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## Water Quality in Hydroelectric Sites

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### 1. Introduction

The most widely form of renewable energy is the hydropower, which produces electrical power using the gravitational force of falling or flowing water. Comparing to fossil fuel powered energy plants, hydropower plants are considered „green” energy source, because they do not produce direct waste and have almost no output level of greenhouse gas carbon dioxide. Hydropower is the most important source of renewable electricity generation – 86.3 %, and essential to operate the others sources of renewable energy that are random generation.

Hydro energy importance also comes from its own source – the water, an essential life resource. Therefore, to maintain the water quality is a main concern from ecological, economical and sustainable development point of view (Bunea et al., 2010).

Hydroelectric sites use the available head and flow rate of a water course. Sometimes, this is made using more natural configuration, but often it involves important construction works and arrangements. The most common hydroelectric sites are based on:

- a. local rise of the water level by means of a dam, which creates a reservoir upstream the dam. The hydropower plant is usually placed next to the dam;
- b. deviation of water course through a free surface channel or tunnel. At the downstream end of the channel or tunnel, the water is put under pressure and driven to the turbines;
- c. other mixed arrangements, with surface or underground hydropower plant, specific to mountain areas. These sites have high dams and large reservoirs.

The water quality used in a hydropower plant depends on many elements such as: the size and depth of the lake, placement along water course, intake depth, hydropower releases, temperature variations, rain intensity and frequency, reservoir thermal stratification and hydropower plant operation regimes.

The ecological impact of hydropower plants will be presented. In the first part is analyzed the processes in the reservoir (fig. 1), then, the influence of water realized on the downstream river. Also, some methods and their efficiency for improving water quality will

be presented. Finally a review of chemical and quality water evolution in time will be presented for a hydroelectric site of Romania.

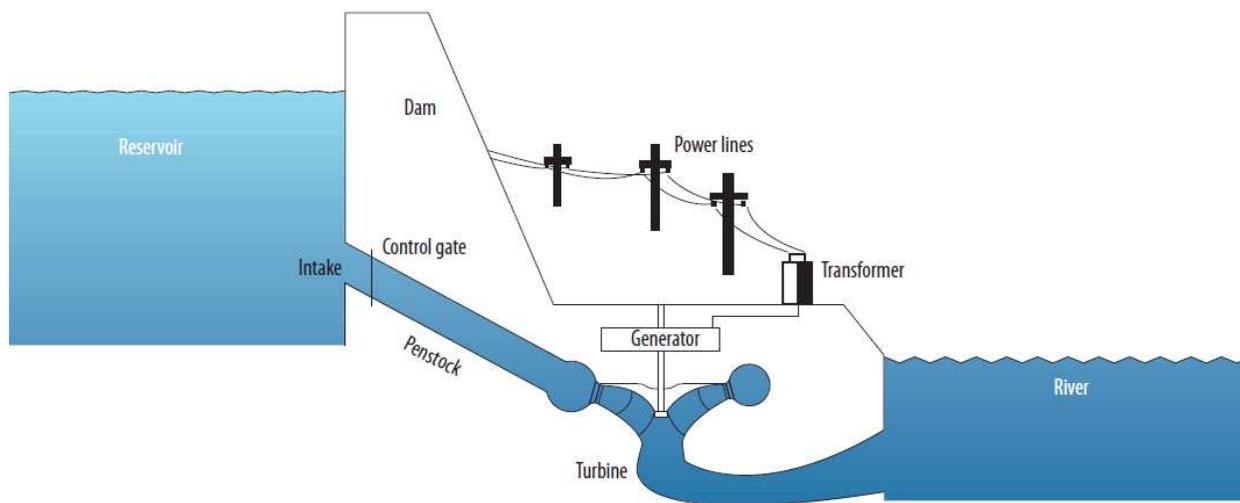


Fig. 1. Cross section of a hydroelectric power plant

During warm seasons the large reservoirs become subject of thermal stratification. Because the upper layers are close to the free water surface, they have a higher level of dissolved oxygen (DO). On the opposite side, the lower layers have a low level of DO, mainly because of the organic sediments at the bottom of the reservoir. When DO level goes under 5.0 mg/l, the aquatic life is endangered and large quantities of fish can die if the DO remains at 1÷2 mg/l for a few hours.

In hydropower plants, the water that goes to the turbines is taken from the lower layers of the reservoirs, sometimes with low DO content, which can affect the downstream water quality. The DO level from downstream water depends also on water head, periodic temperature variations, intensity and frequency of rain, hydropower plant design and its operation regimes.

Recently, the number of studies concerning water quality from hydropower releases increased. Many environment or ecological issues were reported, in different types of hydroelectric schemes. Scientist and engineers try to find solutions and mechanisms which will improve water quality, especially DO level. Generally, the low DO level is caused by organic sediments left on the reservoir bottom floor from the initial filling. When these organic sediments decompose, they absorb the oxygen from water, producing sulphuretted hydrogen, carbon dioxide and methane (like greenhouse gas). This pollution alters the local flora and fauna, even causing total extermination of some aquatic species.

Low DO level happens when the reservoir has a depth greater than 15 m and a volume bigger than  $61 \cdot 10^6 \text{ m}^3$ , the power output is more than 10 MW, and the retention time is longer than 10 days.

Romania has about 170 hydroelectric sites, a quarter of them having reservoirs larger than  $61 \cdot 10^6 \text{ m}^3$  and deeper than 15 m, so they are susceptible for a low DO level (Bucur et al., 2010).

The usual methods used to increase the DO level in the hydropower plants downstream waters include selective intakes, air diffusers, hub and draft tube deflectors. These equipments are used in the hydropower plants with different success rates in the aeration process. Generally, in order to increase the DO with 1mg/l, an air quantity of 1% from water volume is necessary (March, et al, 1992). A bibliographical revue is presented in this paper and recommendations are done for the implementation of aeration devices.

There is no legal support for DO level control downstream hydropower plants, but there are intense concerns regarding this issue. Usually, turbine aeration is made only in order to reduce turbine central vortex, so to increase the efficiency and reduce unsuitable pressure fluctuations and structure vibrations. The aeration made to increase the DO level downstream hydropower plant must be more consistent. Injection of a bigger air quantity can decrease the turbine efficiency; therefore air injection becomes an important factor for the balance between power output and ecology.

## **2. Hydroelectric reservoirs**

Regarding the mean multiannual water flow, the surface water sources in Romania are much higher than ground water sources. Each type of water source has its own physico-chemical and biological characteristics, varying from region to region, depending on the mineralogical composition of the crossed areas, by the contact time, temperature, weather conditions, etc.

