BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 64 (68), Numărul 1, 2018
Secția
HIDROTEHNICĂ

LIMITING THE INFLUENCE OF THERMAL STRATIFICATION FROM ACCUMULATIONS ON THE DOWNSTREAM BAY

BY

VALERIU ALĂZĂROAEI*

“Gheorghe Asachi” Technical University of Iași,
Faculty of Hydrotechnics, Geodesy and Environmental Engineering

Received: February 20, 2018
Accepted for publication: March 28, 2018

Abstract. Planet's freshwater resources are scarce, because 97.3% of the total water is salty while the fresh water is limited to only 2.7%. Besides, it is unevenly distributed in the world.

The water reservoirs created by the construction of dams make possible the accumulation of additional water reserves in deficient countries; but they also have other purposes, such as generating electricity and the hydrological regularization of water courses.

In terms of environmental impact must be taken into account basic elements such as the surface of the water accumulation and the degree of change in water flow, including both habitat modification and other elements specific to the ecosystem and how ecosystems are affected downstream.

In the current context of limiting the negative influence of human activity on the environment, besides the quantitative satisfaction of the water requirements, it is necessary to meet the requirements of water based on quality criteria, including the downstream discharge.

Keywords: dimictic lakes; stratification of lakes; downstream water; environment; water reservoirs; hydrobiology.

1. Introduction

At the planetary level there are about 45,000 large dams (large dams are considered those taller than 15 m) and over 800,000 small dams with an overall

*Corresponding author: *e-mail*: valeriualazaroaei@yahoo.com

storage capacity of 7,000 km^3. The existing dams ensure a 70% increase in the availability of freshwater. Thus, the main reasons for building dams are: facilitating the use of available water, reduction of water level variability of different watercourses, storing water in case of crisis due to some prolonged droughts, regulation of flow for different uses, increased safety in cases of catastrophic flooding, the generation of electric power.

The impact of dams on downstream ecosystems is complex and has both social and environmental components. If the human population in areas affected by construction of a dam must be evacuated, social impact is simple, yet very drastic. The downstream impact is rather represented by a set of impacts related to the time period and volume of changes of the river level, the quality of the river bed, and the connections between hydrological conditions and flooded areas.

The impact of dams on downstream areas clearly involves substantial changes in the dynamics of some parameters and characteristics of the environment. The precise estimation of the effects of a dam construction at the time of its design is almost impossible. There is a high level of uncertainty in terms of prognosis and the type of impact for different areas and the evolution in time of the negative effects.

This mode of operation is particularly met in the case of accumulators whose main role is to ensure a minimum flow downstream during periods of drought. Even in this limiting situation, to ensure an unspoiled biotope downstream of the dam, the evacuated water must meet certain quality criteria. A concrete example of this type is the Lavaud dam - France. In summer, a strong stratification phenomenon occurs in the lake, which also causes an uneven distribution of water quality in the lake.

It is necessary to find a mode of exploitation that allows the downstream discharge of a flow having the quality parameters controlled according to the requirements of the beneficiaries. This is possible if the dam is provided with three water inlets at different rates. The difficulty lies in the fact that the evacuated flow is controlled by a single valve, with no data on the distribution of the flows through the three openings of the plugs.

In this paper I will focus on the knowledge of the ABA Prut-Birlad patrimony and finding solutions for limiting the influence of the thermal stratification from accumulations on the downstream bay.

2. Thermal Stratification of Water

The evolution of the thermal structure of a reservoir is complex. In the case of a natural lake, the weather conditions are the major component of water stratification. In the case of a dam, the destabilization of water bodies caused by volume changes in inputs or withdrawals plays an important role. In the literature, the term water stratification is reduced to the thermal approach, although the same phenomenon also concerns dissolved oxygen.

Lakes are not just water tanks uniformly mixed. They are in fact highly dynamic systems, characterized by complex processes, and a variety of subsystems that vary seasonally and according to longer cycles. Stratification of lake water is due to variations in density, caused by temperature variations. The density of water increases with decreasing temperature and reaches a maximum at about 4°C. The result is a thermal stratification; distinct layers tend to be formed during the summer months, in deep lakes. The phenomenon of stratification of lake water can prevent the dispersion of effluents from the tributaries and thus increases the concentration of pollutants near the shore. However, in most cases, the lake water remains mixed throughout the winter.

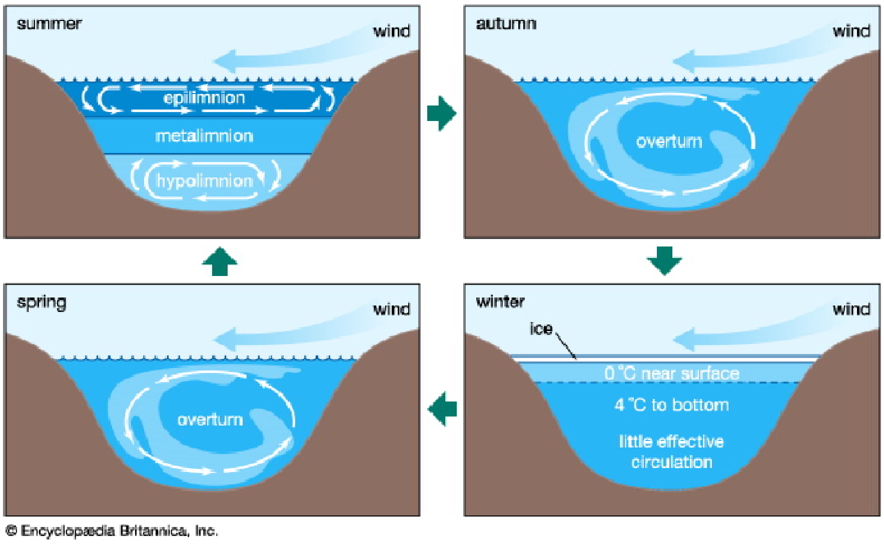

Fig. 1 – Stratification of deep lakes in the seasons of the year.

Understanding environmental processes is the first step to forecasting such evolutions. Furthermore, a good understanding of stratification is required not only to prognosticate the future of our lakes but also to better interpret the past from lacustrine sediment cores (Kjensmo, 1988; Brauer, 2004).

A considerable portion of the lakes on Earth are permanently stratified. Deep lakes especially show this feature. As a consequence, many of the largest lakes (*e.g.*, Caspian Sea, Baikal, Tanganyika, Malawi-Nyasa) and many middle size and small lakes do not circulate completely in the vertical and do not show a homogenized, overturning water body at any time during the annual cycle. The permanent stratification has decisive impact on the redistribution of dissolved substances, such as nutrients or oxygen, and hence determines the biocenosis that can form in the lake (Gaedke *et al*., 1998; George & Hewitt, 2006; Thackeray *et al.*, 2006).

Observations of stratified lakes probably date back to long before the start of scientific literature on the environment. The Romans likely already knew about stratification.

In Romania, the "Romanian Waters" National Administration has in its structure 11 Water Basin Administrations, organized on hydrographic basins, the National Institute of Hydrology and Water Management and Complex Exploitation Water storage of Costeşti Rock. I asked for field measurements at office Operation monitoring parameters for pollutant, temperatures and so on, but the request for concrete data (field measurements) has not been honored so far. Having the example of the Lavaud - France dam that shows the necessary parameters, I will use this data to build the two computational programs. The first allows us to calculate the flows through the three openings according to their size, the water level in the lake and the flow or opening of the bottom drainage. The second program indicates the flows to be taken through each of the three openings and the openings dimensions, so that the water quality criteria are met.

