mg/l , Q; 3 m<sup>3</sup>/s
- Discharge diffluent: DO: 10.3mg/l , BOD : 4.2mg/l, Q;10 m<sup>3</sup>/s
- Discharge Dambovita river :DO: 8.6mg/l, BOD : 7.2mg/l ,Q; 7m<sup>3</sup>/s
- Initial conditions: DO : 10.1mg/l, BOD : 5.2mg/l
- Assuming all conditions are constant for all simulations like T(C<sup>0</sup>) and water level

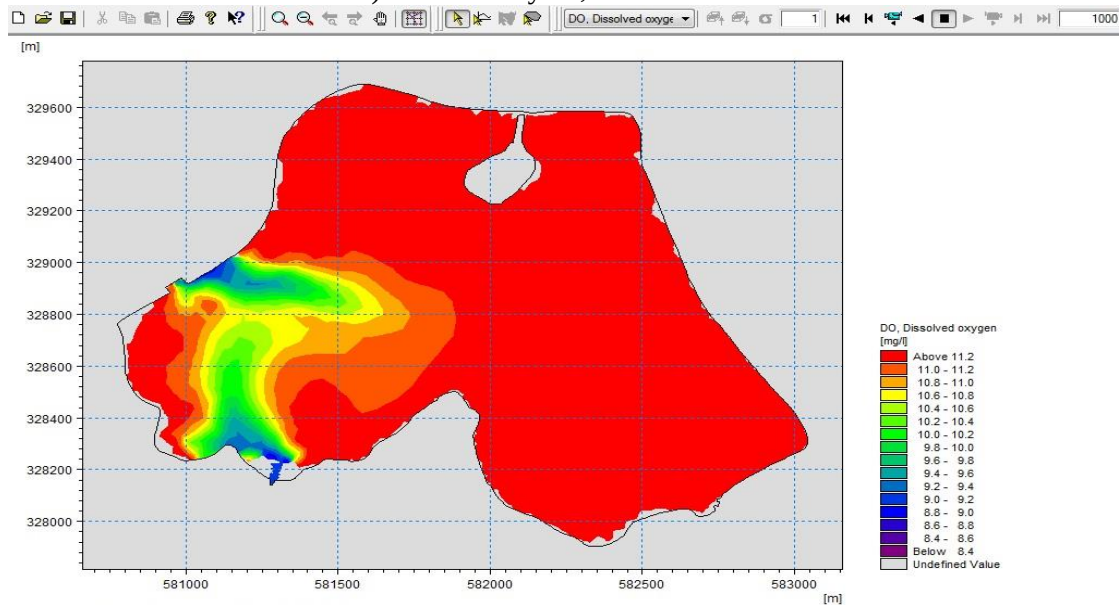
a) BOD decay rate : 0.477, Reaeration rate : 0.35

After seven days have passed since the simulation began, we notice that the concentration of dissolved oxygen in the central region of the reservoir is approximately (10.5 mg/l), where the oxygen concentration increased by (0.4mg/l) over what was present (10.1mg/l) due to the oxygen entering into the reservoir by reaeration.



The effect of BOD decay rate and reaeration rate on DO in reservoir.

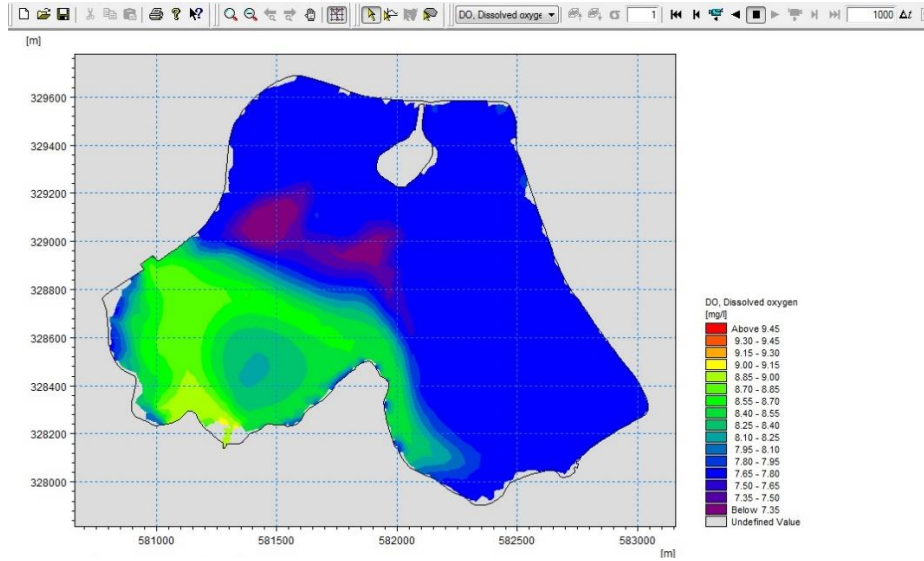
b) BOD decay : 2, Reaeration rate : 1.5



The effect of increased BOD decay rate and reaeration rate on DO in reservoir.

The increase in the BOD decay rate from (0.477) to (2) and the increase in reaeration rate from (0.35) to (1.5) helped greatly to increase the concentrations of dissolved oxygen, as the concentration in the center of the lake reached (12.3mg/l) after one week only. (10.5mg/l) was in the previous simulation

c) BOD decay rate : 0.2, Reaeration rate : 0.08



The effect of decreased BOD decay rate and reaeration rate on DO in reservoir.

Reducing BOD decay rate and reaeration rate in the reservoir will reduce the quantities of dissolved oxygen, as in the first simulation (when the BOD decay was 0.477 and the reaeration rate 0.35). The concentration of oxygen in most parts of the lake reached (9-10.5 mg/l). As for this simulation, we notice the deficit of dissolved oxygen in the middle of the lake, as well as at the dam area, where it reached (7.8-8.4 mg/l), meaning that it decreased by (2 mg/l)

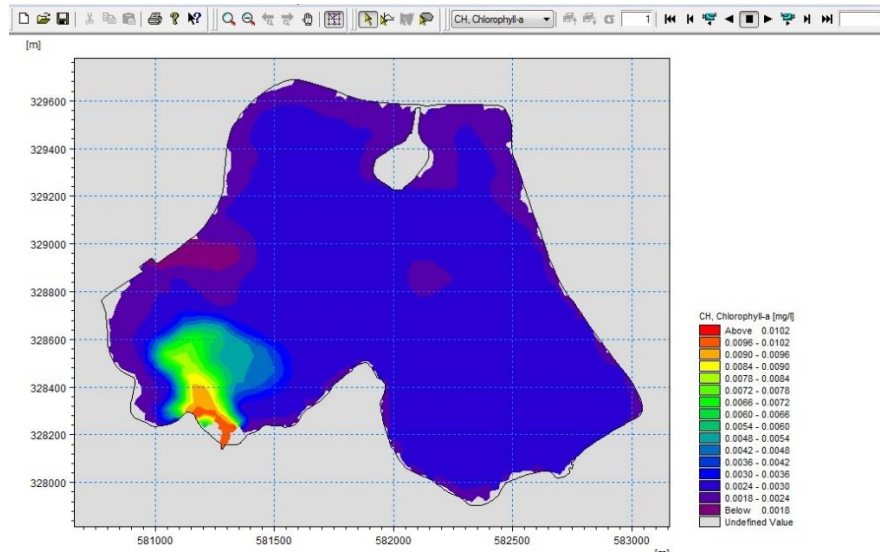
Through these simulations, we put into evidence the best values for the BOD decay rate (0.4-1) as well as the reaeration rate (0.35-1) to obtain optimal oxygen concentrations.

5) Simulations for chlorophyll, phytoplankton and dissolved oxygen, period ( 01/01/2019 – 24-03/2019 )

Table 4. Data of chlorophyll, flow and dissolved oxygen for Lacul Morii reservoir

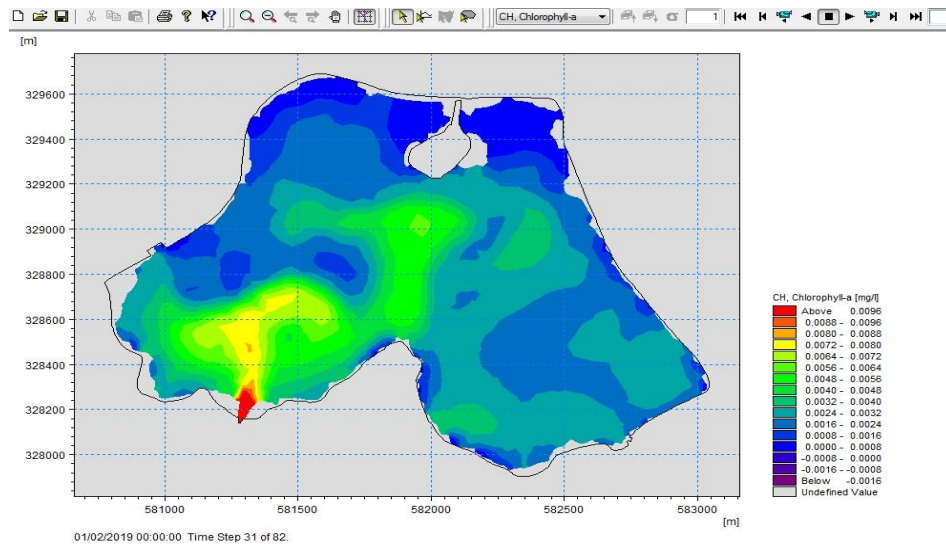
|                          | Dambovită river | Arges river | Middle of the lake | Defluent |
|--------------------------|-----------------|-------------|--------------------|----------|
| Chlorophyll (mg/l)       | 0.001           | 0.01        | 0.003              | 0.012    |
| Flow (m <sup>3</sup> /s) | 7               | 3           | -                  | 13       |
| DO (mg/l)                | 7.15            | 9           | 9.18               | 9.05     |