Water accumulated in reservoirs has the physical - chemical qualities significantly different from water flowing in the river, before the dam construction and the hydropower development. Thus, the processes occurring in lakes can have an important impact on the water quality. On one hand the stagnation of water leads to a natural settling of suspended materials which determinate a good transparency of the water and less sensitive to weather conditions. On the other hand, the stagnation of water leads to thermal and chemical stratification which excludes the water circulation on vertically direction.

### **2.1 Seasonal stratification of water in hydroelectrical reservoirs**

Thermal structure of lakes varies by climate, by configuration of the lake basin, by the water intake surface and by the total mineralization of water. The most common structure is the direct stratification, which involves the higher temperatures at the water surface and lower temperatures to the bottom. For this kind of stratification the decrease of water temperature is not uniform with depth. Temperate regions are characterized by dimictic lake ecosystems. Most lakes in Romania are considered dimictic, meaning they mix twice a year - spring and fall. In the winter season, reverse stratification will be installed, while in the summer period a direct stratification will appear.

The lakes dynamic is characterized by energy and mass exchange processes. Dominant energy flow comes from the kinetic energy of wind and thermal energy produced by solar radiation. The vertical profile of temperature/density established in a lake results by superposing these two energy contributions (Dumitran and Vuta, 2011).

Thermal stratification consists in the existence of a vertical thermal gradient in the water mass. The low thermal conductivity of water contributes also, assuring that thermal energy

is very slowly transferred to the bottom layers of the water. This transfer is accelerated by vertical turbulent mixing and convective cooling of the water body. In time, the cumulative effect of heat loss and convective cooling can be felt throughout the water column, reducing the lake water temperature and causing a full mixing between the water layers (Pourriot and Meybeck, 1995). The cumulative effect of heat loss and convective cooling can be felt in the entire water column, thus reducing the lake water temperature and producing a full mixing between the water near the surface and deeper layers. Turbulent mixing is a process that precludes stratification, tends to destabilize the water column and is caused by shear induced by wind action (Stevens and Imberger, 1996).

Convective cooling occurs only if the net heat flow from the lake surface is negative. Thus the lake is losing heat to the atmosphere and the water layers near the surface are cooling, becoming denser than deeper waters.

At this point thermal stratification becomes unstable, and the volumes of water near the surface descend to a water layer with same temperature. Because of friction, running water entails other volumes of water, producing a new vertical mixing. The movement is done without wind energy contribution and there is a destratification tendency of superior layer to the equilibrium depth (Fig. 2). In summer, a typical temperature/density profile for a temperate lake is composed from two layers of small temperature/density gradient (epilimnion, hypolimnion) divided by a layer of high temperature/density gradient (metalimnion).

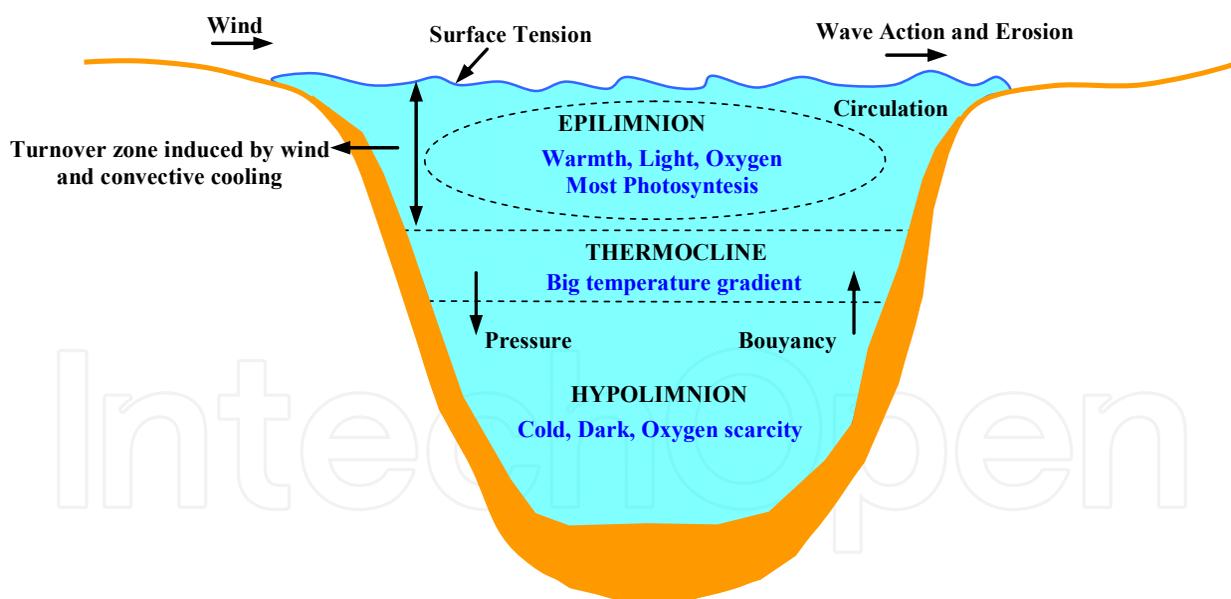


Fig. 2. Cross section of thermally stratified lake

Over the year, the lake water follows the cycle. In spring the ice melts into the lake, the wind picks up and the lake mixes. This is called spring turnover. Oxygen and nutrients get distributed throughout the water column as the water mixes. Then, as the weather becomes warmer, the surface water warms again and sets up summer stratification. During the summer the lake has a barocline structure, so at the surface a stable warmer layer of water

overlies a colder water layer. The water movement due to wind and convection currents produces a mixing process which homogenize just the epilimnion, while the water temperature in the hypolimnion is kept at around 4 °C. In the fall the sunlight is not as strong as during summer and the nights become cooler. This change in season allows the epilimnion to cool off. As the water in the epilimnion cools, the density difference between the epilimnion and hypolimnion is not as great. Wind can then mix the layers. In addition, when the epilimnion cools it becomes denser and sinks to the hypolimnion, mixing the layers. This mixing allows oxygen and nutrients to be distributed across the whole water column. In winter, when surface water temperature drops below 4 °C, circulation ceases again and winter stagnation appear, characterized by an inverse thermal stratification. During this period the water mass is characterized by lower temperature at the surface and higher to bottom.

The lake stratification entails lower dissolved oxygen concentration in the bottom and the emergence of anaerobic oxidation processes. The stratification of lakes has a negative impact on trophic evolution of these ecosystems. Thus, the organic matter content and nutrients concentration will be increasing and sometimes even the hydrogen sulfide will appear at the bottom of lakes.

## 2.2 Day/night stratification of water in hydroelectrical reservoirs

In temperate regions the temperature differences between day and night are significant, so the water cooled during the night, goes down in a deeper layer. This depth is direct correlate with the reservoir size, so it can vary from 5 m up to 20 m (Read et al., 2011). In these conditions, the thermoclin layer appears which is characterized by a temperature drop of 10 to 15 °C (Fig.3).