2.1. Pârcovaci Reservoir

Is located in the water basin of Prut and is located on the Bahlui River.

The lake reservoir has a volume of 17.9 million cubic meters at the maximum level of verification ($1.2 \times 0.1\%$) corresponding to the share of 178.67 mdMN and a volume of 7.9 million cubic meters at the corresponding level of calculation (1%) Share of 177.23 mdMN.

The dam is made of homogeneous soil, with trapezoidal section, protection from upstream concrete slabs. The main construction features are as follows:

– the maximum length of the dam H = 25.00 m;
– length of the canopy: L = 290 m;
– crown width: l = 6.75 m;
– crown ground: 178.70 mdMN;
– capacity overflow: 176.00 mdMN;
– normal retention level - 171.00 mdMN - 2.750 mil m^3;
– ridge level D.A.M. - 176.00 mdMN - 6.400 mil m^3;
– leveling - 178.70 mdMN - 8.750 mil m^3.

2.2. Puşcaşi Reservoir

- Location Water Basin of Prut in the Racova river meadow The nearest town - Vaslui (about 7 km).
- Characteristics:
- dam - from homogeneous land (clays and sandy clays);
    - crown length - 890 m;
    - maximum height - 16 m;
    - crown width - 5 m;
- storage lake - characteristic levels and volumes:
- normal retention level - 115.50 mdMN - 6.2 mil m^3;
- ridge ridge level - 116.83-117.14 mdMN - 9.91 mil m^3;
- coronation level - 119.50 mdMN - 17.5 mil m^3.

2.3. Mitigation Solution for the Influence of Water Stratification Phenomenon in Lavaud Lake on Downstream Waters

Generally, the aim of operating a storage lake is to ensure the consumers water needs and/or to prevent the effects of drought or flood. In the case of Lavaud dam, located in the Department of Charente (France), it is necessary to take into account the phenomenon of water stratification for its operating system. This operation system is facilitated by the fact that the dam is provided by construction with three water intakes located at different levels. Studies on water stratification, and thus on stratification of water dissolved chemical elements, are largely conditioned by the precise knowledge of the flow rates imposed by three openings of the dam. Similarly, temperature and, generally, the quality of water discharged into the lake can be verified only in terms of a precise knowledge of the flow discharged by three openings. The flow that passes downstream the Lavaud dam can be monitored by a single remotely located valve. In this situation there is no information on the flow distribution through the three openings, therefore, the operation of the dam, taking into account the phenomenon of stratification, is difficult.

A mitigation solution for downstream problems caused by water stratification consists of determining the following (problem solved by two specially designed computer programs):

i) the flow rates collected by the three openings, depending on the flow discharged through the bottom outlet, in order to provide solutions to the operational problems of the dam;

ii) the flow rates as well as the openings of the three valves, made under conditions imposed on quality of evacuated water.

Location and Specifications of the Dam

The dam is located in the Lavaud Department of Charente, at the birth of the Charente River. The dam has a capacity close to 10 million m3. The structure of flow control device consists of an intake tower with three openings (including the bottom outlet) located at 220, 215 and respectively 211 NGF respectively. The openings sizes are: for the two at the top 0.80 m × 0.80 m, and 1.10 m × 0.80 m for the bottom valve. The bottom outlet duct is common with the spillway. The drain flow and return flow are regulated by two separate valves: a valve covering the range of small flow: 50 L/s at 1 m m3/s, and a valve covering the large flow: 800 L/s to 12 m^3/s.

Management of the Dam

The Lavaud dam (Fig. 2) stores water during winter. The water level in the lake was at the lowest end in September In late April, the dam reaches its maximum level, stabilized at around 224 m (NGF Level General of France).

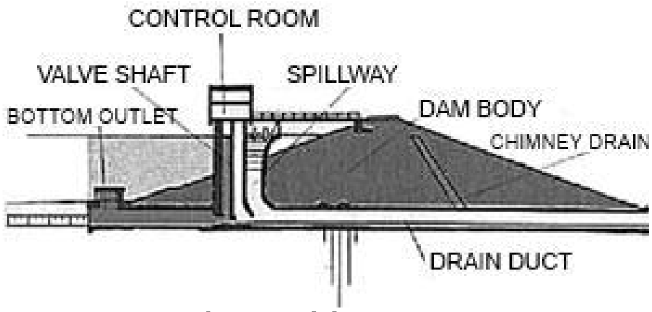

Fig. 2 – The Lavaud dam – cross section.

a) *Dam management - imposed requirements*

During the filling period, the in stream flow will be in any case below the 1/10 of the annual average flow, or below 60 L/s or the sum of the flows entering the reservoir by Charente river and its tributaries, whichever is lower at 60 L/s.

Regarding Lake Lavaud, thanks to the studies undertaken by Christophe Guglielmin, the stratification of the water was established using an original method. The stratification for two consecutive years had the following development: June 1...June 22, no real stratification is recorded; June 29...July 12, stratification begins essentially with that of dissolved oxygen; July 20…August 23, stratification is well defined, corresponding to the warm period of the year; August 16...September 6, the studies indicate a good stratification of dissolved oxygen; the water withdrawal of August 30th indicates a return to original state in the intermediate zone reflecting the end of a state of stratification; September 13…September 27, these withdrawals characterize the absence of stratification. The stratification for second year is similar.

The tracking method used to provide indications is fairly accurate but it has still significant inaccuracies since the inputs and outputs of water are not precisely known. The water inlets are positioned at levels corresponding to their density layers, carrying with them the surrounding water bodies. The water catchment mobilizes a horizontal layer of the reservoir whose height depends on the flow and thermal stratification.

To increase accuracy, a method for calculating the flow rates was required.

b) *The main physicochemical parameters of water and classification of the lake*

Dam LAVAUD, like most reservoirs in temperate regions, is presumably of dimictic type. This means that it undergoes complete mixing in the fall and spring while it has stratification in summer and winter. The main indicators of water quality are: temperature, dissolved oxygen and percentage of saturated oxygen, pH, conductivity, total suspended solids (TSS) and total organic carbon (TOC); ammonium, nitrate and phosphate, the Kjeldahl Nitrogen, the BOD5, COD and nitrite (Fig. 3). The maximum values of the main dissolved elements in Lavaud Lake are shown in Table 1.