## a) chlorophyll

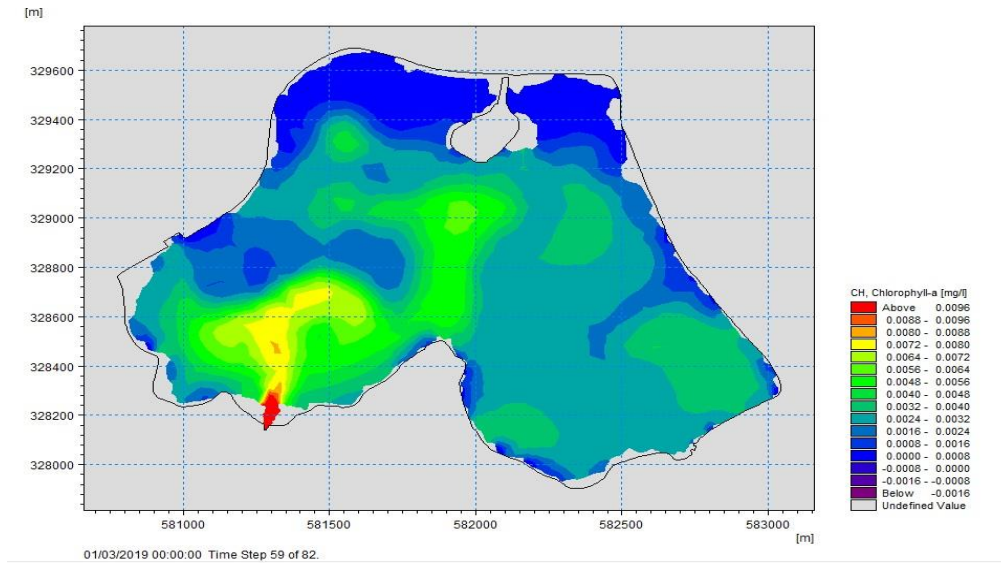


Concentration of chlorophyll in lake after one day from starting simulation

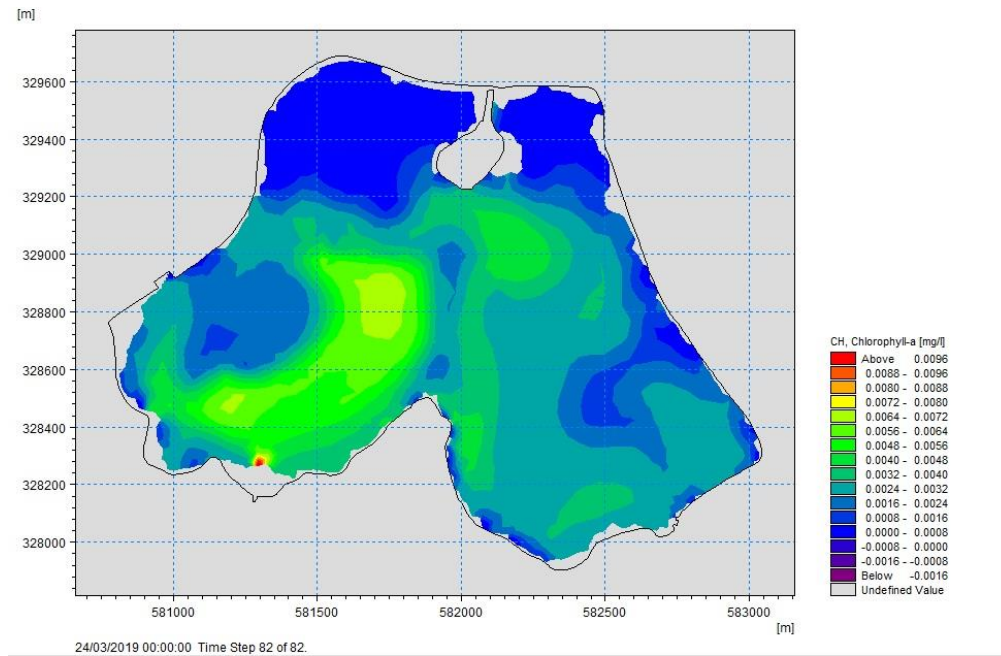
In this simulation we assumed that the outflow is greater than the inflow to know its effect on chlorophyll. We assumed that the concentration of chlorophyll present in the reservoir is (0.003mg/l) which is relatively small, Also the concentration from Dambovita. While a good concentration entered from Arges (0.01mg/l).



Concentration of chlorophyll in lake after one month from starting the simulation, that is showing the distribution of chlorophyll in all points of reservoir. After 30 days we notice an increase in the number of chlorophyll in all parts of the reservoir where it increased at a rate (0.001-0.002 mg/l).



Concentration of chlorophyll in reservoir after two month from strating the simulation. After 60 days, we notice a continuous increase in chlorophyll concentrations, especially in the middle of the reservoir, where the concentration reached to (0.006 mg/l), It increased at a rate of (50%) (0.003 mg/l was the concentration in the beggining). This increase is considered normal due to the introduction of good quantities of chlorophyll from Arges source.



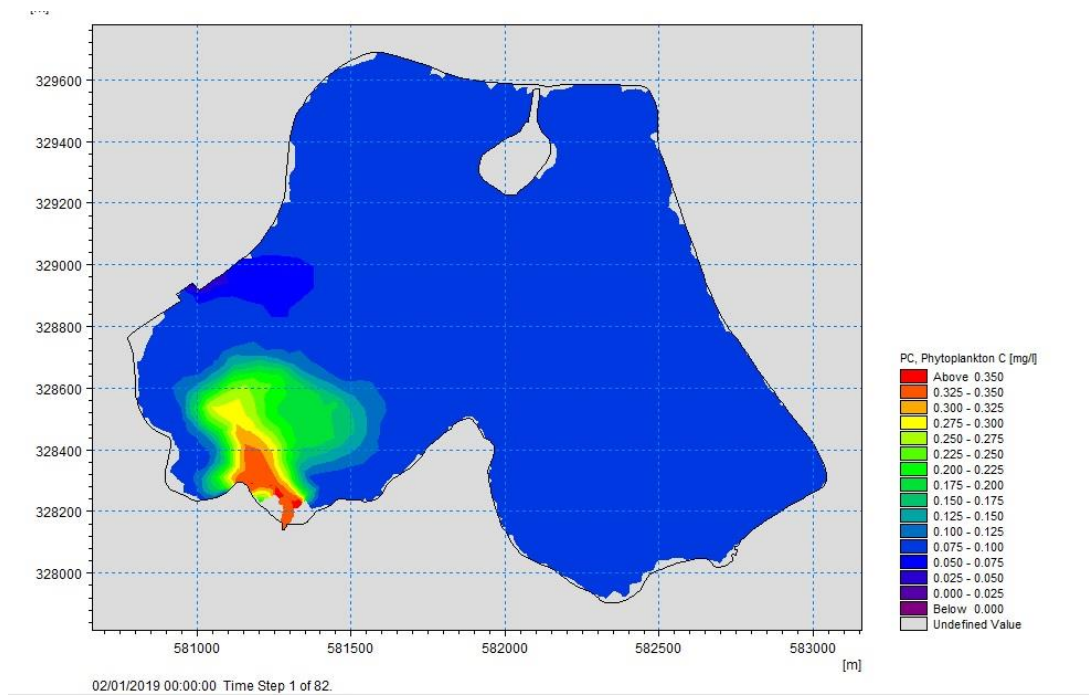
Concentration of chlorophyll in the reservoir at the end of simulation (3 months).

At the end of the simulation, we notice an increase in the concentrations of chlorophyll naturally, due to the continued entry of good concentrations from the Arges river, as well as a gradual increase in temperature, which helped the development of chlorophyll in the reservoir. The increase in chlorophyll



leads to an increase in dissolved oxygen (as shown in the figure). The temperatures increased in these simulations as follows ( $10C^0$ ,  $14C^0$ ,  $21C^0$ ). We also conclude that the increase in the outflow in the case of a polluted entry into the lake for the purpose of the mitigation and evacuation processes will not significantly affect the concentrations of chlorophyll (but with appropriate temperatures, as well as the entry of good concentrations into the lake, as well as the entry of nutrients in moderate quantities).