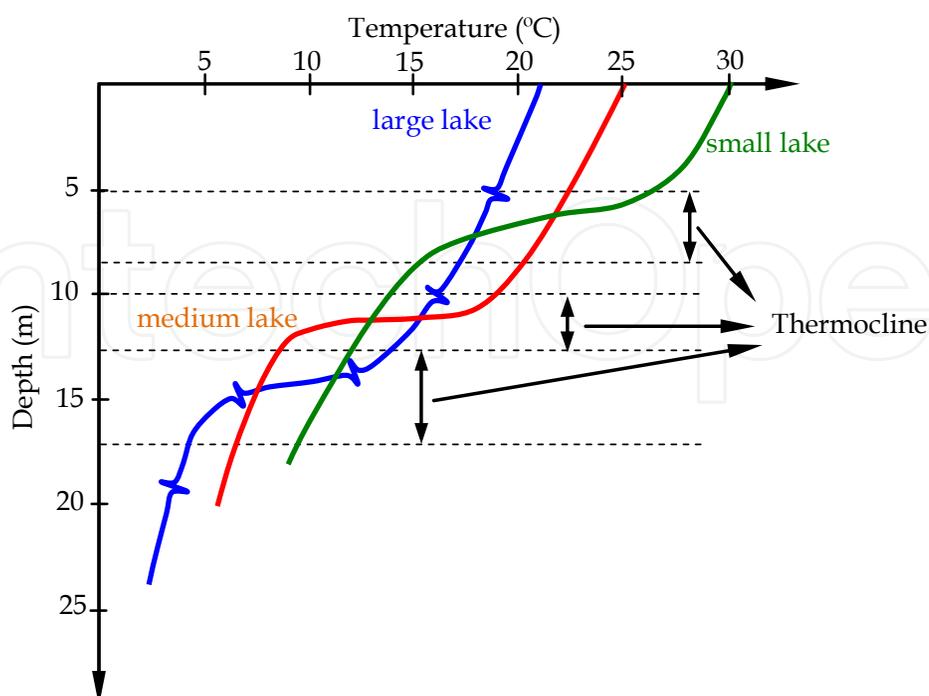


Fig. 3. The batimetric zones of the lake

### 2.3 Eutrophication of hydroelectrical reservoirs

Biological quality of water is essentially affected by eutrophication, a phenomenon favored by building a hydropower plant. Eutrophication has proved to be one of the most widespread and serious anthropogenic disturbances to aquatic ecosystems. The major cause for eutrophication is the increased loading of nutrients, especially phosphorous. Increasing wastewaters, introduction of phosphorous containing detergents, use of fertilisers, and erosion in the watershed are the major reasons for increased loading of nutrients. The effects of the eutrophication phenomenon are negatively reflected on water quality, for reservoir ecosystem and also for river ecosystem (Fig. 4). Thus, eutrophication may lead in some cases even to the impossibility of using the water for certain uses.

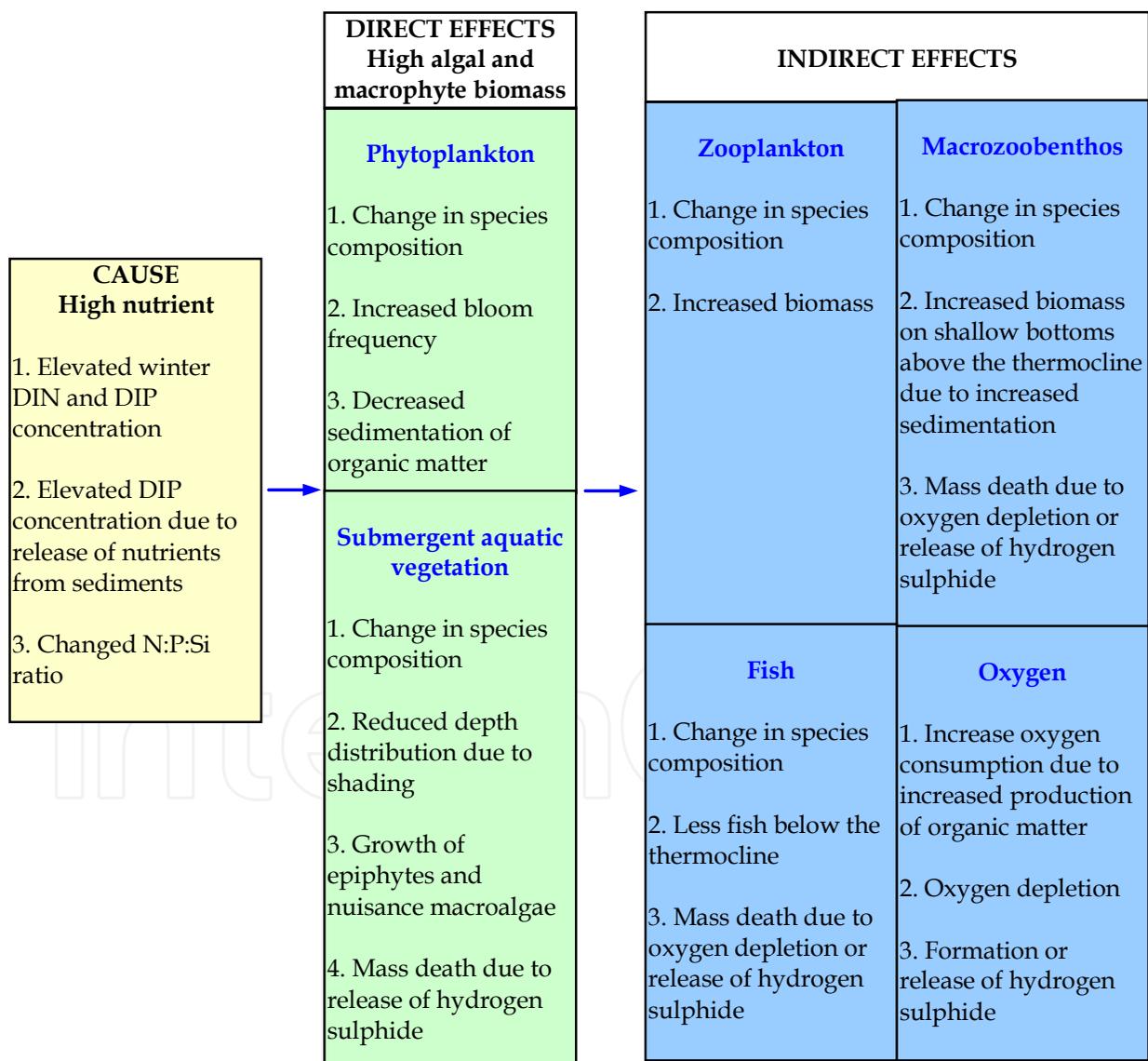


Fig. 4. Causes and effects of eutrophication

Effects of eutrophication emergence affect the lake ecosystem by:

- organoleptic changes of water (color, taste, odor and turbidity) by increasing the biomass of planktonic algae. Water may have a green color due to high content of green algae or diatoms, a red color in blue-green algae species presence, or even brown. This effect gives an unaesthetic aspect of water and leads to additional costs when water is used as a source of drinking water;
- premature clogging of filters and grids of treatment plants which are supply directly from the lake, due to increased phytoplankton biomass;
- biological clogging of the lake and therefore a reduction of its volume due to growth of organic matter content and organic detritus at the lake bottom;
- inability to release and to transform the organic matter due to its excessive quantity;
- pronounced decrease in the dissolved oxygen content, especially at the bottom of the lake, due to increased organic matter decomposition reactions;
- pronounced increase in the concentration of carbon dioxide, iron, manganese, ammonia and hydrogen sulfide due to occurrence of anaerobic decomposition conditions when dissolved oxygen is depleted;
- corrosion of water storage facilities due to the occurrence of precipitation reactions of iron and manganese. The same effect occurs in water in the presence of some *Cyanophyceae* species (*Oscillatoria*), which corrodes steel tanks in the presence of light;
- the appearance of toxic substances in water disposed by some *Cyanophyceae* species (*Microcystis* and *Anabaena flos-aquae aeruginosa*), causing human gastrointestinal disease;
- replacement of special fish species by common species due to changes in water quality.

From all the effects of water eutrophication, the most important consequence is the decrease of oxygen availability. During the day, plants produce oxygen, through photosynthesis, using sunlight. In the night, all organisms consume the oxygen dissolved in water by endogenous breathing.

When excessive amounts of biomass exist in the water body, decomposing organic matter will lead to higher oxygen consumption. Thus the oxygen in the water will be depleted, leading on the one hand to the impossibility of aquatic organisms breathing and on the other hand to the occurrence of anaerobic decomposition. Therefore all the biotic components of the aquatic ecosystem will suffer.

The heterotrophic organisms will be the first affected (fish and shellfish) because of their increased sensitivity to changes taking place in the chemical composition of water, like excessive alkalinity that occurs during intense photosynthesis processes and the lack of dissolved oxygen.

Eutrophication leads to changes in the populations of organisms that live in water. This is done through changes in ecological factors, which are becoming limiting factors for development of the aquatic organisms. Mostly are considered abiotic ecological factors, such as light, temperature, water movement or quantity of certain nutrients in water.

Since eutrophication involves a high input of allochthonous nutrients, often the light is the limiting factor for algae flourishing. Thus, due to changes in optical properties of water through cover of the surface water by vegetation, a high mortality of zoobenthos, nekton and zooplankton appear.

The nutrients demand vary widely from one species to another, both in terms of type and nutrient intake, so that a deterioration of the relationship between nutrients (nitrogen, phosphorus, silicon and iron) determine changes in qualitative and quantitative composition of the phytoplankton. From all the nutrients in the aquatic ecosystems, phosphorus is given the most attention, because is essential for all phytoplankton species. From the 5000 phytoplankton species with high abundance and wide geographical distribution, only 300 produce algae flourishing. Among the species that produce large biomass are many *Cyanobacteria*, which have the capacity to produce toxic substances in the water with effects over health. Changes in the phytoplankton composition in an aquatic ecosystem will cause major changes in the entire trophic chain. Thus, the composition of primary consumers (zooplankton and fish) will change (Cooke et al., 2005).

## 2.4 Accidental pollution of hydroelectrical reservoirs

The death of fish is mainly caused by the level of dissolved oxygen. There are also some situations of water pollution with toxic substances, but they will not be detailed in this paper. As an example, in river Târnava Mare (downstream Odorheiul Secuiesc, Romania) an historical pollution incident happened in 2002 (table 1) [Serban, 2005]. It caused fish morbidity, because of high temperature (over 20°C), water flow lower than annually average, low water velocity (0.3 ÷ 0.6 m/s) and overloading with some organic substances from an upstream wastewater treatment. All these made the level of DO lower than 4mg/l.

River	F [km <sup>2</sup> ]	$Q_{ma}$ [m <sup>3</sup> /s]	$v$ [m/s]	$Q$ [m <sup>3</sup> /s]	OD [mg/l]	$T_{apa}$ [°C]	CCO-n [mg/l]	NH <sub>4</sub> [mg/l]
Crasna	1702	5.56	0.31	1.40	4.2	25	16.6	8.82
Someș	9753	82.60	0.60	33.9	4.5	28.4	15.8	4.2
Zalău	54	0.80	0.55	0.32	3.8	25	18.2	5.2
Someșul Mic	2954	17.50	0.38	6.88	1.03	28	32.4	6.2
Bistrița	650	8.38	0.40	4.70	4.2	21	4.49	2.6
Târnava Mare (Od. Scuiesc)	646	5.70	0.35	1.31	4	23.9	32.0	4
Târnava Mare (Copșa Mică)	2960	12.10	0.33	3.12	2.6	22.4	13.9	0.8

Table 1. Fish morbidity on water courses in Romania in 2002 after water pollution incident ( $Q_{ma}$  - average multi annual water flow,  $Q$  - water flow at the incident time)

If the water pollution is limited, the reconstruction of original water quality is possible only by eliminating the accidental pollution sources.

## 2.5 Management of water quality in hydro electrical reservoirs

Because the lake stratification has a negative effect on water quality, the depth of reservoirs is a great disadvantage from water quality point of view. Therefore very deep lakes are not desired. For deeper reservoirs, one measure to combat the stratification is to locate water intakes at different depths.

The main effect of the stratification in the hypolimnion and sediments is the increased consumption of oxygen and appearance of anoxic conditions which impoverish the deep

water fauna. This condition may also lead to a series of chemical and microbial processes like nitrate ammonification, denitrification, desulphurication and methane formation. The release of phosphorous from the sediments is extremely important as it accelerates eutrophication.

The following actions are required to maintain water quality in the reservoirs used by the hydroelectric development:

- the watershed management by river bed erosion control works, which will reduce the intake of silt in the lake;
- discharge of the effluent downstream the reservoir section;
- reducing water pollution;
- setting up sanitary protection perimeters around the lake and adjacent control of tourist areas;
- prevention of lake stratification and insurance of water vertical circulation through water intake at various depths and periodic use of bottom discharge system at a flow able to ensure hygiene riverbed downstream and hipolimnion renewal.
- discharges in reservoir mass is advantageous to be submerged, perpendicular to the surface of the lake for a maximum effect of aeration and movement of water layers.
- flows discharged from tailrace must have a minimum impact for downstream environment. Discontinuous discharge destroys the river bed, erodes the banks and can even break the roads and bridges. Such flows also have a stressful effect on fish.