Table 1
The Main Elements Dissolved in the Water Of Lavaud Lake with their Maximum Values, Recorded at Maximal Depths, Corresponding to the Water Discharge Level of 209 M

Element	2005 – Maximum concentration, [mg/1]	2006 – Maximum concentration, [mg/1]	Normal value, [mg/1]
Total Fe (Fe2+, Fe3+)	28.54	34.94	0.01...2.0
MnJ+	4.25	6.77	0.01...2.2
Ortho POz	0.5	0.67	0.01...14
NH£	5.67	8	0.1...8
F~	3.699	0.67	0...5
cr	10.77	10.54	0.5...2
NOz	0.81	0.46	0.1...2
NO^	3.429	4.17	5...80
5042~	8.34	5.31	250

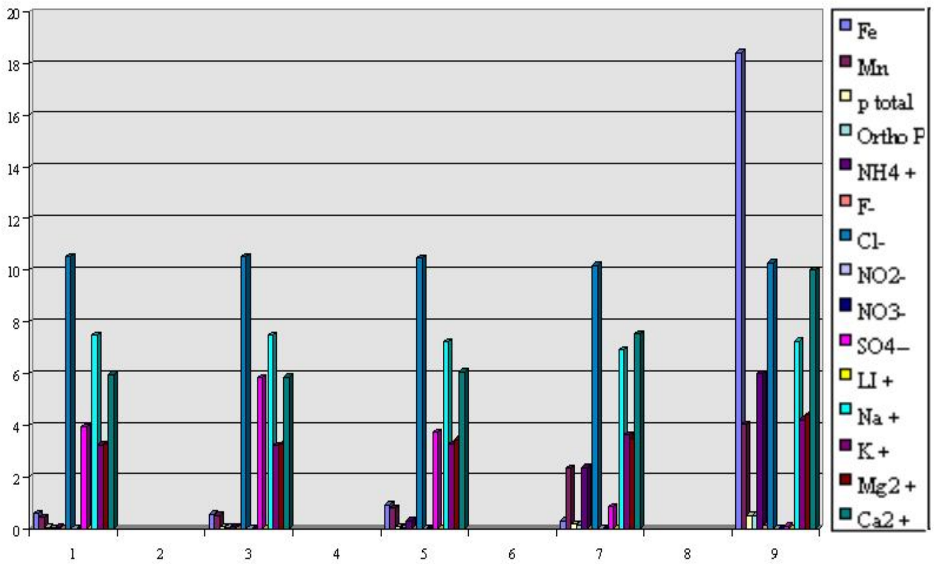

Fig. 3 – The evolution of dissolved elements in the Lavaud lake, second year, [mg/l].

c) *Problems needed to be solved for Lavaud dam operating*

These problems have in view:

A – calculation of withdrawal rates;

B – minimization of pollutants dissolved in downstream water of a dam at an imposed temperature using Simplex method.

A. *Calculation of Withdrawal Rates*

In the case of Lavaud dam there is only one remote control valve to adjust flow rates and evacuated three water intakes located at different levels. To operate the dam taking into consideration the real stratification of water, it is necessary to know the three flow rates that pass through the openings in the situation in which the height of the openings and the value of evacuated flow is modified.

To solve this problem, we matched the expressions of flow rates that pass through the three openings, with the flow discharged through the bottom outlet, the charge for each opening being expressed in terms of the variable height of the water tower. Varying the height, at a given time, the equality of both terms of the relationship is obtained. In that moment, the appropriate values for the flows $Q_1...Q_3$ represent the flows are looking for:

$$Q_{\mathrm{botton}} = Q_1(z) + Q_2(z) + Q_3(z), \tag{1}$$

or

$$\mu_{\mathrm{fond}} b_{\mathrm{fond}} h_{\mathrm{fond}} \sqrt{2gz_{\mathrm{fond}}} = \mu_1 b_1 h_1 \sqrt{2gz_1} + \mu_2 b_2 h_2 \sqrt{2gz_2} + \mu_3 b_3 h_3 \sqrt{2gz_3}, \tag{2}$$

where: b_i, h_i are the intakes openings; μ_1 – the flow coefficients, z_i – the variable loads + linear head-losses of the openings at a given time.

B. *Minimization of some pollutants dissolved in downstream water of a dam at an imposed temperature using Simplex method.*

The operating conditions of the dam have been imposed in order to guarantee a minimum downstream flow, with respect to the quality parameters of the discharged water. The quality criteria imposed are often contradictory, because of the previously presented stratification phenomenon. For example for a small concentration of iron dissolved in water, at the same time is required to avoid exceeding a maximum temperature for the downstream water in the river. Iron ion is found in small amounts on the surface of the lake, but the water is colder at the bottom of the lake where the iron concentration is maximal. Obviously, in this situation it is necessary to find an optimum which is framed within the imposed operating conditions.

Precisely, one must find the flow rates discharged by three (or two, in the last period of the summer) water intake openings, whilst the mixture meets these requirements. We solved this problem using the well known Simplex Optimization Methods.

3. Computer Programs for the Proposed Dams Management

To solve the first problem, the operation of the dam taking into account the real situation of water stratification, that is, to know the three flows that pass through the openings, the first computer program was designed. It calculates the flows that pass through the three openings of the tower, when one changes the water intake openings and the flows that pass through the bottom outlet. Normally, the values of the flow passing through each opening cannot be measured directly by remotely operating the bottom outlet.

The entering data are: the lake water surface lavel, the downstream flow, the height of the three opening.

The flow coefficients are entered as constants as in the code lines. For a better accuracy, their values should be verified by field measurements. As output data there were obtained the flow discharged by three (or two for low lake levels) openings.

The second program is a program that solves the problem of minimization of a certain pollutant, respecting the restrictions downstream the dam. The entering data are: water level in the lake, concentrations of the contaminant (*e.g.*, iron) in front of each opening, maximum values allowed for restriction (*e.g.*, the temperature downstream the dam).

As output data the program gives the flows that must be evacuated by the three (or two for low lake levels) openings and the minimum value of the pollutant resulted under the given conditions. The code lines of the first program can be provided if required.

3.1. Results and Disscussions

3.1.1. *Some Results Regarding the Calculation of Flow Rates Running the Program No.1*

The program was run having as input data the flow rates evacuated by the bottom outlet during the second year. As there is no data on the dimensions of the openings for this period, several tests for different values of the openings were done. Subsequently diagrams of flow rates by three openings for the same opening of 10 cm for all outlets are presented. Note that the flow rates, which go through the catchment at the lower level, is increasing in the same time the discharged flow is higher, whilst the flows passing through outlet at a higher level is diminishing. The flow rates passing through the middle outlet remain almost constant, with a slight tendency of growing. It means that in general for the same opening of the catchment, mainly water at a lower level is discharged downstream the dam. That is, the quality of discharge water will be influenced by the quality of water in these layers.

The changing of the flow rates evacuated by three openings is more evident for flow rates larger than 0.5 m^3/s. At 1.35 m^3/s appears a delimitation of evacuated flows due to the too small openings of the catches. As the evacuated flow rates exceeded this value, in reality, it appears that the openings were larger.

Since running the program for openings of 0.2 m height, does not produce limitations of the withdrawal, we can say that such a situation may be similar to that existing in the second year.

Obviously an infinite number of combinations between the openings are possible, this mean that thanks to this program it is possible to know the real rates of water withdrawals, and the actual modeling of sedimentation can be possible. We recall that the results obtained using this program can become more precise if real values of the discharge coefficients are determined by direct measurements.