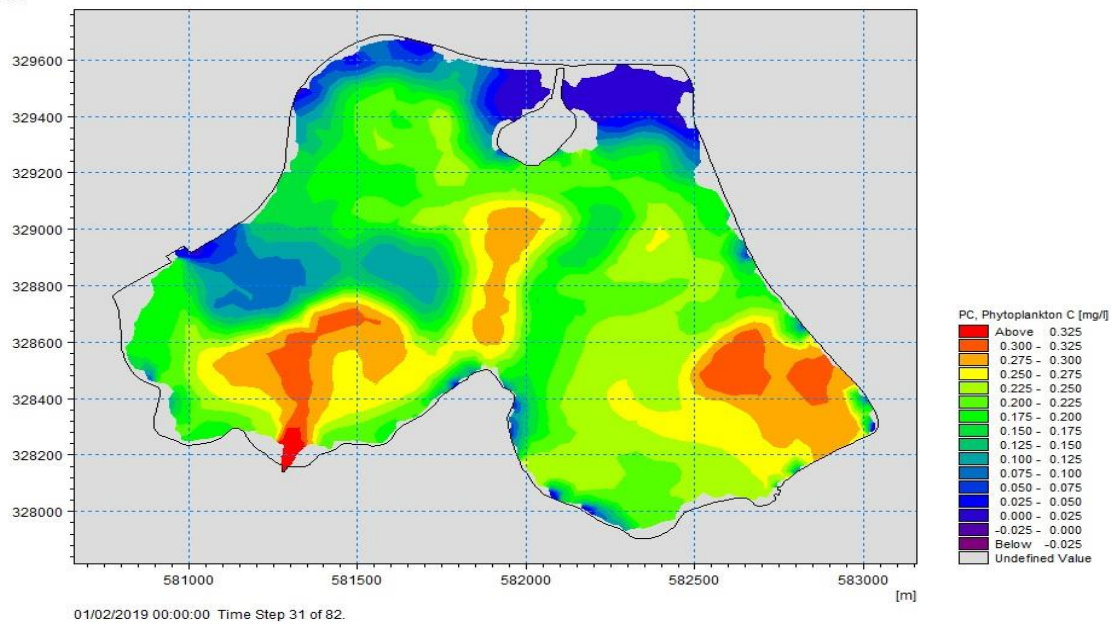
## b) phytoplankton



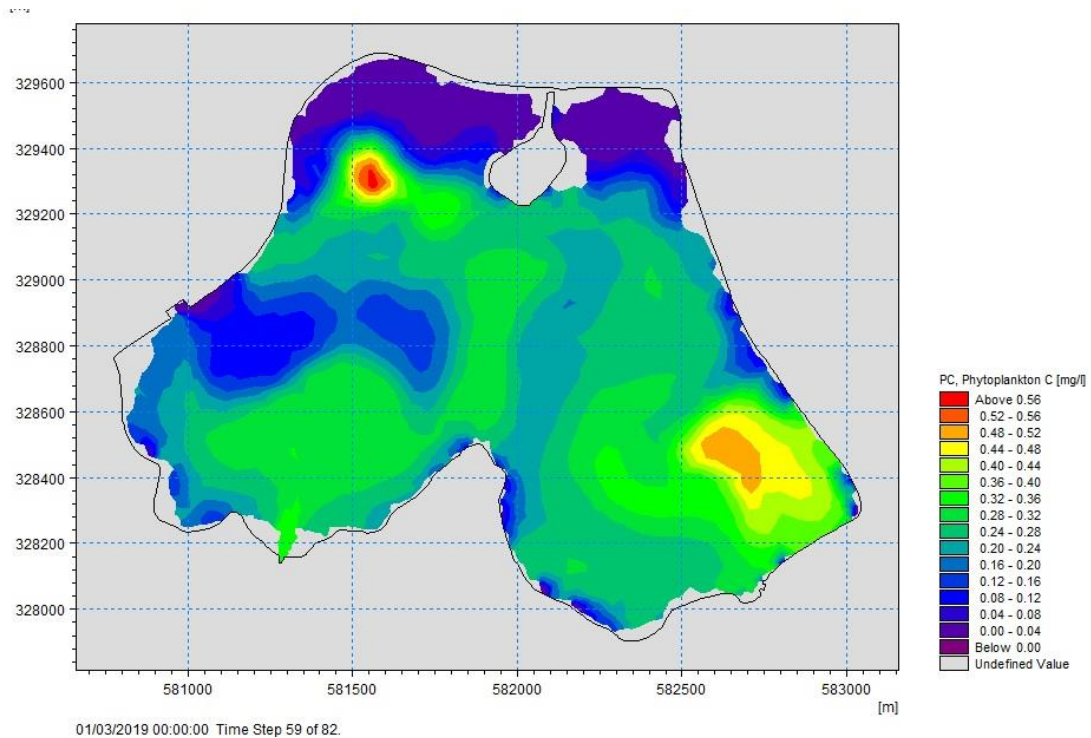
Concentration of phytoplakton in reservoir after one day from starting simulation.

Phytoplakton concentrations in the Mike software are calculated using chlorophyll concentrations as well as dissolved oxygen. With the same concentrations mentioned in the previous chlorophyll simulation, we note that the concentrations were as follows:

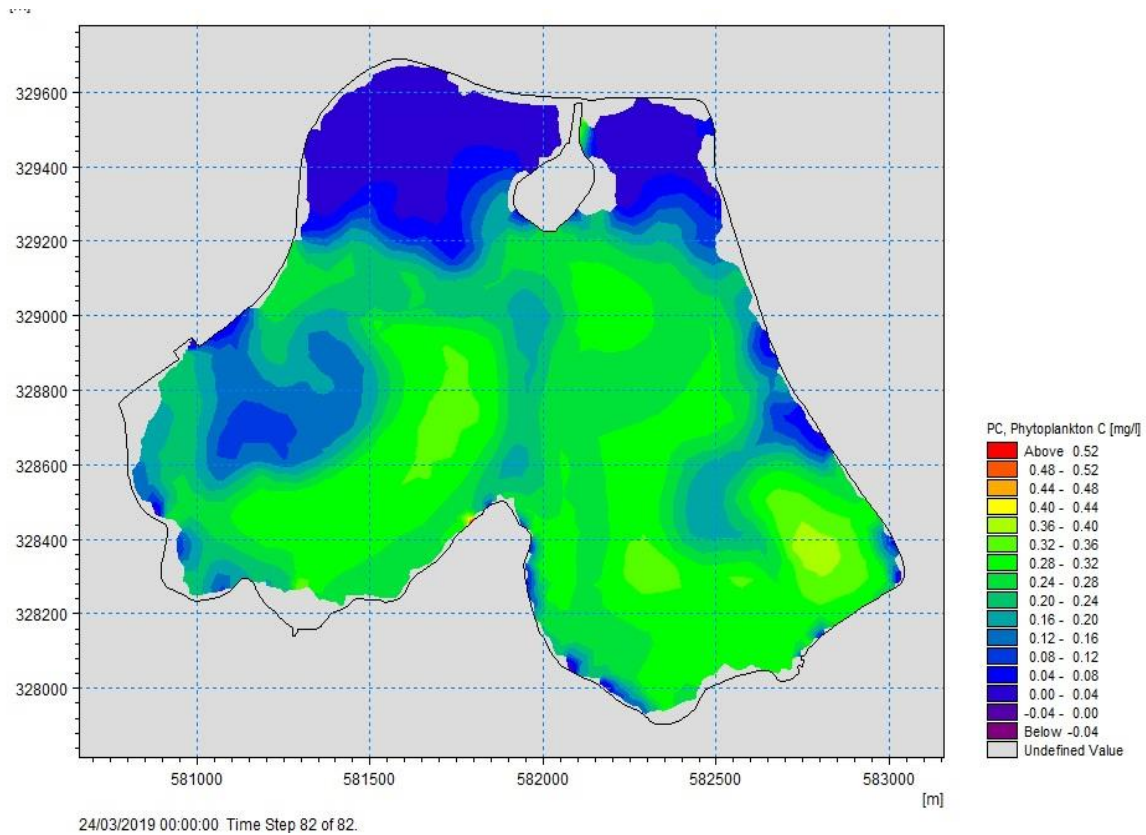
- at the area dam : 0.05-0.07 mg/l
- in the middle of reservoir: 0.05-0.08 mg/l



Concentration of phytoplakton in lake after one month from starting the simulation. Concentration of phytoplakton at the area of dam reached to (0.25-0.33 mg/l), in the middle of reservoir (0.25-0.35 mg/l).



Concentrations of phytoplakton in reservoir after two month from starting the simulation.

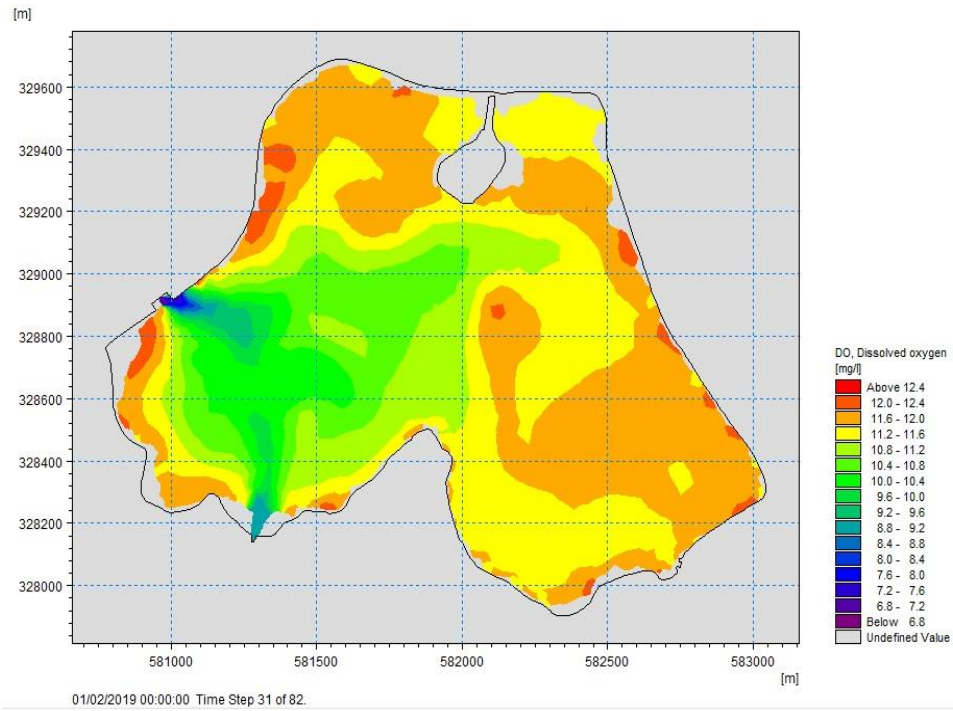


Concentration of phytoplankton in the reservoir at the end of simulation (3 months).