In this way the water quality can be maintained in reservoirs without negative effects on water quality.

### 3. Aeration methods inside hydraulic turbines

As presented before, the water quality downstream hydropower plant depends mainly on the quality of water from the upstream reservoir. After water passes through the turbines, a supplementary degasification of water takes place, because of the low pressure in turbine draft tube, which lowers the DO level. This process happens mostly in Francis turbines at partial load operating regimes.

This is the main reason for developing and installing new aeration methods to increase DO level of turbinated water. From hydraulic point of view, an air quantity injected downstream turbine runner, could affect turbine efficiency. For this reason, it is recommended that air inflow to be maximum 1÷3% of turbine water flow.

#### 3.1 Existing solutions for aeration of hydraulic turbines

Measurement data are available for different technical solutions for water aeration:

- auto ventilation turbines, developed by Voith Hydro and Tennessee Valley Authority. The aeration can be made central, distributed or peripheral (through the outlet edge of blade) (Figure 5). Test were made for each aeration system individual and combined with the others. The air injection is made through new or existing passages (vacuum braking system and snorkel tubes), using air compressors or natural air admission (proffered for a lower cost).

- a system with air injection in turbine and another one with oxygen injection through porous hoses in penstock were installed at Tims Ford Dam (Harshbarger et al., 1999 and 1995).

The autoventing turbines (central, peripheral or distributed) were implemented for the first time at Norris Dam. These aeration systems can be used individually or combined. The justification for any solution depends on many parameters, characterizing each hydroelectric site. For autoventing turbines all combination were tested. When a group operates with all aeration systems the DO increased up to 5.5 mg/l. In this case the air absorbed in turbine is twice than the air absorbed by the original runners.

Depending on the operational conditions and the aeration system, the energetic efficiency decreased with 0 ÷ 4 %.

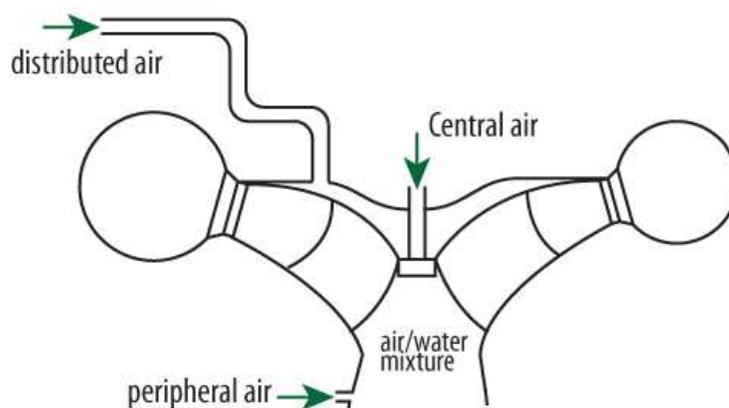


Fig. 5. Aeration methods for autoventing turbines

In other researches (March et al., 1992) the DO level in downstream water was up to 6 mg/l, trying to affect as little as possible the energetic efficiency. A few solutions were tested, like injecting air through runner, the design of a new deflector, low pressure edge blades, coaxial diffuser, injection in the conical part of the draft tube, or combination of them.

Aeration performance can be evaluated by measuring the DO level upstream and downstream turbine,

$$E = DO_u - DO_d \quad (1)$$

where  $DO_u$  and  $DO_d$  are the OD concentration upstream and downstream turbine.

The effect of aeration over the hydraulic efficiency of the turbine is

$$\Delta\eta = \eta_a - \eta_0 \quad (2)$$

where  $\eta_a$  is turbine efficiency with aeration system and  $\eta_0$  is turbine efficiency without aeration system.

Two aeration systems were tested at Tims Ford Dam (Harshbarger et al., 1995), in order to achieve a DO level of 6 mg/l, by injecting air in turbine and oxygen in penstock, through porous rubber pipes. For an upstream DO level of maxim 1 mg/l, if both aeration systems were operational, the DO level got to 5.2 mg/l and if only air system was on the DO level was 4.2 mg/l.

The air was injected with high pressure compressors under runner cover or in the draft tube. Also, porous line diffusers were installed in penstock, for oxygen injection, in case the desired DO level (6 mg/l) is not reached only with the air injection system. The cost of this oxygen injection system in 1995 was of 300'000 \$.

Both systems were used during low DO level periods. In order to evaluate the DO level increase and turbine efficiency, the air, oxygen and water discharge were modified during tests. In any of the cases, the turbine efficiency decreased with maxim 1%, so the aeration didn't affect it too much. But this technology was rejected because of the rate between initial installing cost, long time operation and service cost.

Another research study, developed during two years, was made at la Bagnell Dam (Sullivan et al., 2006), over two turbines (with runner aeration orifices), an old one and a new one, with some changes. The tests were made for 51 combinations of water discharge, downstream water depth and aeration orifices diameters and were determined the water discharge through orifices, DO level and water temperature in sections upstream and downstream turbine. As a general conclusion, the oxygen transfer efficiency increases with the increase of air discharge and of downstream water level.

For the older turbine, it was noticed that for smaller openings the runner orifices are more efficient than draft tube orifices, and that when both aeration systems were operational and the water discharge was small, the DO level was over 5 mg/l.

Some researchers made studies concerning DO, temperature and fish growth downstream the hydro plants (Boring, 2005). For the Saluda River (U.S.) a model based on the historical data from 1990-2005 had been developed. In accordance with Environmental Protection Agency (EPA), the criteria established for 2006 are: for survival of trout - min. 3 mg/l, for growth protection - 6.5 mg/l for an average of 30 days, and for sensitive cold-water invertebrates - min. 4 mg/l.

The studies and researches continued with mathematical modelling of the flow (Rohland et al., 2010) for the three classical aeration methods in a Francis turbine. Each classical injection method has different characteristics and influence over the dimension and distribution of bubbles that flow through the draft tube and over the operating efficiencies.

The parameters that influence the efficiency are: the shape and length of draft tube, bubble retention time, quantity of air or the void fraction, air admission intake, bubble size and distribution. From quantity of air or the void fraction point of view, central aeration is the most efficient. The calculations for turbine efficiency and the aeration methods were used for optimization of aeration solution at Bridgewater plant, one of the first power plants designed in respect to aeration.

In Romania, environmental impact and water quality are main concerns, but the aspects of DO level are not taken in consideration. Even if the hydropower operators are preoccupied about environmental issues, there is no legal support for DO level. Turbine aeration (especially central zone) is made only in a few sites, but with hydraulic purposes (to reduce central vortex at partial load) in order to reduce pressure fluctuations.