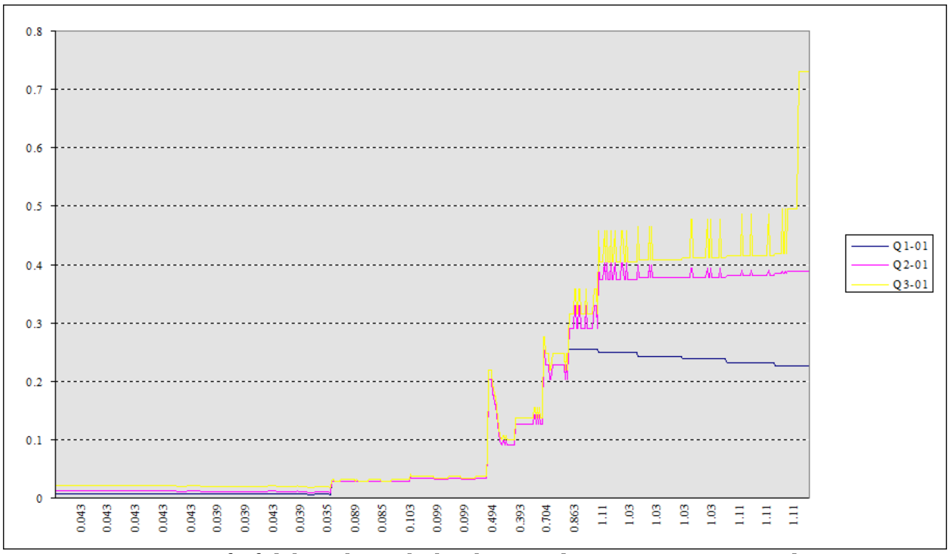

Fig. 4 – Graf of debits through the three outlets in summer second year.

3.1.2. *Some Results as Regards the Calculation of Flow Rates for a Requested Downstream Water Temperature of 15°C,and a Minimal Iron Concentration, with the Program no. 2*

During the summer, the water user, situated downstream of the dam, requests that the water delivered by accumulation meet certain conditions. The most common requests are from the *Fishermen's Association* that relate especially to the temperature of water released from the lake.

A modeling for the months of July and August in the first year was carried out, for a required water temperature of 15°C under the conditions of minimizing the total iron content. The requested flows comprised between 0.5 and 2 m^3/s. The program allows the processing of all values encountered in any real situation. Obviously, up to now, it was difficult to fulfill these demands especially since the flow discharged through each opening were unknown.

The program can be used for any demands since the optimized parameters can be modified at any demand. There are presented the data as a result of running the program, with the recommended flows and openings for the three water intakes of the tower. Regarding the second year, the data are more accurate, since the flows are known.

From the above, it is seen that problem of operating the lake so that its impact on existing wildlife downstream of the dam is minimal, can be solved using two computer programs. Note that starting from the adjusted value of total evacuated flow using the only remotely adjustable valve, the program No. 1 calculates the values of Q_1 - Q_3 flows passing through the three openings (e.g. of 0.1 m) of the dam's intake tower, at different elevations (Figs. 4,..., 6). This is very important because the pollutants concentration varies depending on depth, due to stratification of lake water. From Table 1 we see that at the lake bottom (209 m), the concentration of the pollutants is maximal. For example, Total Fe reaches a concentration of 34.94 mg/L, far exceeding the allowable value of 2 mg/L. As a logical consequence, one can improve the water quality discharged from the lake, if smaller flows are allowed to pass through the bottom opening, where the concentration of the pollutants is maximal. Similarly, the same can be said for another important environmental factor for wildlife that can be adjusted using the flow, namely the temperature of evacuated water. Lower values of the temperature (12º…13ºC) are also recorded at the lake bottom. The required optimal value for evacuated water is 15ºC, while minimizing the concentration of the pollutants. Achieving this minimum is possible using program No. 2. This gives the values of the required heights for the intake tower openings in July and August when stratification take place. Note that at the beginning of the period is recommended that the h1 opening value (at the lake surface) should be maximum (about 0.25 m), and the bottom should be minimal (< 0.05 m), while the in the next period, there are no longer taken any flow through the top opening, since water level in the lake is below this elevation (Fig. 7), the height of other openings alternating depending on the month, in order to ensure the temperature criteria and a minimal for pollutants. The numerical values of the openings in the tower, as well as the values of pollutant element (Total Fe) for the studied two years consecutivesare presented in Tables 2 and 3. Note that the minimum concentration value achieved downstream the dam, using the proposed two programs, does not exceed the value of 20.33 in the most unfavorable month (first year), when the maximum concentration in the lake is 28.54 mg /L. Some measured data of the physical parameters of the lake for the second year are graphical presented.

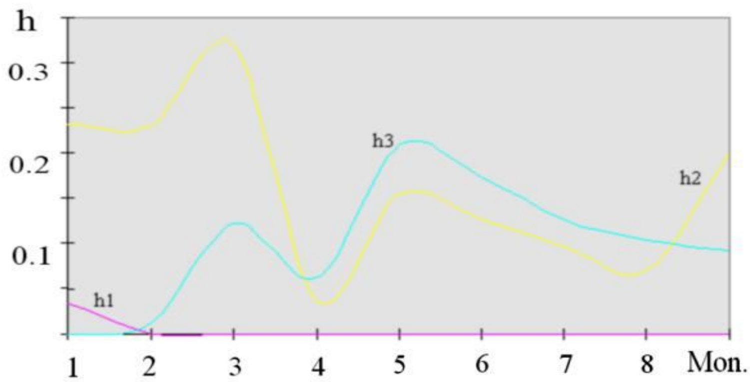

Fig. 5 – Graph of openings(m) calculated for a water demand of 15°C and minimum of total iron content (July-August, first year).

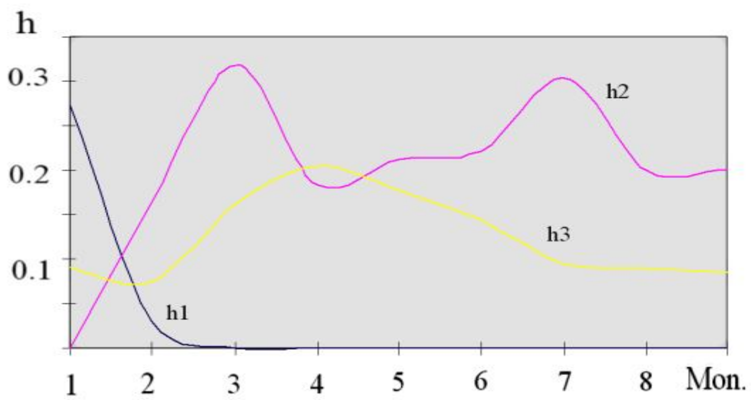

Fig. 6 – Graph of openings [m] calculated for a water demand of 15°C and minimum of total iron content (July – August, second year).

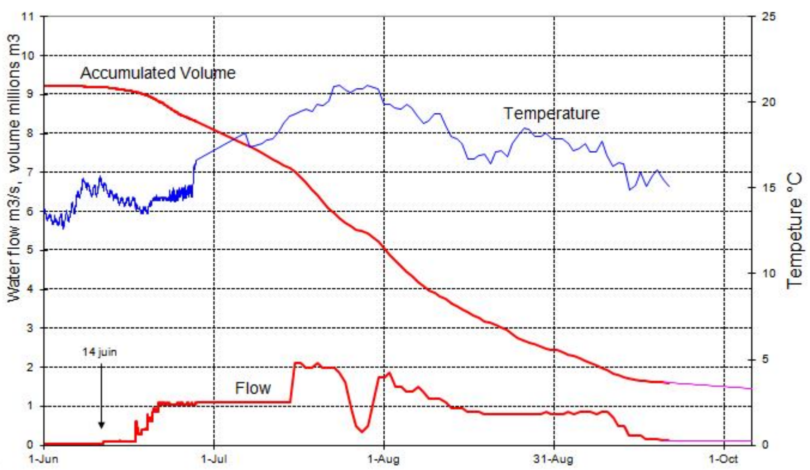

Fig. 7 – Flows, [m^3/s], and temperatures, [°C], recorded at the water surface level - summer (second year).

