THE STRATEGY OF THE CONTROL OF NUTRIONAL ELEMENTS IN THE WATER RESERVE

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ABSTRACT

The eutrophication of lakes and reservoirs is rising universal problem. The increase of the degree of nutritive elements caused by the proliferation of organic, and industrial waste and fertilizer, can lead to a complication of various problems.

The thermal stratification of lakes and reservoirs may be a consequence of the hypolimnion oxygen lost, which can have negative impacts on cool water fish, on the drinking water and the quality of downstream water.

In such situation, the techniques of restoration of lakes for the prevention against eutrophication are numerous (chemical, biologic, mechanical…). Due to their excessive cost and the relatively insignificant income of some of these techniques, the process of dynamic aeration is one of the most promising methods

Four strategic techniques of the control of nutritional elements are selected for this study: artificial destratification by the bubble plume, partial (or total) lift hypolimnetic aerator, bubble plume oxygenation and Speece Cone oxygenation.

Each of these methods has its advantages and inconveniences. A technical and economic analysis established by different researches reveals that the hypolimnetic oxygenation is the most favourable strategy for the control of nutrional elements. In hypolimnetic aeration systems, the aeration system by bubble plume appears to be the most economic and perhaps the simplest among the systems used in Standley lake (Colorado, U.S.A), even as other researches select Speece Cone aeration system.

On the base of these researches, this study makes a state of synthesis on a number of issues related to the aeration in lakes and reservoirs, including the advantages and the inconveniences of these aeration systems. As well, this study concentrate on the economic and technical sides associated to these aeration systems.

Keywords: Eutrophication, aeration, stratification, techniques of restoration, pollution.

1. INTRODUCTION

Density stratification of lakes and water storage reservoirs is a common occurrence (Paterson et al. [1] and Schladow [3]). Thermal stratification of lakes and reservoirs can result in substantial hypolimnetic oxygen depletion, which may have a negative impact on the cold-water fisheries, the drinking-water treatment process, and water quality downstream of hydropower reservoirs (McGinnis et al. [2]). When the duration is sufficiently long, oxygen depletion resulting from biochemical and biological demand can occur in the hypolimnetic water that became isolated from the water surface. The immediate consequences are varied and can include the formation of iron and manganese solution and suspension compounds, methane, hydrogen sulfide, ammonia, phosphorus, and which cause to fish killing (Schladow [3]; Kirke et al. [4] and McGinnis et al. [5]), accelerated internal recycling of nutrients, solubilization of metals, and provoke also taste and odor problems that are undesirable in water supplies (Kirke et al. [4]; McGinnis et al. [2] and McGinnis et al. [5]). These conditions eradicate fish populations because the eggs deposited in anoxic sediments may not develop (McGinnis et al. [5]).

There are two large categories of artificial aeration of lakes, which can be used separately or in combination (Wuest et al. [6]):

- Artificial mixing of the water column during the cold season;
- Input of oxygen into the hypolimnion during summer in such a way as to preserve the stratification

  Each of these methods has its advantages and inconveniences.

2. AERATION SYSTEMS

2.1 Aeration by the Destratification System

Aeration by destratification was first reported by Scott and Foley (1919), this technique in commonly achieved by air injection through a single air diffuser (Fig. 1) (Fast [9]).

In addition to the air injection described, other techniques include mechanically pumping bottom water to the surface, and mechanically pumping surface water to the bottom (Fast [9]).

Figure 2 shows oxygen and temperature values at El Capitan reservoir (San Diego, USA) before and during artificial déstratification**.** These values are for mid-August each year. The lake was not aerated during 1964. It was aerated in June 1965 and March 1966 (Fast [9]).