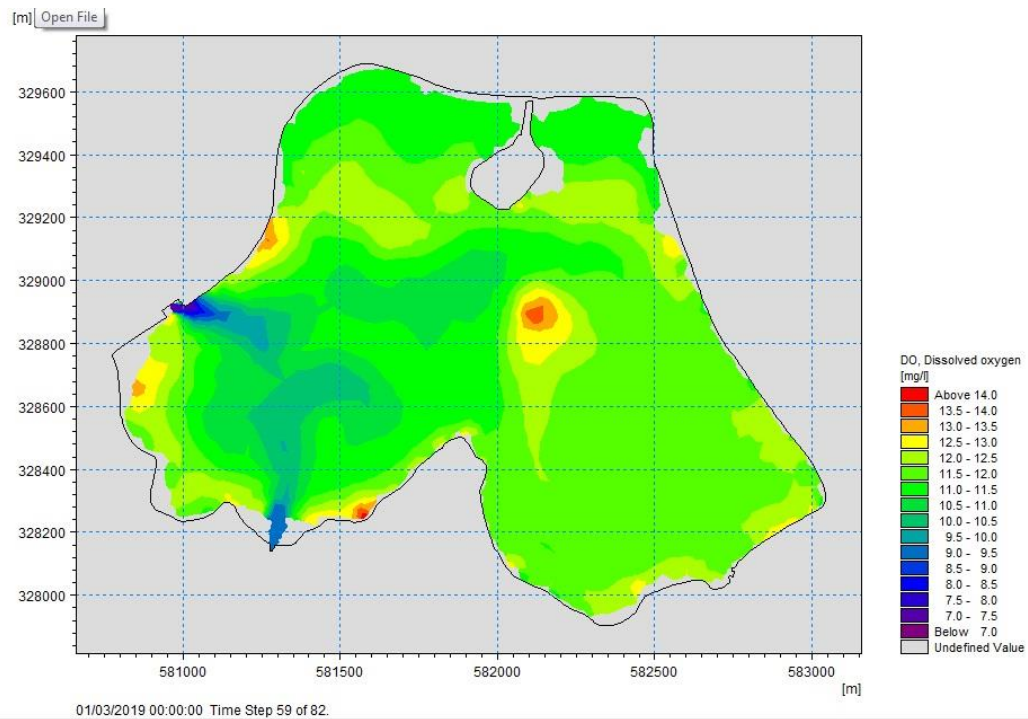
From the above we can see the variation of chlorophyll and phytoplankton which depends on the amount of nutrients that entered into the reservoir and the temperature of water that change from a season to another (due to the sun radiation that reach the surface of the water ). In the Mike program, we notice a systematic increase in the concentration of phytoplakton after the simulation is over (after 84 days ), as the phytoplakton in the center of the reservoir increased from (0.05 mg/l ) to (0.3mg/l at the end of simulation), that is it almost an increase of (0.23 mg/l). Through the previous simulations we conclude the increase in temperature and the abundance of chlorophyll from the internal sources increases the productivity of phytoplankton and therefore an increase in the concentrations of dissolved oxygen even if the outflow is higher than the inflow.



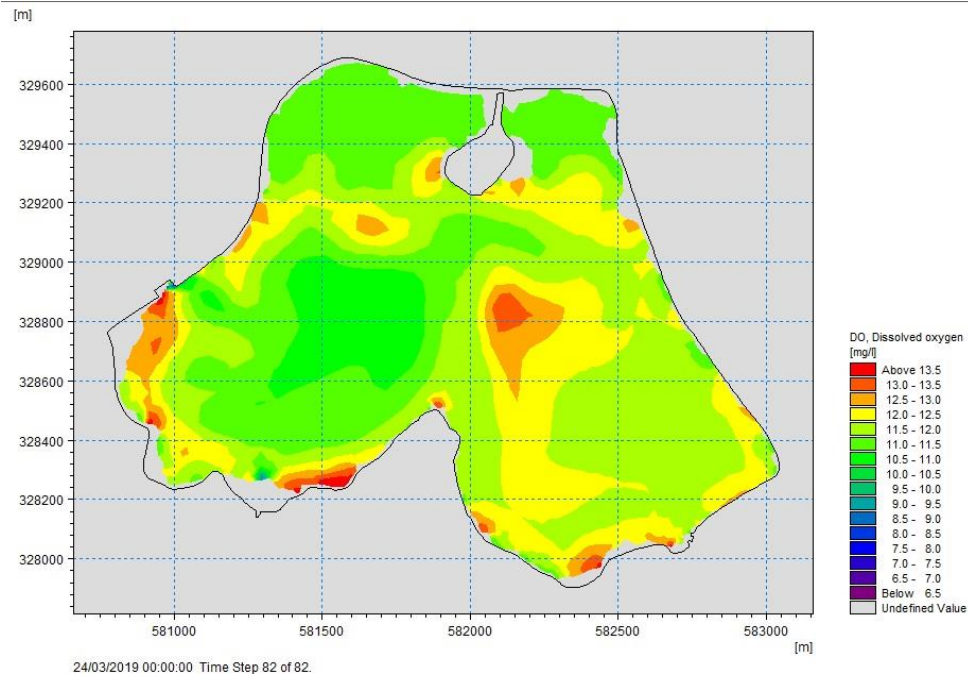
c) dissolved oxygen



Concentration of DO in lake after one month from starting the simulation.

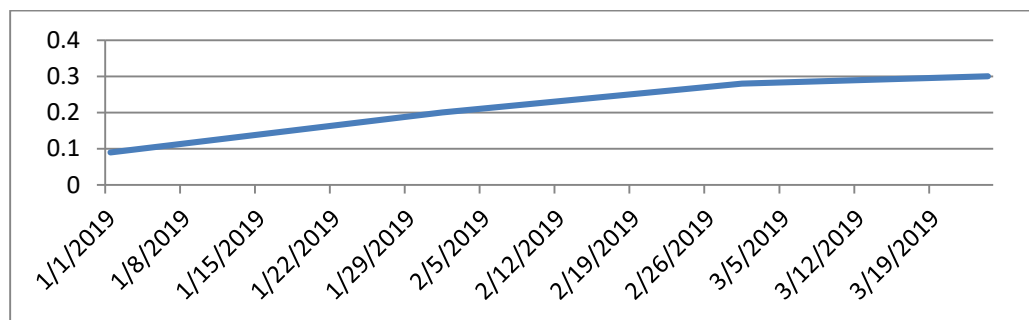


Concentrations of DO in reservoir after two month from starting the simulation.

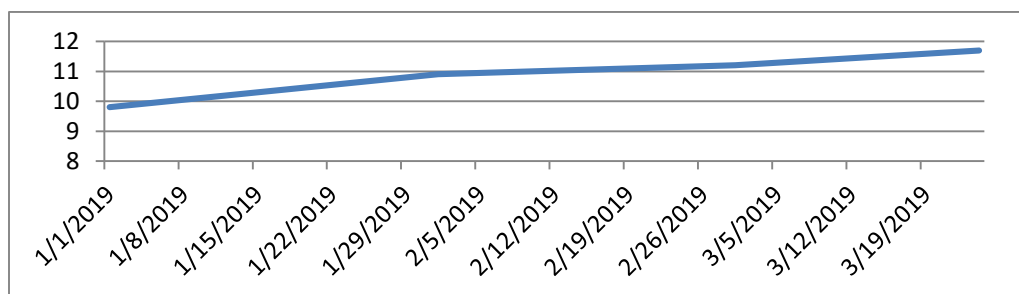


Concentration of DO in the reservoir at the end of simulation (3 months).

From the simulations above we can find the relation between dissolved oxygen and phytoplankton in the center of the reservoir. And how the productivity of phytoplankton will increase the amount of DO in reservoir.



The growth of phytoplankton population in Lacul Morii reservoir.