Table 2

Quality Classes of Surface Waters Physical and Chemical Quality (*Low Grid*)

Parameters	Units	Excellent	Good	Accept.	Mediocre	Classwise
Class		1A	1B	2	3	FC
Dissolved oxygen	mg O2/l	7	5-7	3-5	1.5-3	1.5
Oxygen saturation	%	90	70-90	50-70	50-20	20
CBO5	mg O2/l	3	3-5	5-10	10-25	25
NCO	mg O2/l	20	20-25	25-40	40-80	80
Amoniu	mg NH4/l	0,1	0.1-0.5	0.5-2	2-8	8

Table 3
Eutrofization Parameters: Azot, Phosphor

Parameters	Units	Excellent	Good	Accept.	Mediocre	Classwise
Azote		N1	N2	N3	N4	N5
Nitrate	mg NO3/l	5	5 - 5	25-50	50-80	80
Nitrite	mg NO2/l	0.1	0.1-0.3	0.3-1	1-2	2
Ammonium	mg NH4/l	0.1	0.1-0.5	0.5-2	2-8	8
Azot Kjeldahl	mg N/l	1	1-2	2-3	3-10	10
Phosphorus		P1	P2	P3	P4	P5
phosphate	mg PO4/l	0.2	0.2-0.5	0.5-1	1-2	2
Total Phosphorus	mg P/l	0.1	0.1-0.3	0.3-0.6	0.6-1	1

3.1.3. *Thermal Stratification of Water, Determination of Parameters Necessary for Modeling*

Water stratification in lakes is due to variations in water density caused by temperature variations. Water density increases as the temperature decreases, reaching a maximum of around 4 degrees Celsius. Thus a thermal stratification occurs, in deep lakes the distinct layers tend to form in the summer months. The deepest areas, the farthest from the sun, remain cold and consequently the densest, forming the lower layer called hypolimnion. The upper heated areas of the sun form the superficial layer called epilimnion. Between them develops the intermediate layer called mezalimnion characterized by fast thermal transitions. The stratification phenomenon can prevent the dispersion of effluents leading to the concentration of pollutants in certain areas.

The superficial, warmest layer also contains the largest amount of living organisms in the lake, algae production is also greatest in the superficial area, where the sun easily penetrates. The upper layer is also the richest in oxygen, which dissolves in the water in contact with the atmosphere. A second layer of high productivity is formed immediately above the hypolimnion, due to the upward diffusion of nutrients. Productivity is lower because the amount of light that can penetrate is smaller. Sometimes an oxygen deficiency may also occur due to the decomposition of organic matter.

At the end of the fall, the superficial waters cool down, become denser and lower, causing the water to rise from the deep layers and thus cause the lake water to be homogenized. Generally throughout the winter the lake waters remain homogenized. Sometimes in the cold season there may also be a reverse layer with a cold top layer having a temperature close to zero degrees and a warmer layer of about 4°C in depth.

The superficial, warmest layer also contains the largest amount of living organisms in the lake, algae production is also greatest in the superficial area, where the sun easily penetrates. The upper layer is also the richest in oxygen, which dissolves in the water in contact with the atmosphere. A second layer of

high productivity is formed immediately above the hypolimnion, due to the upward diffusion of nutrients. Productivity is lower because the amount of light that can penetrate is smaller. Sometimes an oxygen deficiency may also occur due to the decomposition of organic matter.

The amount of oxygen dissolved in the water of a lake depends on the photosynthesis activity, that is, on the light and temperature. Thus, it is normal to find a significant oxygen production in the epilimnion. On the contrary, in hypolimnion, where photosynthesis is reduced, the dissolved oxygen content is small, while the materials resulting from the decompositions produced by the anaerobic bacteria contribute to the massive consumption of oxygen. In the eutrophic lakes, oxygen supersaturations (sometimes up to 200%) can occur in the epilimnion and its total deficiency due to the decomposition of organic matter by the anaerobic bacteria in the other layers. The wind plays an important role in the oxygenation of deep lakes. In regions with cold winters, frost can stop gas exchanges with the outside, while light-beam radiation penetrates the ice with limited photosynthesis. Snow over ice can drastically reduce its transparency and consequently oxygenation of water. Regarding the studied lake, there is a pronounced thermal stratification (a difference of 7°C between the surface and the layer at the depth of 7 m) between July 15 and August 31, accompanied by a net stratification of the dissolved oxygen.

The stratification phenomenon can be mathematically modeled using vertical uni-dimensional EOLE models. The calculation principle is based on quantification of turbulent kinetic energy (ECT), whose surface input allows the potential increase of the energy of the water column, trained by dense and non-turbulent water in the mixed layer.

For that calculation I wrote the program:

```
    clear all
cota_lac=input('Share in the lake  = ');
qt=input('Total outflow =');
     z=0;
     n=3;
  if 'Share in the lake  <221
     n=2;
     z=1;
  end
     min=100;
     max=1;
       for i=1:n
     t(i+z)=input(sprintf('Water temperature at socket no. %d = ',i+z));
        if (t(i+z)<min)
           min=t(i+z);
        end
        if (t(i+z)>max)
           max=t(i+z);
        end
     end
```

```
        t(4)=input(sprintf(''Allowable downstream temperature = '));
              while (t(4)<min )OR(t(4)>max)
        disp(sprintf('Allowable value between %d si %d',min,max));
        t(4)=input(sprintf('Allowable downstream temperature = '));
              end
               min=100;
               max=1;
               for i=1:n
                C(i+z)=input(sprintf(''Concentration of pollutant at socket no.%d
=',i+z));
                  if (C(i+z)<min)
                     min=C(i+z);
                  end
                  if (C(i+z)>max)
                     max=C(i+z);
                  end
               end
               if n==3
               A=[t(1:3);-eye(3)];
               b=[qt*t(4);0;0;0];
               [x,fval]=linprog(C./qt,A,b,[1 1 1],qt);
               end
               if n==2
               A=[t(2:3);-eye(2)];
               b=[qt*t(4);0;0];
               [x,fval]=linprog(C(find(C))./qt,A,b,[1 1],qt);
               end
   disp(sprintf('The minimum concentration is = %5.2f',fval));
   disp(sprintf('The optimum flows are :  '));
   if n==3
      disp(sprintf('q1 = %5.2f',x(1)));
   end
   disp(sprintf('q2 = %5.2f',x(n-1)));
   disp(sprintf('q3 = %5.2f',x(n)));
```

The program allows for the calculation of flows passing through openings in an infinite number of combinations of valve openings. We have now exemplified a flow calculation for a constant opening of the 0.1 m sockets at a variable drainage flow rate recorded in second year.

3.1.4. *The Main Parameters of Water Quality in the Lake, their Evolution with the Development of the Stratification Phenomenon*

The main parameters of water quality are: temperature, dissolved oxygen and its saturation percentage, pH, conductivity, suspended matter, total organic carbon, specific pollutants such as ammonium ions, nitrates and phosphates. Other additional parameters are equally important: biochemical oxygen demand (CBO5), chemical oxygen demand and nitrite. According to the

French rules, five quality classes can be distinguished in terms of surface water quality:

CLASS 1A : Characterized by pollution-free waters, the quality of which is "excellent"..

CLASS 1B : Characterized by poor quality soils, so-called "good", which can satisfy all uses.