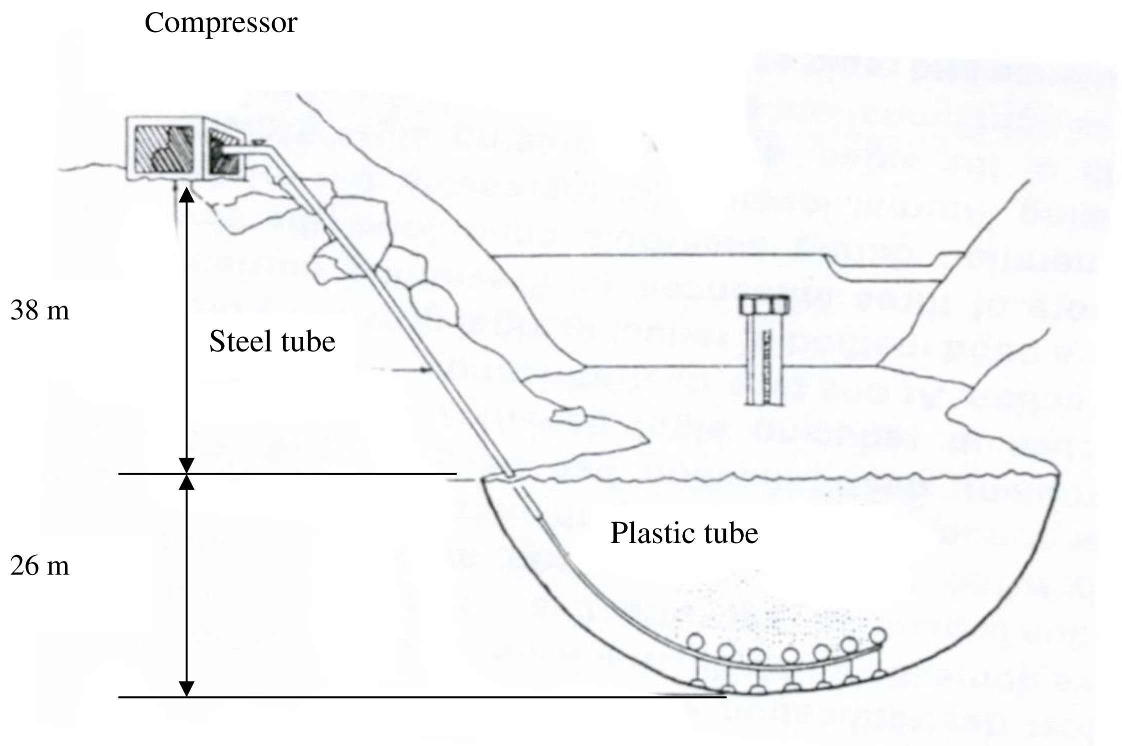

Figure.1. A simple lake destratification system (Fast [9])

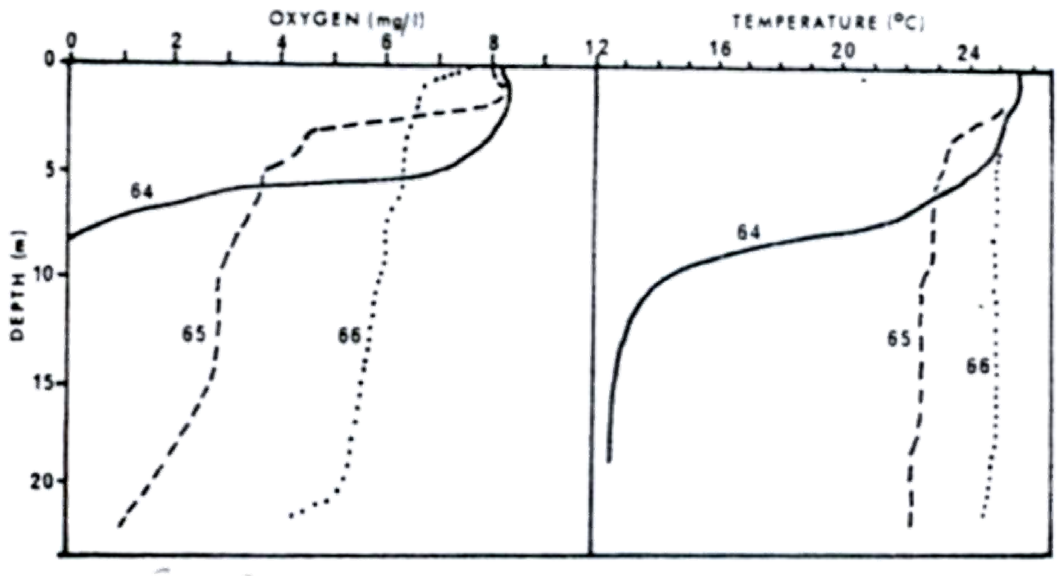

Figure 2. Oxygen and temperature values at El Capitan Reservoir before and during artificial destratification (Fast [9])

2.2 Hypolimnetic Aeration

Figure 3 shows oxygen and temperature values in Waccabuc Lake, N.Y. (San Diego, USA) before and during hypolimnetic aeration. The lake was not aerated during 1972, but aeration began during early July 1973. Oxygen concentrations increased from 0.0 mg/1 to more than 4 mg/1, while the temperature did not change much (Fast [9]).