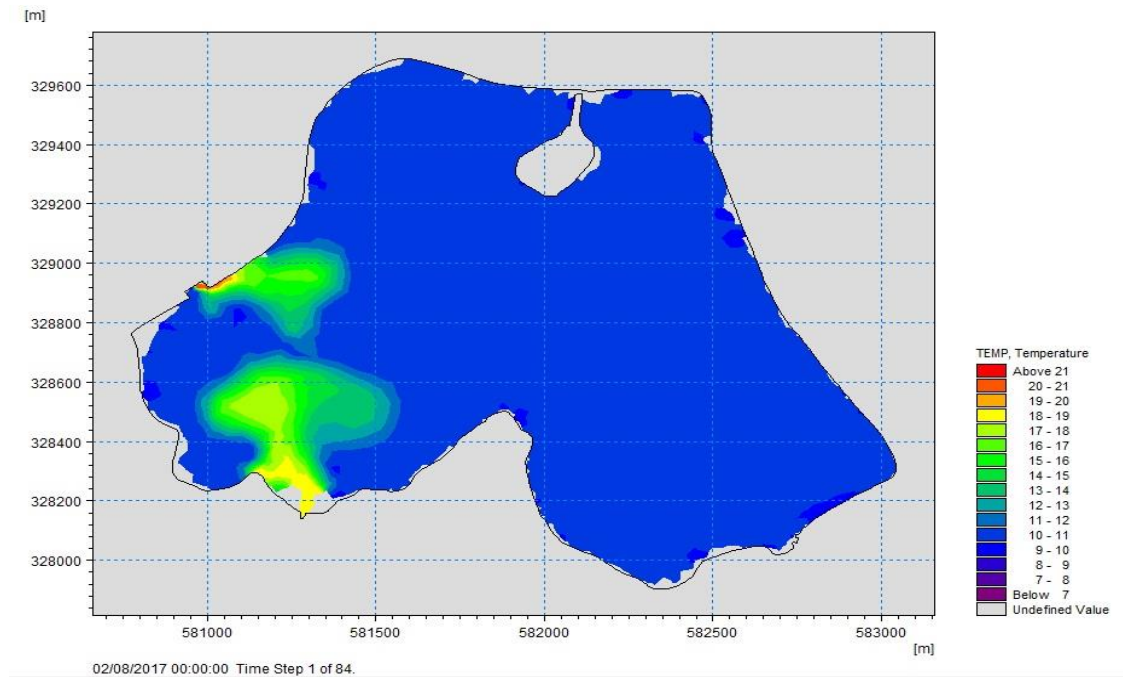
The growth of DO concentration in Lacul Morii reservoir.

- 6) Simulation for distribution of water temperature in Lacul Morii reservoir in the period (01/08/2019 – 24/10/2019)

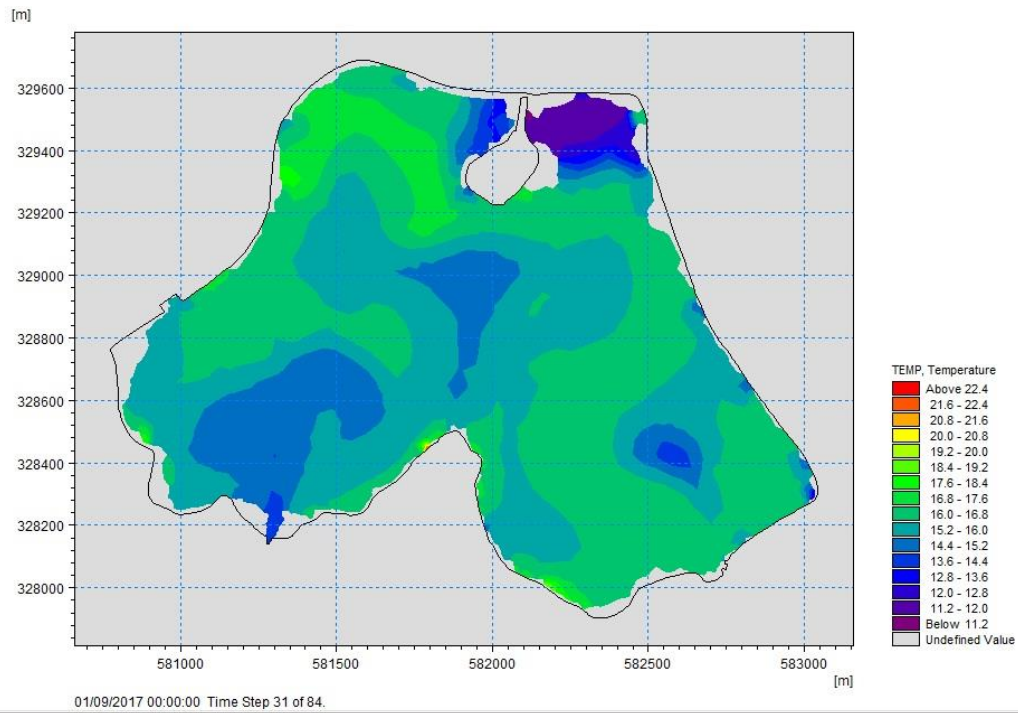
Table 5 : data of water temprature

| Data                  | Source    | Temperature C <sup>0</sup> |
|-----------------------|-----------|----------------------------|
| 17/08/2019            | Dambovita | 21                         |
| 07/08/2019            | Dam       | 27                         |
| 01/08/2019            | Arges     | 19                         |
| 14/09/2019            | Dambovita | 16                         |
| 14/09/2019            | Dam       | 18                         |
| 02/09/2019            | Arges     | 14                         |
| 23/10/2019            | Dambovita | 12                         |
| 09/10/2019            | Dam       | 10                         |
| 01/10/2019            | Arges     | 11                         |
| 01/08/2019-24/10/2019 | Midle     | 10                         |

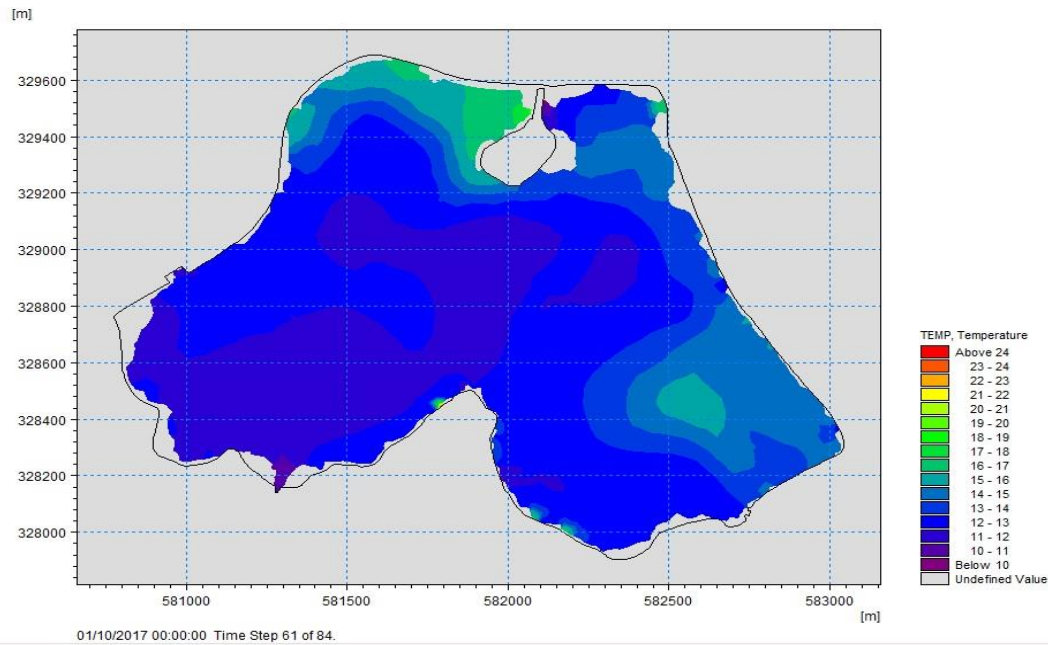
In this simulation we will see how the temperature of water will spread in the reservoir for a period of 84 days . Q arges (3 m<sup>3</sup>/s), Q dambovita (7 m<sup>3</sup>/s), Q defluent (10m<sup>3</sup>/s). Water level 82m.



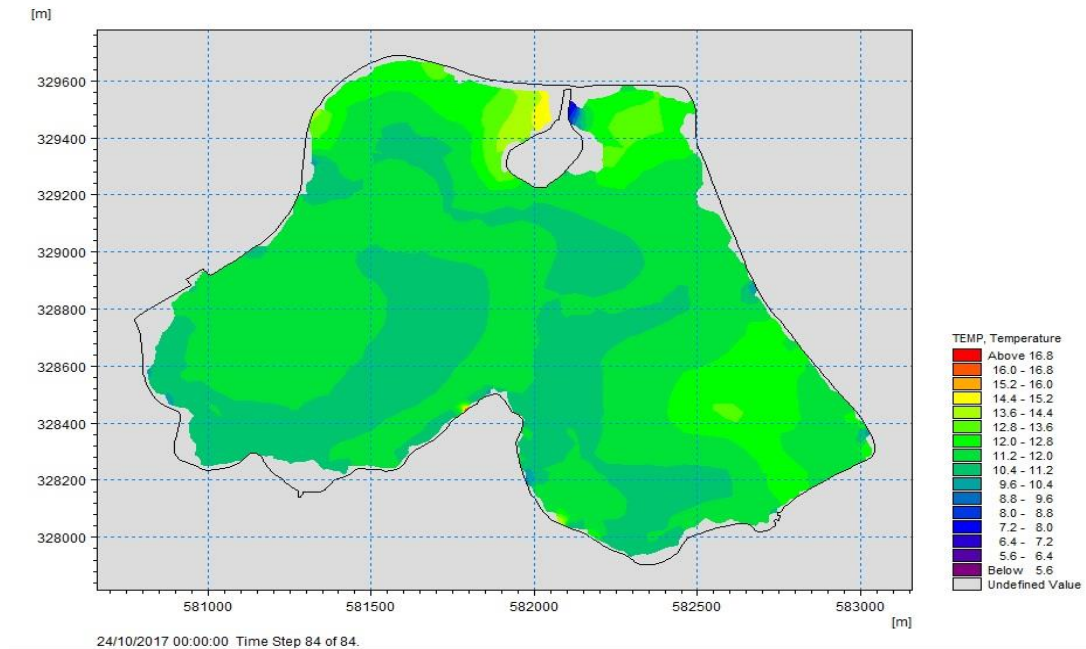
Temperature distribution in reservoir after one day from beginning of simulation.