CLASS 2 : Their quality is "acceptable", ie good enough for irrigation, industrial use, as drinking water after proper treatment, for animal welfare and restrictive for fish farming.

CLASS 3 : Quality is mediocre, suitable only for irrigation and navigation. Aquatic life can subsist, but it becomes random in times of low flow and high temperatures.

CLASSWISE : The maximum tolerated values for class 3 are exceeded for one or more parameters. They are considered unfit for most uses, constituting a threat to public health.

3.1.5. *Minimizing the Concentration of Some Pollutants in Downstream Water*

The exploitation conditions of the dam during the summer require, in addition to ensuring a minimum downstream flow and compliance with certain quality parameters of the discharged water. The quality criteria imposed are often contradictory, due precisely to the stratification phenomenon presented above. For example, for a minimum amount of iron dissolved in water, it is also necessary to avoid overtaking a maximum water temperature in the downstream river sector. Iron is found to be minimal at the surface of lake water, and water is colder at the bottom of the lake, where the iron concentration is maximum. Obviously in this situation it is necessary to find an optimum that would fit the required operating conditions. Specifically, the flows discharged through the three (or two in the last exploitation period of the lake in summer) must be found in openings of the water intakes so that the resulting mixture meets these conditions.

We have solved this problem using the Simplex method as an optimization method. An optimization problem is generally characterized by the existence of a goal and a series of restrictions. Obviously, it is impossible to consider all the elements in reality, but only the most important components. The process of formulating an optimization problem begins by defining the following terms:

– Decision variables: unknown values that can be controlled. Each decision variable has a definition limit;

– State variables: (or dependent) are the quantities that define the status of a system. These variables are normally dependent on decision variables;

– Particular or auxiliary variables;

– Goal function: Goal that is maximized or minimized;

– Restrictions: Limitations to be met in obtaining the final solution.

In linear programming optimization, the goal and restrictions must be formulated in linear form. In most models of water resource management, the common goal is to maximize or minimize water flows or volumes. In the specific case of the analyzed situation, it is the minimization of the pollutant concentration.

The problem can be solved mathematically using the Simplex algorithm (Dantzig, 1963). The Simplex method is iterative. The algorithm first identifies a basic admissible solution (if any) and then starts from it improves it to an optimal solution, or informs that the optimum is infinite.

The algorithm is based on solving a matrix system of equations, the standard form being the following (Kinzelbach, 1986):

The program was obtained by adapting to the specific conditions required by the studied accumulation of a library program [65]. I will only present the extra routines:

```
{Optimal solution using the Simplex algorithm, flows, openings}
clear all;
nlac= input(''Share in the lake  (m)=');
    c=input('enter c (c<=3.501) =');
if (c>3.51)
 c=input('enter c (c<=3.501) =');
end
niv(1) = 221;
niv(2) = 217.5;
niv(3) = 206.85;
niv(4) = 206.85;
dt=1.5;
zv=.2;
lm=.025;
for i=1:4
zeta(i)=.5;
if i==3
      zeta(i)=.24;
end
if i==4
   zeta(i)=.2;
end
miu(i)=.62/((1+zv+zeta(i))^.5);
b(i) = .8;
v(i)=0;
 end
i = 1;
while i < 4
 h(i)=input(sprintf('opening of the prize no. %d este (<0.81!)= ',i));
           if h(i)>.81
      i=i-1;
   end
           i = i + 1;
   end
h(4)=1.1;
```

```
prec=1;
for t = nlac-niv(4): -0.1: 0
i = 1;
       sq=0;
   while i < 5
     sarc(i) = nlac-(niv(4)+t+(lm*v(i)^2*(niv(i)-niv(3)))/(dt*2*9.81));
         if niv(i)>=(t + niv(4))
           sarc(i) = nlac - niv(i);
         end
         if (i ==4)
            sarc(i) = t-(lm*v(i)^2*(niv(i)-niv(3)))/(dt*2*9.81);
         end
         if sarc(i)<0
           sarc(i)=0;
         end
           q(i) = miu(i)*b(i)*h(i)*(2*9.81*sarc(i))^.5;
         if i<4
           sq=sq+q(i);
         end
           i = i + 1;
   end
           v(i)=sq/(3.1458*(dt/2)^.5);
           q(4) = c;
         if ((sign(prec)~=sign(q(4)-(q(1)+q(2)+q(3))))&(t<(nlac-niv(4)-.02)))
           disp(sprintf('Pentru Q drain-bottom = %d',q(4)));
           h4 = q(4)/(miu(4)*b(4)*(t*2*9.81)^.5);
           if q(4)>.799
             disp(sprintf('( h_fund = %d)',h4));
             disp(sprintf('Debitele  prizelor sunt:'));
             disp(sprintf('Q1= %5.3d',q(1)));
             disp(sprintf('Q2= %5.3d',q(2)));
             disp(sprintf('Q3= %5.3d',q(3)));
             disp(sprintf('Q4= %5.3d',q(4)));
             disp(sprintf('H_lac = %5.3d',(nlac - niv(4))));
           end

          elseif t<= 0.005
             j = 1;
           while j < 4
             sarc(j) = nlac - niv(j);
           if sarc(j)< 0
             sarc(j) = 0;
           end
             q(j) = miu(j)*b(j)*h(j)*(2*9.81*sarc(j))^.5;
             j = j + 1;
           end
             qp = q(1)+q(2)+q(3);
           if qp<c
             f = 0;
```

```
        disp(sprintf('For Q bottom-drain = %5.3d',qp));
        h4 = 1.1
        if q(4)>.799
        disp(sprintf('(h_fund= %d)',h4));
        end
        disp(sprintf('Debitele  prizelor sunt:'));
        disp(sprintf('Q1= %5.3d',q(1)));
        disp(sprintf('Q2= %5.3d',q(2)));
        disp(sprintf('Q3= %5.3d',q(3)));
        disp(sprintf('h_tour= %5.3d',f));
        disp(sprintf('H_lac = %5.3d',(nlac - niv(4))));
        disp(sprintf('(Limitat de prize, val. ceruta = %5.3d)',c));
                    end
      else
        lf = niv(3) - dt;
        sq=0;
        for j=1:3
            if (nlac - niv(j))<= 0
              q(j) = 0;
            else
              q(j)=miu(j)*b(j)*h(j)*(2*9.81*(nlac-niv(j)))^.5;
            end
          sq=sq+q(j);
        end
        for j=1:3
          q(j)=q(j)*q(4)/sq;
        end
          disp(sprintf(For Q bottom-drain = %d',q(4)));
          h4 =q(4)/(miu(4)*b(4)*((nlac-niv(4))*2*9.81)^.5);
        if q(4)>.799
          disp(sprintf('(h_fund= %d)',h4));
          disp(sprintf('Debitele  prizelor sunt:'));
          disp(sprintf('Q1= %5.3d',q(1)));
          disp(sprintf('Q2= %5.3d',q(2)));
          disp(sprintf('Q3= %5.3d',q(3)));
          disp(sprintf('h_tour= %5.3d',(nlac-niv(4))));
          disp(sprintf('H_lac = %5.3d',(nlac - niv(4))));
          prec=q(4)-(q(1)+q(2)+q(3));
        end
                  end
end
```

During the summer season, water users downstream of the dam, asks for the water delivered from the storage to meet certain conditions. The most frequent requests come from the Fishermen's Association and refer in particular to the temperature of the water discharged from the lake. We made a modeling for the months of July and August two year consecutive of a water temperature demand delivered of 15ºC under the conditions of minimizing its iron content. Requested flows ranged between 0.5 and 2 m^3/s and cover the entire range of actual flows recorded in the operation of the accumulation. Obviously, by the time the study was completed, it was difficult to meet these requests. The flows out through each socket were unknown, for a certain opening and variable level in the lake. The program allows these requests to be met. Following program run, the recommended program flow rates are taken to be drawn through each of the three sockets as well as their opening heights so that the required conditions are met. The modeling results are presented in the Tables 4 and 5 and Fig. 8.