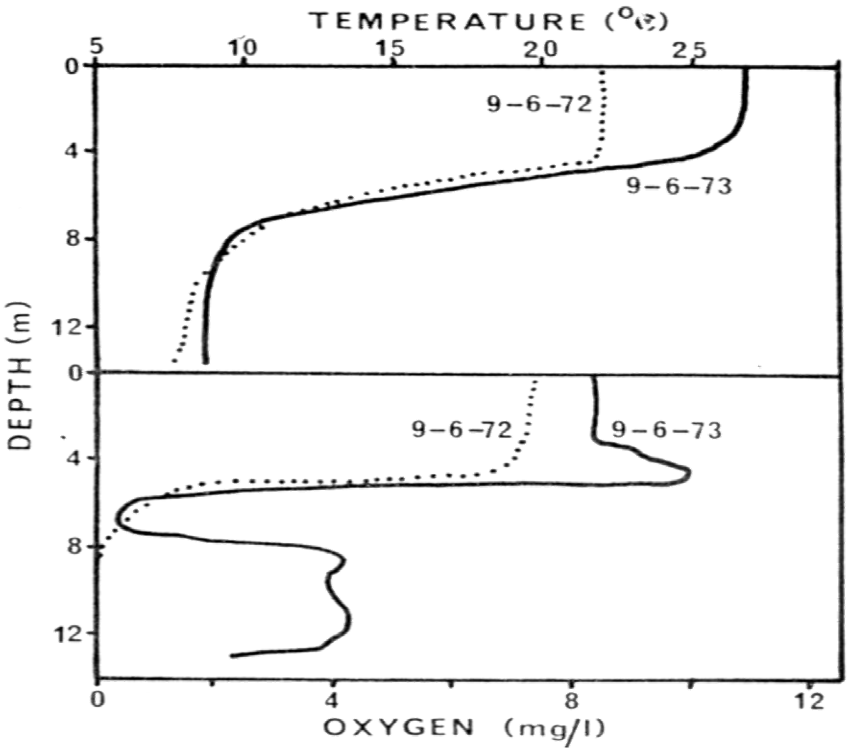

Figure 3. Oxygen and temperature values at Waccabu Lake, N.Y before and during hypolimnetic aeration (Fast [9])

Three oxygen input devices are used for hypolimnetic aeration (Fig. 4) (McGinnis et al. [7]):

- Partial-lift hypolimnetic aerator (Fig. 4-a).
- Bubble-plume oxygenator (Fig. 4-b).
- Speece Cone oxygenator (Fig. 4-c).

In the three mechanisms of oxygenation, the bubbles gas in contact with water make easier the interfacial transfer of oxygen, as well as nitrogen and other soluble gases (McGinnis et al. [2]).