Temperature distribution in reservoir after one month from beginning of simulation.



Temperature distribution in reservoir after two months from beginning of simulation.



Temperature distribution in reservoir at the end of simulation.

The changes in water temperature can disrupt the life cycles of aquatic creatures. The natural river affects the amount of DO and suspended solids it contains and influences the chemical reactions.

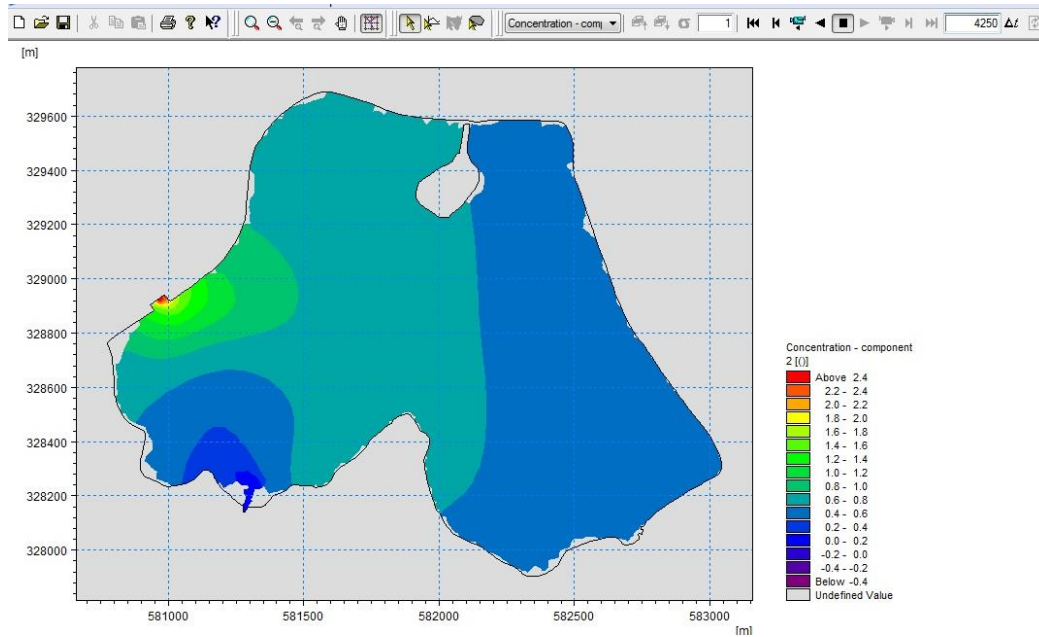
#### 7) Simulation Concentration for petroleum products

Oil is one of the most dangerous pollutants, as a small amount of it is enough to threaten the lives of humans and other living organisms. Because of the different density of fluids, the oil either floats on the surface of the water or semi-submerge in the reservoir or river. Likewise, the interaction of petroleum substances with sea water differs due to the presence of salt that changes the density of water.

##### a) Simulation 2013 petroleum products

A pollution on Dambovită river with concentration (0.301 mg/l) and for a month was considered for simulation. We assumed that the water level was constant (82m). The temperature is also constant (13°C). The flow from Argeș (1m<sup>3</sup>/s) and from Dambovită ( 7m<sup>3</sup>/s) and the outflow from the reservoir (8m<sup>3</sup>/s) represent input respectively output for the simulation period.





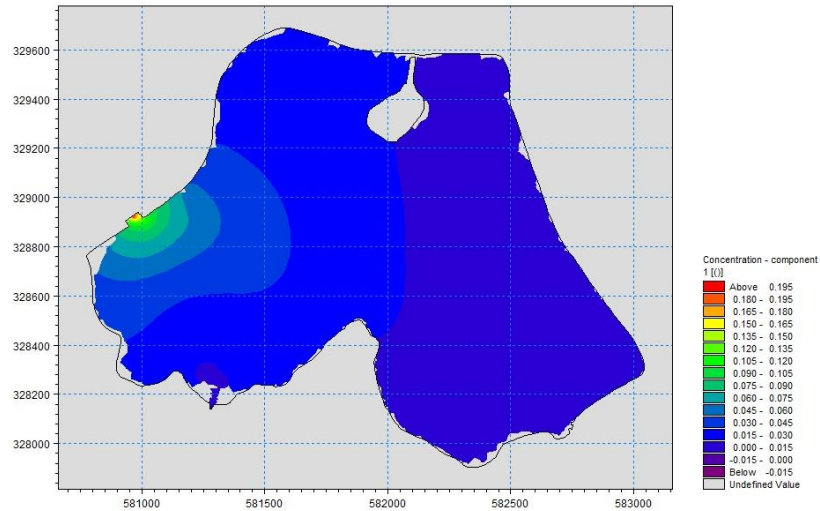
The dispersion of petroleum products after 30 days showing a high value of dispersion of this material in water reservoir.

One week after the start of the simulation, the pollutant concentration reached (0.2-0.3 mg/l) in the middle of the lake. After the simulation ended (after 30 days) the pollutant concentration in the middle of the lake reached (0.9mg/l). As for the dam it reached (0.4-0.6 mg/l) within one month. The dispersion coefficient that we assumed helped this process (0.4). In order to reduce the pollutant's concentration and its effect, the flow should be increased from Arges source (which contains 0 pollutant concentrations and contains clean water). Then the outflow discharge from the reservoir was increased so to be greater than the inflow by using dilution flow from Arges river and evacuation process as a water quality management tool. The same mitigation method can be used for every pollutant in the reservoir.

- Simulation for petroleum products in reservoir after evacuation process for one week

In the first simulation, we have a pollutant entered by Dambovită river at a concentration of (0.301mg/l) for a week. The effluent discharge from the reservoir was increased from (8m<sup>3</sup>/s) to 10m<sup>3</sup>/s, and the inflow from Arges (assuming an uncontaminated source) increased from 1m<sup>3</sup>/s to 2 m<sup>3</sup>/s while maintaining a steady flow from Dambovită 7 m<sup>3</sup>/s.

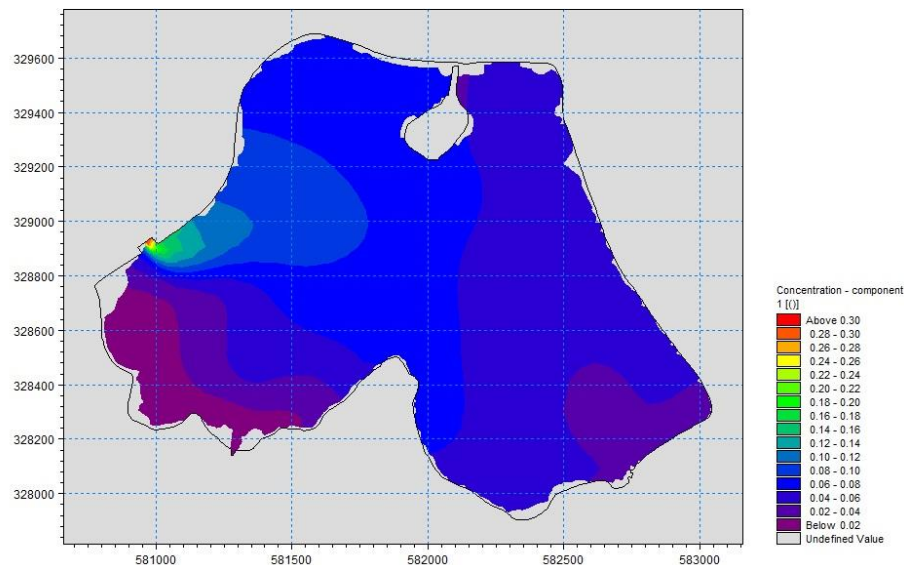
One week after the pollutant enters into the reservoir through Dambovită river, and after increasing the effluent flow and increasing the flow from Arges, we notice:



Dispersion of petroleum products in the reservoir at discharge defluent  $10\text{m}^3/\text{s}$ , surface elevation 81.2 m.

- The water level has decreased from 82m to 81.2m .
- The concentration of the pollutant reached (0.045-0.06 mg/l) in the middle of the lake, meaning that the concentration was less than what it was in the previous simulation (the pollutant concentration was 0.2mg/l).

In the second simulation we assumed the entry of the same pollutant with the same concentration and the same conditions, but the outflow was increased from  $8\text{m}^3/\text{s}$  to  $13\text{m}^3/\text{s}$  , and the flow coming from the Arges increased from  $1\text{m}^3/\text{s}$  to  $3\text{m}^3/\text{s}$  and the same flow of Dabovita was preserved  $7\text{m}^3/\text{s}$ .



Dispersion of petroleum products after evacuation at discharge defluent  $13\text{m}^3/\text{s}$ , surface elevation 79.8 m.