### 3.2 Aeration efficiency and main parameters

As mentioned before, two main parameters must be considered in the aeration process: the DO transfer through air injection and the total energetic consumption to realize it.

The DO transfer necessary for water quality improvement, depends on many physical parameters: the quantity of injected air, the gas – liquid contact surface, time of contact, temperature, pressure gradient flow, DO level gradient, turbulence level of flow.

The energetic consumption necessary to introduce the air in liquid depends on the following operational parameters: the quantity of injected air, injection method (natural or induced), air influence over turbine efficiency (flow changes).

In order to obtain a good global balance the DO transfer must be done with a minim energetic consumption. For this purpose is necessary to generate an optimal dimension for the gas bubble – as small as possible (the positive effect is double, because of increasing contact surface and retention time), but with low hydraulic losses for decreasing energetic consumption.

The main parameters that must be considered to find the best compromise between the improvement of water quality and modification of turbine efficiency - see table no 2.

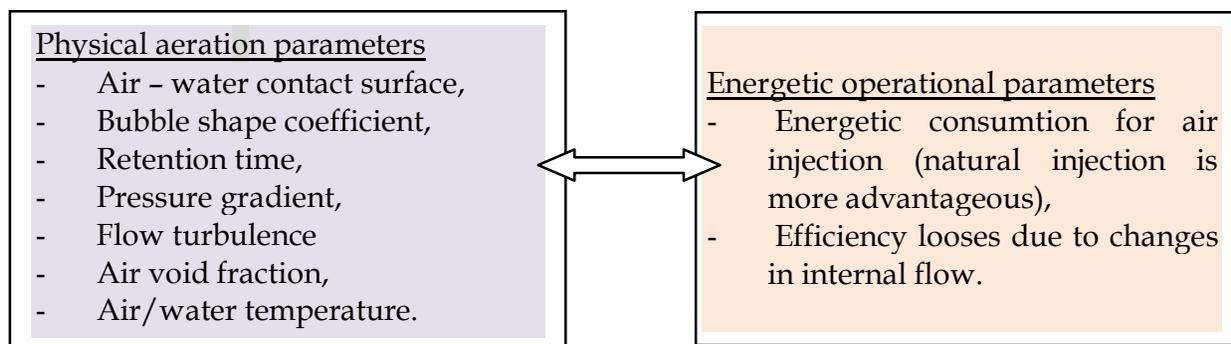


Table 2. Parameters considered for aeration efficiency balance

The air injected in turbine affects its efficiency in two ways: because of the flow perturbation caused by air introduced in water flow and because of energetic consumption necessary to introduce the air. Considering the above, the injected air flow is limited to 1÷3% of water inflow. Usually, this air quantity is not enough to have a good aeration and to obtain the minim reference DO level (5÷6 mg/l) in downstream waters. The natural absorption of atmospheric air is preferred, because it uses the existent turbine depression.

The hydrodynamics and the mass transfer of bubble columns are the subject of many research studies. The matter is analyzed from different aspects: the velocity induced by the bubbles to the liquid (Krishna et al., 1999), (Wiemann and Mewes, 2005), (Ekambara and Dhotre, 2010), bubbles generation regimes (uniform, transient and heterogeneous) (León-Becerril et al, 2002), (Pincovschi et al, 2007), size distribution of gas bubble gas (Katerina et al, 2004), (Polli et al, 2002), Laser Doppler Anemometry and Particle Image Velocimetry measurements (Mayur et al, 2010) (Laakkonen et al, 2005), (Becke et al., 1999), (Ciocan et al., 2011), void fraction and volumetric transfer coefficient (Krishna and van Baten, 2003), numerical simulation of mass transfer (Painmanakul et al. 2009), (Connie et al, 2003).

Mathematical models for turbulent two phase flow in complex configurations is one of the most difficult part in gas - liquid flow simulations, not solved until now. A more detailed representation of bubble movement and of their interaction with the liquid phase can get to development of turbulence models. In spite of consistent efforts for a correct description of closing rules for drag forces, lift forces and mass forces, the precisely model of interfacial forces remains an open matter in this kind of numerical simulations.

This paragraph is focused on correlation of aeration quality (oxygen transfer for a constant injected air flow), with the energetic efficiency of the transfer (energy consumption for introduction of the air flow).

Further on is presented the air bubble dimension influence on DO transfer, in relation to aerator required pressure, for different air discharges. Five metallic perforated plates were used (Bunea et al., 2010) with different orifice sizes ( $d$ ) and identical geometries (Figure 6).

The total perforated surface area is equal in all configurations ( $12 \text{ mm}^2$ ). The tests were made in same hydrodynamic conditions, in a tank with 79.2 l of water. For each plate were determined the DO level ( $C$ ), water temperature ( $t$ ) and pressure losses ( $\Delta p$ ) on aeration system. The experimental results concerning DO level in time, are determined according ASCE regulations 2-91/1993.