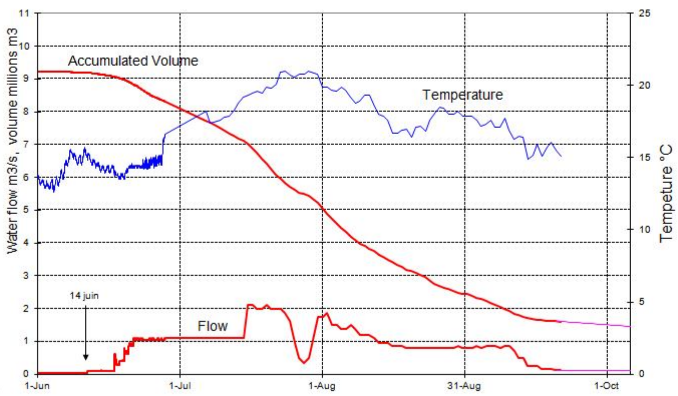

Fig. 8 –Evolution of temperatures, discharge rate and lake volume/first year.

Table 4

Calculation Results for Water Demand at 15°C and Minimum Iron,July–First Year

Data	Cota priză	Cota lac	Qt	T	Fe	Fe_min	Q1-m^3/s	Q2-m^3/s	Q3-m^3/s	h1-m	h2-m	h3-m
6.07	219	223	1	21.9	0.34	0.7	**0.08**			**0.034**		
	217			14.4	0.73			**0.92**			**0.233**	
	206.85			11.9	8.64				**0**			**0**
12.07	219	223	1	25.5	0.34	0.94	**0**			**0**		
	217			15.3	0.39			**0.91**			**0.23**	
	206.85			12	6.47				**0.09**			**0.012**
20.07	219	222	2	28	0.27	0.94	**0**			**0**		
	217			16.9	0.64			**1.14**			**0.318**	
	206.85			12.5	6.85				**0.86**			**0.121**
27.07	219	220	0.5	-	-	8.02	**0**			**0**		
	217			24.4	0.25			**0.09**			**0.036**	
	206.85			12.8	9.84				**0.41**			**0.061**
2.08	219	220	1.8	-	-	6.53	**0**			**0**		
	217			22.4	0.31			**0.41**			**0.155**	
	206.85			12.8	8.38				**1.39**			**0.209**
9.08	219	220	1.5	-	-	8.34	**0**			**0**		
	217			23.3	0.33			**0.34**			**0.126**	
	206.85			12.6	10.65				**1.16**			**0.175**
16.08	219	219	1	-	-	10.36	**0**			**0**		
	217			23.1	0.65			**0.2**			**0.096**	
	206.85			13	12.76				**0.8**			**0.126**
23.08	219	219	0.8	-	-	13.77	**0**			**0**		
	217			24.6	0.68			**0.14**			**0.07**	
	206.85			12.9	16.63				**0.66**			**0.103**
30.08	219	218	0.8	-	-	20.33	**0**			**0**		
	217			20.9	0.96			**0.24**			**0.2**	
	206.85			12.5	28.54				**0.56**			**0.092**

Table 5
Calculation Results for Water Demand at 15°C and Minimum Iron,Second Year

Data	Cota priză	Cota lac	Qt	T	Fe	Fe_min	Q1 m^3/s	Q2 m^3/s	Q3 m^3/s	h1 m	h2 m	h3 m
2.07	219	222	1.11	20.4	0.13	1.6	0.46			0.272		
	217			19.4	0.58			0			0	
	206.85			11.2	2.63				0.65			0.091
9.07	219	222	1.11	18.8	0.16	5.74	0			0		
	217			18.4	0.32			0.59			0.164	
	206.85			11.2	11.8				0.52			0.074
16.07	219	221	2.12	23.4	0.08	6.62	0			0		
	217			18.9	0.15			1			0.318	
	206.85			11.5	12.43				1.12			0.162
23.07	219	221	1.99	24.5	0.24	9.05	0			0		
	217			23.1	0.26			0.58			0.183	
	206.85			11.7	12.63				1.41			0.205
30.07	219	220	1.74	23.5	0.16	12.42	0			0		
	217			22.7	0.64			0.56			0.212	
	206.85			11.3	18.08				1.18			0.177
6.08	219	219	1.37		-	13.63	0			0		
	217			22	0.43			0.46			0.221	
	206.85			11.5	20.23				0.91			0.143
13.08	219	218	0.943	-	-	14.24	0			0		
	217			20.2	0			0.36			0.302	
	206.85			11.8	23.3				0.58			0.095
20.08	219	218	0.783	-	-	16.79	0			0		
	217			23.3	0.62			0.24			0.199	
	206.85			11.4	23.8				0.55			0.089
27.08	219	217	0.783	-	-	12.04	0			0		
	217			20.2	0.59			0.28			0.2	
	206.85			12.1	18.42				0.5			0.086

4. Conclusions/Recommendations

In this work I tried to understand what processes create stratification and which approaches can be taken to evaluate fundamental parameters such as distribution of density and conductance.

Among the various impacts on the environment produced by artificial lakes is water stratification. It occurs mainly during summer, and as result, the chemical and physical structure of the lake water and of the downstream water as well, is modified. Also, the temperature of the downstream water varies as compared to the natural status. This may have impact for the existing wild life in the river.

We are proposing a solution for minimizing the effect of water stratification consisting of an operating method based on the use of two special conceived programs. Although the solution was proposed particularly for Lavaud dam in France (studied within the framework of a joined EU program) this specially designed software package may be used for any similar artificial lakes including Accumulation Pârcovaci or Puşcaşi, with minimal structural changes (ex. additional water intakes at different levels).

The use of these two programs made possible an environmental friendly way of management for the Lavaud dam the same can be for the accumulation Pârcovaci or Puşcaşi**.**

The first program within this package makes possible an accurate application of the water stratification modeled for Lavaud dam because it provides the real values of the flow rates at each opening.

The second program enables the management of water quality downstream the Lavaud dam, as a response to a corresponding request.

The examples of running the programs allow the reconstruction of the real cases of dam operating during the years 2005 and 2006. This facilitates eventual calibrations of the programs by tuning the flow coefficients to match the already measured data.

The use of these two programs should be interactive, based on real field-data.

Graphics of the variation of the dissolved chemicals and water temperature in the lake and downstream the lake is also presented.