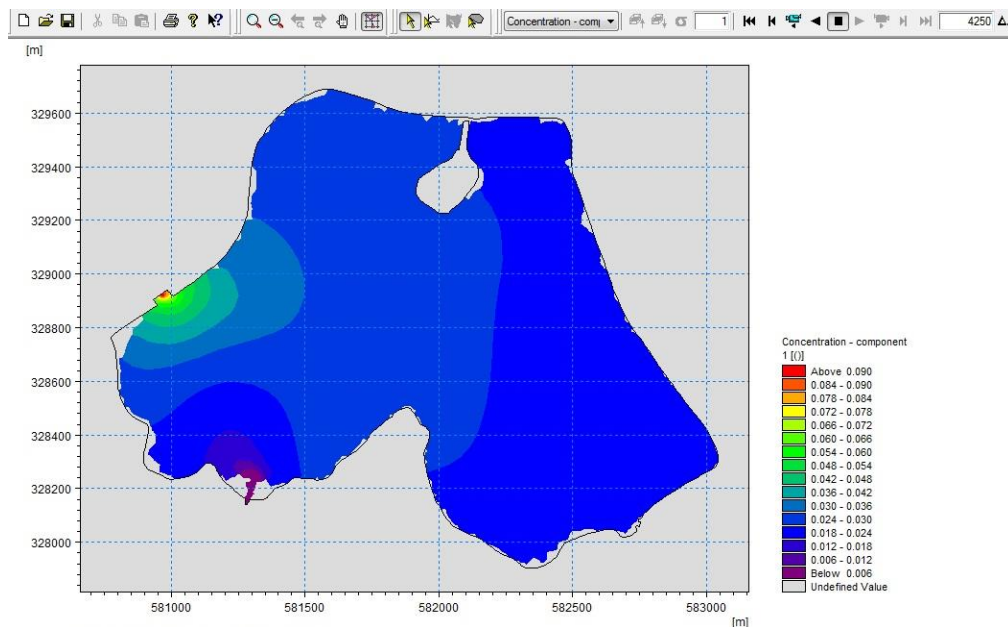


After the simulation is over, we notice that the water level has decreased from 82m to 79.8m. The concentration of the pollutant reached (0.06-0.07 mg/l) in the middle of the reservoir, and also reached (0.01-0.02) at the dam area.

In both previous simulations, we obtained good results to remove the pollutant as soon as possible from the reservoir by increasing the inflow of Arges and increasing the outflow, especially in the second simulation where the pollutant concentration reached the lowest levels at the dam area and at Arges entrance.

#### b) Simulation 2015 petroleum products

A pollution on Dambovită river with concentration (0.06 mg/l) and for a month was considered. We assumed that the temperature is constant (22°C). Other input data: the flow from Arges (3m<sup>3</sup>/s) and from Dambovită (7m<sup>3</sup>/s) and the outflow from the reservoir (10m<sup>3</sup>/s), water elevation constant 82m, The inflow is equal to the outflow and evaporation and precipitation are assumed zero. The purpose of this simulation is to know the effect of pollutant on water quality after a period of time and comparing it with the previous simulation results (when the pollutant concentration was 0.301 mg/l) for the same period of time.

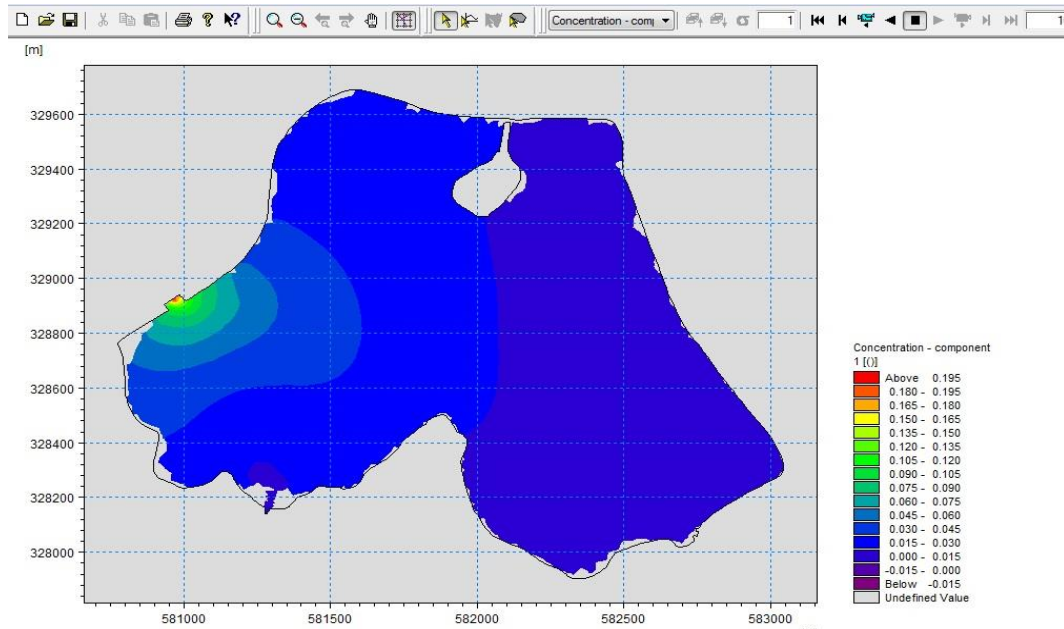


Petroleum products in reservoir after 30 days.

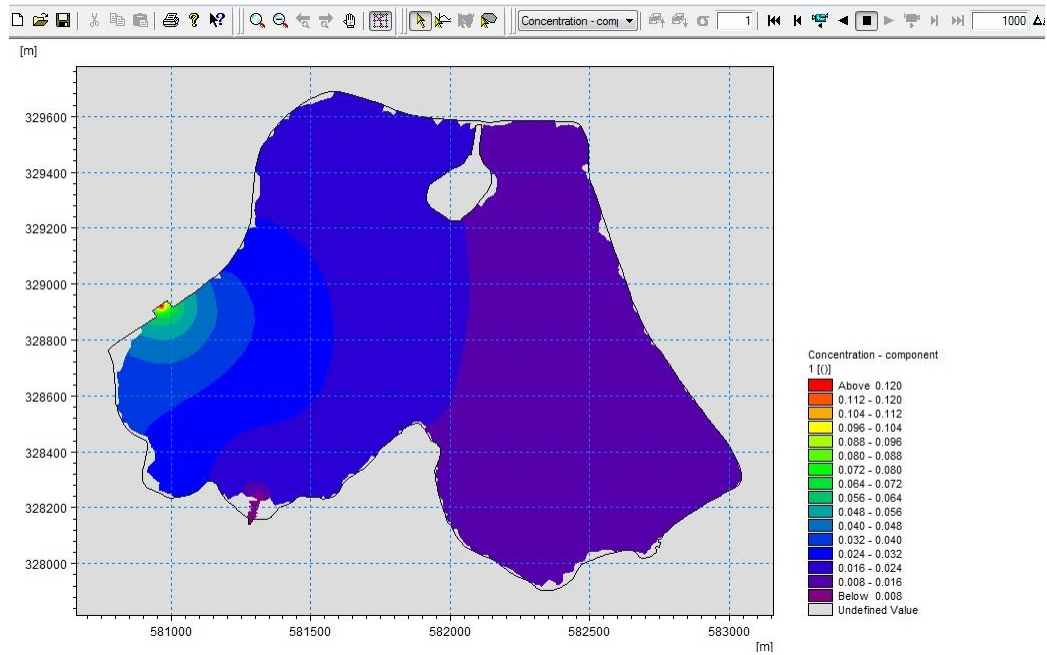
After the simulation is over, the pollutant has spread in the lake (from the source to the dam area), the pollutant's concentration in the middle of the lake has reached (0.03-0.035 mg/l) which is much less than the previous simulation, when it reached 0.9mg/l). In the area of the dam arrived a flow with low concentration (0.015-0.03 mg/l). The concentration of the pollutant in this case from Dambovită river was low. The entry of a pure water source from Argeș helped to reduce the effect of the pollutant. With this process continuing, the pollutant will remain less concentrated without the need for large quantities of outflows.

- Comparison of dispersion rate effect for transport model on petroleum products for one week .

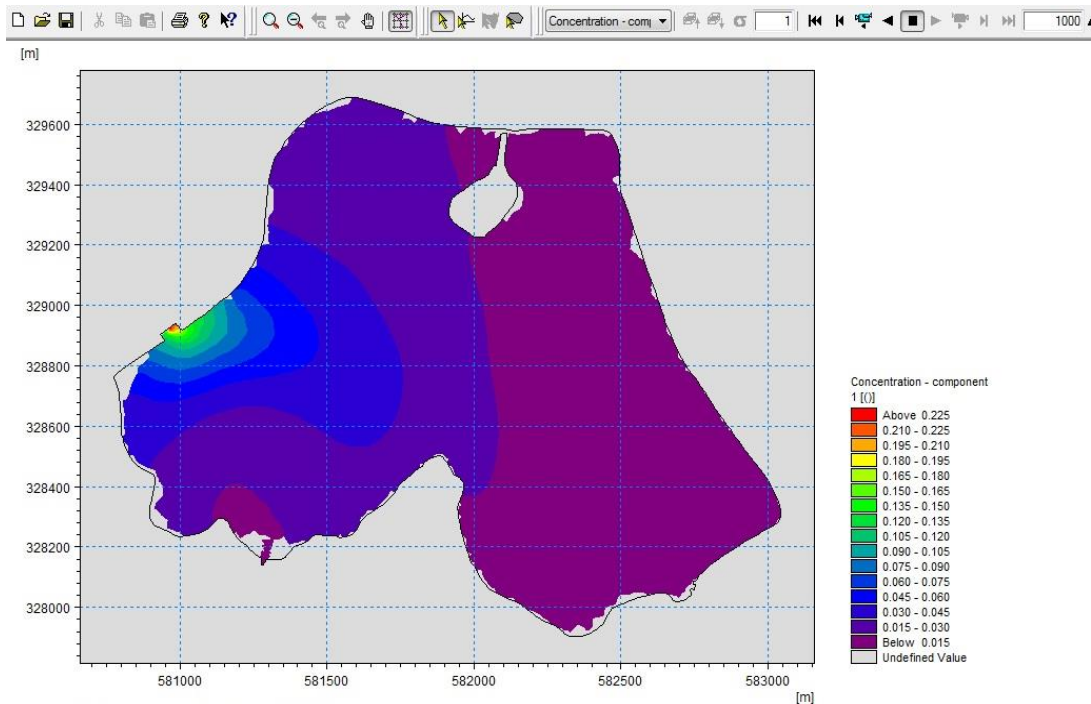
In the following simulations, we used different values of the dispersion rate of the petroleum pollutant to study the effect on the pollutant and its spread in the reservoir. The simulation conditions were constant: the Dambovită flow ( $7\text{m}^3/\text{s}$ ) , Q Argeș ( $3\text{m}^3/\text{s}$ ) and the Q diffluent ( $10\text{m}^3/\text{s}$ ). The water elevation is stable (82m) and the temperature is constant( $18\text{C}^0$ ). The simulations time 7 days. The concentration of the pollutant entering from Dambovită (0.301 mg/l) degree of evaporation and precipitation is zero. The dispersion rate was used as follows (0.8; 2,0; 0.4)