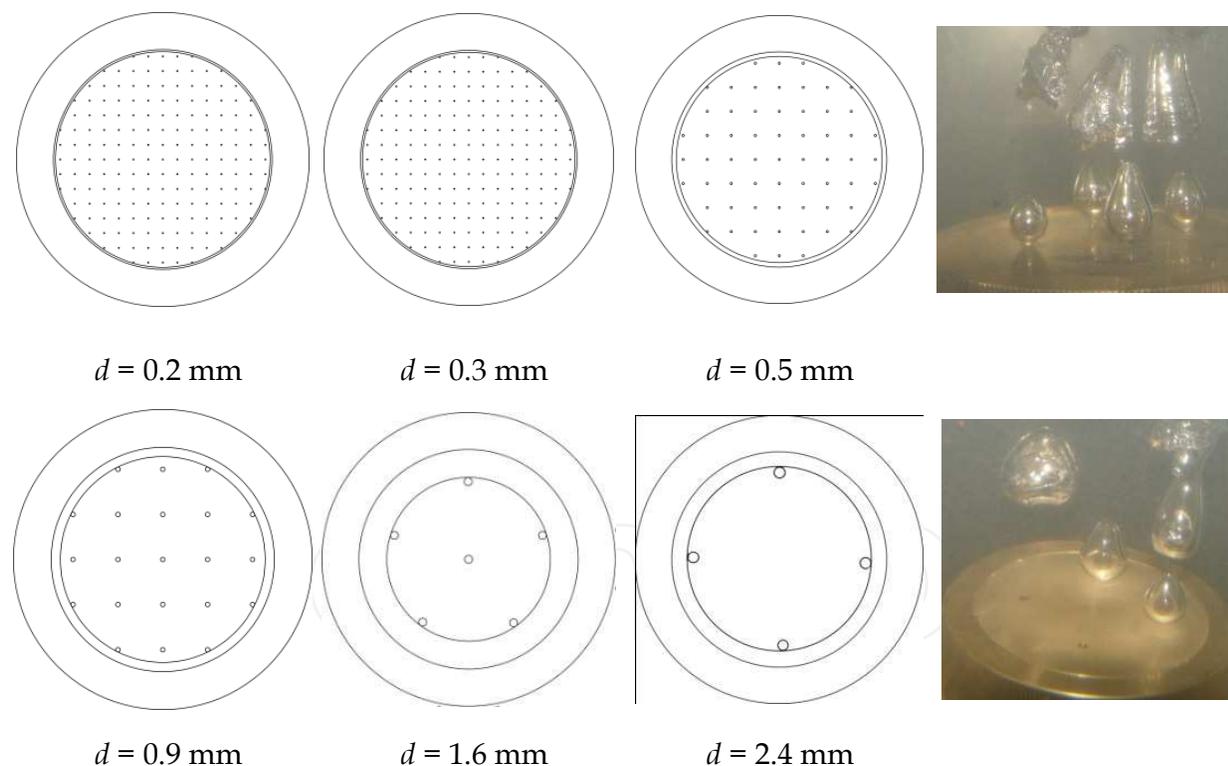


Fig. 6. The layout of the orifices on metallic plates

By keeping constant the following parameters: air flow rate  $Q_{air}$ , water volume and total area of perforations, the increasing of air-water interfacial area for the first layer of bubbles ( $A$ ), standard oxygen transfer rate ( $SOTR$ ) and standard aeration efficiency ( $SAE$ ) with the decreasing of orifice diameter can be observed, while the pressure loss on perforated metallic plate ( $\Delta p$ ) increases with maximum  $27 \text{ mmH}_2\text{O}$  (Table 3).

d (mm)	A (mm <sup>2</sup> )	$\Delta p$ (mmH <sub>2</sub> O)	SOTR (mg/min)	SAE (kg/kWh)
1.6	326	16	33.37	2.50
0.9	781	28	33.35	2.48
0.5	1524	30	49.74	3.67
0.3	3150	34	67.45	4.95
0.2	5233	43	77.08	5.59

Table 3. Evolution of mass transfer parameters with the orifice diameter for constant air discharge  $Q_{air}=360$  l/h

Figure 7 shows the influence of orifice diameters on standard aeration efficiency provided by the metallic plates for different air flow rates (Bunea et al, 2010). Also, by increasing orifices diameter is necessary to increase the air flow rate, otherwise the plates generate bubbles from half of their surface. A bigger air flow rate leads to increased pressure losses on the aeration device and diminishes the standard aeration efficiency. Finally is obtained the efficiency of the oxygen transfer rate related to power needed to inject the air.

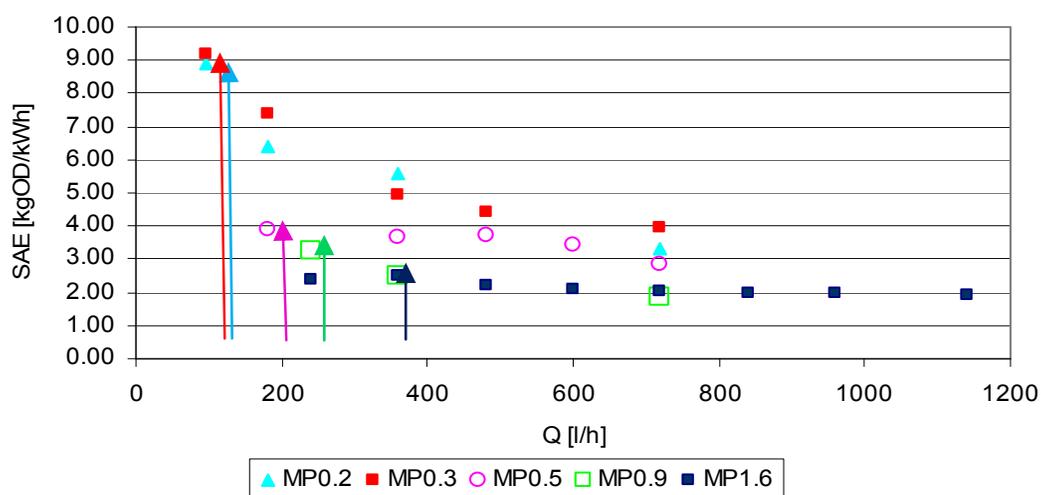


Fig. 7. Variation of SAE with the air flow rate and the orifice diameter of plates

A basic study of the air column in a water tank shows the importance of the quality of air injection, meaning: bubble size, pressure loss on the aeration device etc. for the oxygenation purpose. Different types of bubble aeration systems have been tested and compared. Starting with the experimental results, the influence of air bubbles dimension upon mass transfer is pointed out and the results are correlated with the pressure needed for the aeration device operation (pressure loss) at different air flow rates ( $Q = 180\div 1160$  l/h). Thus, efficiency SAE increases while air flow rate and the size of orifices in plates decreases.

#### 4. Water chemical parameters in reservoirs of low head hydropower plants

It is important to study in time the water chemical parameters in large reservoirs. Big hydroelectric projects change the environment, creating retention lakes, the interaction between water and equipment materials causing different corrosion stages. In the same time, the equipments and their operation can affect the water quality (oil leaks, water degasification the through the turbines etc.).

The Lower Olt cascade from Romania (fig. 8) is an important and unique hydroelectric site, made of five identical plants (HPP). Each HPP has four bulb turbine-pump units, with a total installed discharge of 500 m<sup>3</sup>/s and 13.5 m net head. The corresponding reservoirs have a volume to normal retention level between 62 · 10<sup>6</sup> m<sup>3</sup> and 99 · 10<sup>6</sup> m<sup>3</sup>.