Humanity needs to be prepared for the changes it imposes upon the Earth, especially in times of global change and of direct human impact on the hydrological cycle. The anthropogenic impact of the last decades on our aquatic environment has shown that a responsible use of our natural resources is mandatory to guarantee sustainable conditions. Over the last decades, not only have new large water bodies been created on the Earth's surface e.g., reservoirs, but also entirely novel aquatic systems developed in the aftermath of mining in abandoned opencasts (*e.g*., Miller *et al*., 1996; Kru¨ger *et al*., 2002). In addition, the hydrological regime of many lakes has been modified to the extent that lakes have fundamentally changed their appearance, e.g., Aral Sea (Le´tolle & Mainguet, 1993; Cre´taux *et al*., 2005), or their stratification pattern has been altered by human impact, *e.g*., Dead Sea (Gat, 1995) and Mono Lake (Jellison & Melack, 1993) or by climatic variability, *e.g*., Caspian Sea (Peeters *et al*., 2000).

REFERENCES

Aeschbach-Hertig W., Hofer M., Schmid M., Kipfer R., Imboden D.M.,*The Physical Structure and Dynamics of a Deep, Meromictic Crater Lake (Lac Pavin, France)*, Hydrobiologia, **487**, *1*, 111-136, (2002), doi:10.1023/A: 1022942226198.

Arai T., *Climatic and Geomorphological Influences on Lake Temperature*, Verh. Int. Ver. Theor. Angew. Limnol., **21**, 130-134 (1991).

Bedient Ph., Huber C., *Hydrology and Floodplain Analysis*, Addison – Wesley Pub. Co, New York, 1992.

Cioc D., *Hidraulica*, Edit. Didactică şi Pedagogică, Bucureşti, 1983.

Cotiuşcă D.,*Contribuții la modernizarea exploatării lacurilor de acumulare*, Teză de doctorat, 'Gheorghe Asachi' Technical University of Iaşi, 1998.

Crețu Gh., *Economia apelor*, Edit. Didactică şi Pedagogică, Bucureşti, 1976.

Giurma I., *Sisteme de gospodărirea apelor*, Edit. Cermi, Iaşi, 2000.
Idel'cik I.E., *Memento des pertes de charges*, Ed. Eyrolles, Paris, 1986.
Ionescu H., Dinescu C., Săvulescu B., *Probleme ale cercetării operaţionale*, Edit. Didactică şi Pedagogică, Bucureşti, 1972.
Kiselev P.G., *Îndrumător pentru calcule hidraulice* (trans. from Russian), Edit. Didactică şi Pedagogică, Bucureşti 1988.
Kolghi M., *Gestion conjointe des eaux de surface et souterraine, approchée par simulation, optimisation et aide a décision,* Thèse de doctorat, Univer. de Poitiers, France, 1997.

LIMITAREA INFLUENŢEI STRATIFICĂRII TERMICE DIN ACUMULĂRI ASUPRA BIEFULUI AVAL

(Rezumat)

Resursele de apă dulce ale planetei sunt limitate, deoarece 97,3% din totalul apei este sărată, în timp ce apa proaspătă este limitată la doar 2,7%. În plus, este distribuit inegal în lume. Ţările industrializate, care cuprind doar o treime din populaţia lumii, dispun de majoritatea resurselor de apă dulce disponibile. În multe zone, lipsa resurselor de apă dulce este o problemă mare, aşa cum se întâmplă în ţările în care aceste rezerve sunt mai mici de 1 000 m^3 pe persoană.

Rezervoarele de apă create prin construirea barajelor fac posibilă acumularea unor rezerve suplimentare de apă în ţări cu deficit, dar au şi alte scopuri, cum ar fi obţinerea energiei electrice, regularizarea hidrologică a cursurilor de apă etc. În ceea ce priveşte impactul asupra mediului, trebuie luate în considerare elementele de bază cum ar fi suprafaţa acumulării de apă şi gradul de schimbare a debitului de apă, incluzând ambele habitate. Modificarea şi alte elemente specifice ecosistemului şi modul în care ecosistemele sunt afectate în aval. În contextul actual al limitării influenţei negative a activităţii umane asupra mediului, pe lângă satisfacerea cantitativă a cerinţelor de apă, este necesar să se îndeplinească cerinţele apei pe baza unor criterii de calitate, inclusiv descărcarea în aval. Acest mod de exploatare se întâlneşte în special în cazul acumulărilor al căror rol principal este cel de asigurare a unui debit minim pe sectorul aval în perioadele secetoase. Chiar şi în această situaţie limită, pentru asigurarea unui biotop nealterat aval de baraj, apa evacuată trebuie să îndeplinească anumite criterii de calitate. Se impune găsirea unui mod de exploatare care să permită evacuarea în aval a unui debit având parametrii de calitate controlaţi în funcţie de cerinţele beneficiarilor. În cazul Administraţiei Naţionale "Apele Române " aproape toate barajele sunt prevăzute cu o priză de apă situată în turnul de manevră care au două nivele de captare a apei la cotele 163,9 mdMN şi respectiv 171,00 mdMN cum este cazul acumulării Pârcovaci datele fiind reale dar şi în cazul celorlalte acumulări. Deci ar fi vorba mai mult de o adaptare decât modificări constructive care nici acestea nu ar fi imposibile şi costisitoare.

Stratificaţia apei din lacuri este datorată variaţiilor de densitate a apei cauzată de variaţiile de temperatură. Fenomenul de stratificaţie poate împiedica dispersia efluenţilor conducând la concentrarea poluanţilor în anumite zone. În literatură, în general, când se vorbeşte despre statificaţia apelor se face de fapt referire doar la stratificaţia termică a apelor cu toate că fenomenul priveşte deopotrivă şi oxigenul dizolvat.

Se propune o limitare a influenţei stratificaţiei termice din acunulări asupra biefului aval pe unul din lacurile administrate de ABA Prut-Bârlad dar solicitarea de

date concrete (masurători din teren) nu a fost onorată pâna în prezent. Neavând fizic timpul necesar căci era o operație de durată am ajuns în spațiul virtual şi am găsit un lac asemănător ca parametri cu lacurile din România şi voi face modelarea pe aceste date şi voi propune o soluție pentru lacurile noastre. Un exemplu concret de acest tip este barajul Lavaud - Franța. În timpul verii, în lac apare un puternic fenomen de stratificare care antrenează şi o distribuție neuniformă a calității apei din lac. Dificultatea constă însă în faptul că debitul evacuat este controlat de o singură vană, neexistând date asupra distribuției debitelor prin cele trei deschideri ale prizelor. Cercetările au fost finalizate prin furnizarea a două programe de calcul. Primul permite calcularea debitelor ce trec prin cele trei deschideri în funcție de dimensiunile acestora, de nivelul apei din lac şi de debitul sau deschiderea stavilei golirii de fund. Al doilea program indică debitele ce trebuie prelevate prin fiecare din cele trei deschideri şi dimensiunile deschiderilor, astfel încât să se respecte criteriile de calitate pentru apa evacuată. vietuitoarelor din mediul acvatic. Lucrarea prezintă o soluție de atenuare a acestui fenomen, precum şi un program de calculator pentru controlul deschiderii evacuatorilor unui baraj, în scopul de a minimiza efectul de stratificare al apei. Această soluție de atenuarea fost propusă pentru barajul Lavaud, Franța (în cadrul unui program de cooperare european). Sunt prezentate de asemenea, grafice de variație ale substanțelor chimice dizolvate precum şi ale temperaturii apei din lac şi din aval acest pachet software special conceput poate fi utilizat pentru orice lacuri artificiale similare, cum ar fi Acumularea Pârcovaci sau Puşcaşi, cu modificări structurale minime (ex. Aporturi suplimentare de apă la diferite niveluri).