The effect of dispersion rate at 0.8. The concentration of the pollutant in the middle of the lake reached (0.02-0.04mg/l) and at the dam area it reached (0.015-0.02 mg/l)



The effect of dispersion rate at 2.0. The concentration of the pollutant in the middle of the lake reached (0.04-0.05mg/l) and at the dam area it reached (0.016-0.025 mg/l).



The effect of dispersion rate at 0.4. The concentration of the pollutant in the middle of the lake reached (0.015-0.03mg/l) and at the dam area it reached (>0.015).

Through the previous simulations, we notice the effect of dispersion rate affecting the presence of pollutant concentrations in the reservoir, but to a small degree, the lower dispersion rate lead to lower contaminant concentration in the water surface. But its effect is not very large, as the difference between the concentrations of the pollutant when the dispersion rate was 2.0 and the concentrations when the dispersion rate 0.4 can be observed. However, the effect of the dispersion rate of a particular pollutant will be greater at higher concentrations.

## **Chapter 6, Conclusions and personal contributions:**

### **General conclusions**

Consideration of all social, environmental and economic effects, both positive and negative, is the most difficult issue to solve in a manner which is acceptable for all stakeholders.

- The construction of dams and the creation of large reservoirs have a very significant effect in that land and river environment, actually transformed into a new environment. Complex of impacts may be generated on the human, biological, atmospheric and land components.
- Dams have many positive environmental effects. Environmental conditions are improved when water management practices regulate and augment low flows of rivers and streams, decrease erosion, control floods, minimize water waste, cultivate deserts and improve health and sanitary standards. Dams contribute significantly toward fulfilling society's water supply requirements; at the same time, they provide a renewable, nonpolluting source of electric energy.
- Reservoirs entrap sediments diminishing their capacity to regulate the natural flow. However, special sediment handling measures and watershed management practices can and do permit reservoirs to avoid siltation (filling with sediment), thus ensuring their ability to fulfill their intended purposes. All rivers carry suspended solids in greatly varying amounts. A high suspended solids content is a water quality problem thus limiting the use of the water. Although the deposition of solids in the reservoir can improve the downstream water quality, settling of solids in the reservoirs reduces the

solid load downstream. Without a sediment supply, increased erosion of the downstream stream bed will occur until a new equilibrium has been established.

- Large dams contribute to the global warming and induce earthquakes. The methane, carbon dioxide and nitrous oxide emitted by reservoirs is the result of the decompositions of the vegetation and soils flooded by reservoirs, and of the organic matter. The gases are released at the reservoir surface, at turbines and spillways, and downstream of the dam.
- The flooding of a reservoir is often associated with substantial increase in nutrients and the level of minerals which cause, on the one hand beneficial effects such as a higher productivity, but also negative effect including the proliferation of plants, taste and odor problems.
- The eutrophication process, especially in the summer, must be controlled by removing the algae bloom using specific equipment, as well as controlling the nutrient concentrations entering into the reservoir.
- The presence of dissolved oxygen in a river is one of the main tests of good water quality. A high dissolved oxygen content of water is very important to the aquatic life. Water poor in dissolved oxygen can harm aquatic organisms and make water unfits to drink. If low oxygen concentrations are anticipated in reservoirs with heavy metals in the sediments, these toxic substances may be released as a result of anoxic chemical reactions.
- The decomposition of the organic matter from the soil and sedimentation of planktonic organisms may lead to the depletion of dissolved oxygen in the deep layers of the reservoir and the release of heavy concentration of highly toxic reduced substances such as sulphide, ferrous and manganese, as well as organic mercury.
- The water temperature stratification affects directly the amount of dissolved oxygen, influences the chemical reactions and have effects on the biological cycle of reservoir.
- Dams and their reservoirs influence directly and indirectly the environment in all its elements (biotope, biocenosis and ecosystems) and characteristic impact (upstream the reservoir, reservoir area, downstream, in neighboring areas).
- Main effects of damming, perceived in the reservoir are: biotic instability during the first 3-5 years, stimulating bacteria decomposing, reduction of the dissolved oxygen quantity, change of the P and N cycle dynamics, change of the sediment dynamics, modification of

the fish distribution and interruption of their migration ways, supplement of nutrients for the insect larvae, favoring secondary phenomena related to pollution, etc.

### **Main findings and Personal contributions**

- By using Mike Zero software, future forecasts of the water quality in the reservoir can be obtained. Based on the model outputs, it is possible to know the oxygen concentrations in the all parts of the reservoir, as well as to know the concentrations of a specific pollutant and how to control it.
- The concentrations of DO and BOD in the reservoir are strongly depending on the value of reaeration rate and CBO decay rate.
- The wind helps to improve the water quality as a reaeration factor, as the wind helps in the faster mixing process of the concentrations entering into the reservoir, which led to a faster reduction of the BOD values.
- An increase in the outflow from the reservoir in case of an accidental pollution will not significantly influence the chlorophyll concentrations in the reservoir.
- An increase in the amounts of chlorophyll increases the amounts of phytoplankton and thus an increase in the oxygen concentrations. This occurred in simulation of chlorophyll and phytoplankton; when the phytoplankton concentrations increased from 0.05mg/l to 0.3 mg/l, the oxygen concentrations increased from 9.18 mg/l to 12.5 mg/l during the same period of time.
- Higher temperatures help greatly with increasing chlorophyll concentrations, but it must be controlled to prevent occurring the eutrophication process.
- The concentration and spread of any pollutant in water surfaces is directly affected by the change in the value of dispersion rate.
- The mass of the petroleum pollutant entered into the reservoir can be reduced by increasing the outflow from the reservoir. But the increase must be in reasonable quantities and commensurate with the water level and inflows. However, this operation will lead to a quick spread of the pollutant. The increased outflow along with the decreased water level help the pollutant spread faster towards the middle of the reservoir; when the outflow increased from 8m<sup>3</sup>/s to 10m<sup>3</sup>/s, the pollutant concentration reached 0.045mg/l in the center of the reservoir, but when the outflow increased from 8m<sup>3</sup>/s to 13m<sup>3</sup>/s, the pollutant concentration reached 0.06 mg/l.
- When low concentrations of a certain pollutant, such as petroleum, enter into the reservoir the inflow that contain water with good water quality (Arges river for instance) should be increased for dilution and evacuation purposes. This measure should be



accompanied by a similar increase of the outflow to maintain the water level in the reservoir.

- The values of pH, which ranged between 6-8, were considered ideal for the period under study. Lower values than 7 (acid character) causes great damage to the aquatic life.
- Lake Morii has a privileged situation, being fed not only by Damabovita but also by Arges river, which has clean water. The introduction of good quality water from Arges helped greatly by ventilating the reservoir and reducing the values of BOD during pollution episodes. As well it has a major contribution to reducing the concentration of petroleum pollutants products.
- BOD concentrations must be controlled, especially in the summer. The highest levels of BOD concentrations were recorded during the summer for the period of time that was studied, greatly affecting the quality of the water inside the reservoir. In most countries of the world the BOD value should be less than 2.5mg/l.
- Certain methods must be used to increase ventilation in the lake in times of need, such as turbines or aeration pumps, which are of low cost in relation to the environmental benefit. Based on the simulation results, the oxygen concentration increased after the degree of reaeration rate was increased, thus improving water clarity and aquatic life.
- From my point of view, more attention and care should be paid to the quality of the water in Lacul Morii. As the outflow reaches the center of Bucharest (Piața Unirii), the poor water quality in the lake can lead to an unacceptable appearance for some areas of the city. Increasing investment in around Lacul Morii, such as building terraces or sports activities, will increase economic benefits and develop the surrounding areas.
- More accurate results are obtained as the simulation time increases. Therefore, simulations must be done using a high-speed computer to get results faster. At the same time accurate information is a must to create a bathymetry to avoid errors that may occur during use the mike zero software. In this thesis, the Lacul Morii bathymetry was obtained by using the stereo 70 coordinates and ARCGIS environment.
- To get more accurate results, all variables and constants required by the software should be entered, such as precipitation, evaporation, etc. But the biggest challenge is to obtain this data.

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