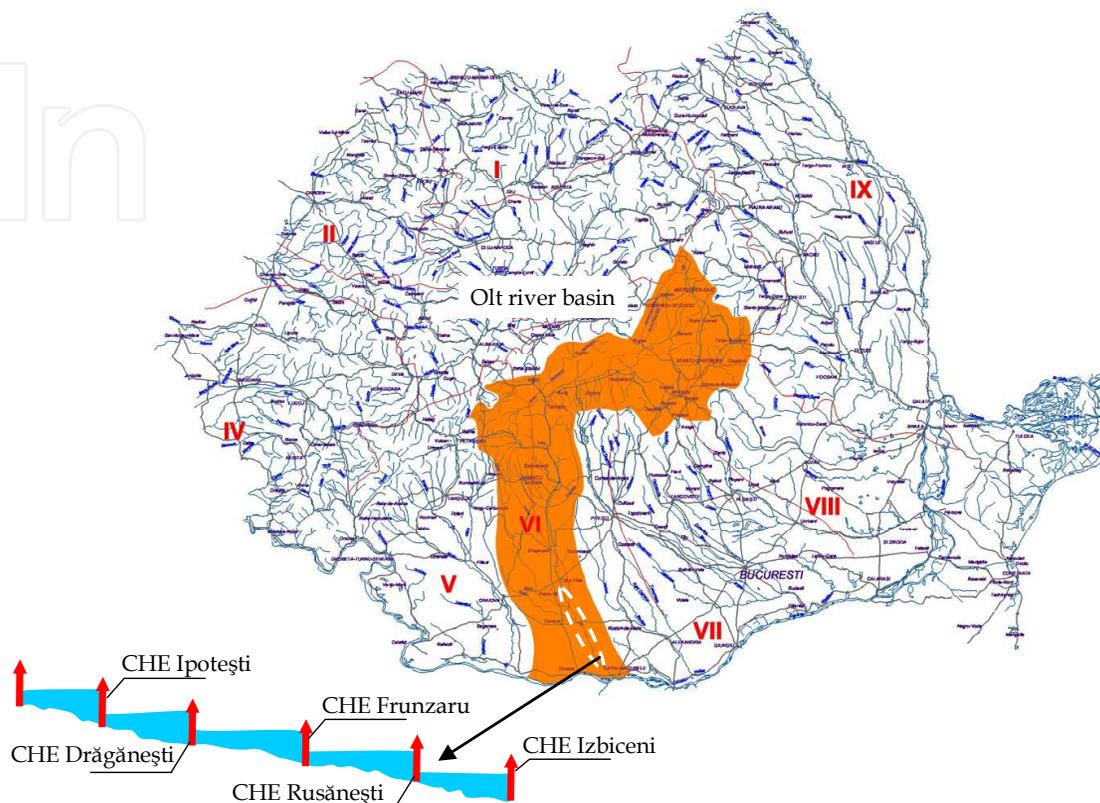


Fig. 8. Lower Olt cascade

A special particularity is that all five HPP operate both turbine and pump regime, which means important volumes of water are transported downstream and upstream in the same site. This could affect in a negative way the water quality by preserving for a longer time the accidental pollution effects.

Because water quality and environment protection are main concerns, the chemical parameters of water in Olt River, is periodically analyzed. For example, a few parameters recorded after ten years of operation and after twenty years, shows that the long time interaction between water and the equipment of HPPs, did not affect the quality of water.

Generally, all parameters remained at the same values, or even decreased, excepting sulphuretted hydrogen, but still remains in admitted values. During the analyzed period, there were no pollution accidents, neither in the hydropower plants in the Olt River and nor in its effluents.

It is also important to determine the effect of water on the equipment (corrosion). For this purpose, determinations in ten different measurement points along Lower Olt cascade were made for the level of pH indicator, chlorine content and manganese content. The results showed for pH indicator that five values are between 5.5÷6.5, and five of them are between 6.5÷7.0, all being between 6.5 ÷ 8.5, the reference limits for natural waters.

Parameter	Unit	Measured values	
		After 10 years	After 20 years
pH	u. pH	8.19-8.23	7.15
Dissolved oxygen	mg/l	4.8-5.9	5.1
CBO <sub>5</sub>	mg/l	1.8-2.2	1.1
CCO-Mn	mg/l	5.7-6.2	2.203
Sulphuretted hydrogen	mg/l	<0.001	0.409
Phenols	µg/l	10	1.68
Phosphate	mg/l	<0.01	0.06
Chlorides	mg/l	85.3-92.1	73.4
Total hardness	°G	7.91-8.38	10.53

Table 4. Water chemical parameters in Lower Olt cascade reservoirs

The chlorine content is between 20 mg Cl/l and 106.5 mg Cl/l and the total manganese contents are up to 0.004 mg Mn/l, but mostly is zero. The total manganese content being so low the possibility of strong oxidizer appearance on the steel surface can be excluded (Bucur et al., 2010).

These results show that after twenty years of continuous, the water quality in this complex hydroelectric site was preserved from physical - chemical point of view. The dissolved oxygen quantity has a level that allows the preservation of aquatic life.

## 5. Conclusion

The hydraulic energy is an essential green energy source and important for the integration of the others energy sources in the energy system. However, as an essential live source - water - is used for energy generation, to conserve the green character of power generation, accompaniment measures are to be implemented on the hydropower plants sites.

The quality of water in a hydro electrical site depends on both natural factors - like temperature variations, precipitation intensity and frequency, thermal stratification reservoirs, and operational parameters and components of the hydro electrical site. The behaviour of the water in the lake is to be studied and considered in operation. To not take in consideration this behaviour, the complete eutrophication of the lake can happen, with huge consequences of the ecological system.

Another essential topic is related to the released water. The required parameters to preserve the aquatic life are to be insured; the main parameter is the DO, and 5 mg/l are needed. Aeration devices can be implemented to improve the DO content. The implementation has to consider the compromise between the positive effect of air injection and the inconvenient of energy losses due to air injection (energy needed for injection and energy losses due to flow perturbation by the air injection). Aeration devices can be implemented on new facilities or in the refurbishment process. Actual studies are done to improve the efficiency of the aeration.

The environmental impact of a hydroelectric power plant should be minim, and the water parameters should be as close as possible to natural water course values. The necessity of supervising of the water quality is a reality that should be a main concern for all

hydropower users and will permit to prevent the degradation of the ecological system or to implement the needed system to improve the water quality.

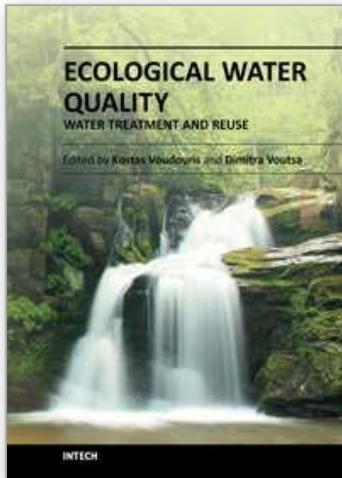
## 6. Acknowledgment

This paper has been elaborated with the support from the Romanian National Council for Scientific Research in Education, IDEAS program, contract no. 705/2009, ID 1701, and by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/89/1.5/S/62557.

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## **Ecological Water Quality - Water Treatment and Reuse**

Edited by Dr. Voudouris

ISBN 978-953-51-0508-4

Hard cover, 496 pages

**Publisher** InTech

**Published online** 16, May, 2012

**Published in print edition** May, 2012

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### **How to reference**

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