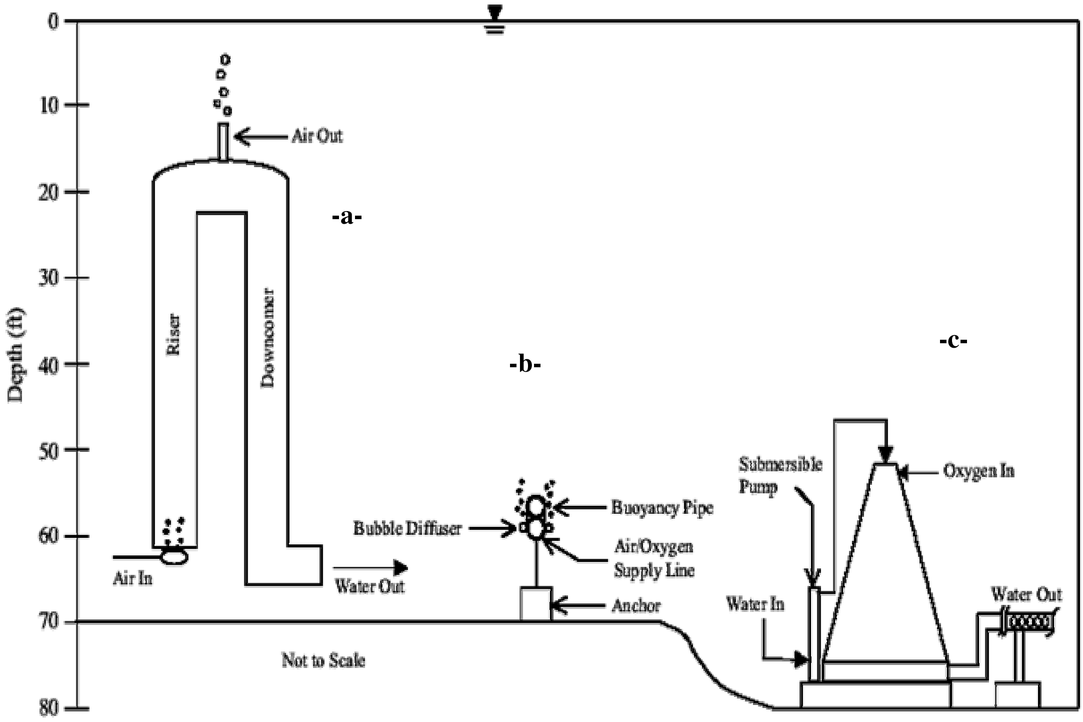

Figure 4. Schematic Representation of Three Oxygen Input Devices (McGinnis et al. [7])

2.3 Compared Effects for Aeration Systems

2.3.1. Compared Effects for Hypolimnetic Aeration Systems

On the base on a study made for Standley Lake (Colorado, USA), McGinnis and Little [7], revealed a technical and economic analysis for these three systems of aeration (Fig. 4) in order to select the most appropriate mechanism for a specific lake and thus optimize both the conception and operation which can assures the most great efficiency of oxygen transfer.

Table 1: Partial-lift hypolimnetic aerator (McGinnis et al. [7])

Variable and predicted performances:	Values
- Air flow (Nm^3/s)	0.12
- Height of ascending tube (m)	12.2
- Diameter of ascending tube (m)	3.10
- Flow of drained water (m^3/s)	1.17
- Increase in oxygen concentration (g/m^3)	4.60
- Efficiency in oxygen transfer (%)	**16**
- Total oxygen transfer (16 aerators) (kg/jour)	464
- Oxygen transfer by aerator (kg/day)	7400

Table 2: Bubble plume (McGinnis et al. [7])

Variable and predicted performances:	**Values**
- Oxygen flow (Nm^3/s)	0.069
- Initial diameter of bubbles (mm)	2.5
- Length of the diffuser (m)	2.500
- Initial speed of the plume (m/s)	0.038
- Height of the plume rise	1.5
- Efficiency in oxygen transfer (%)	**93**
- Total oxygen transfer (kg/day)	7400

Table 3: Speece Cone (McGinnis et al. [7])

Variable and predicted performances:	**Values**
- Oxygen flow (Nm^3/s)	0.068
- Initial diameter of bubbles (mm)	2.0
- Imposed water flow (m^3/s)	1.3
- Detention time of bubble (min)	2.0
- Increase in oxygen concentration (g/m^3)	66
- Total oxygen transfer (kg/day)	7400
- Efficiency in oxygen transfer (%)	**94**

Results

McGinnis and Little [7] showed that the diffuser of the bubble plume is the most economic system and may be the most simple among these three systems. Their conclusions have been based on the following facts (McGinnis et al. [7]):

- In the 16 aerators of air ascension, the efficiency of oxygen transfer is the smaller (16 %).
- For the Speece Cone, and the bubble plume, the values of the efficiency of oxygen transfer are very close (respectively 94 and 93 %). In addition a high value of the water speed must be maintained in the whole cone in order to insure that the bubbles would not reach the equilibrium with water in the cone. This may lead to a huge accumulation of bubbles and coalescence in the cone yielding to a decrease in the total efficiency.

By his side, Fast [9] proposed a comparative study for the three systems of hypolimnetic aeration (Fast [9]):

- Side-Stream Pumping (S.S.P) (Fig. 6).
- Hypolimnetic aerator of partial air ascension.
- hypolimnetic aerator of total air ascension**:** This system is typically operated at pressures high than 3 atm and water temperatures of 10°C or less. The efficiency of this system is based on the great solubility of pure oxygen and its pressure injection in the water (Fast [9] and Fast et al. [10]).

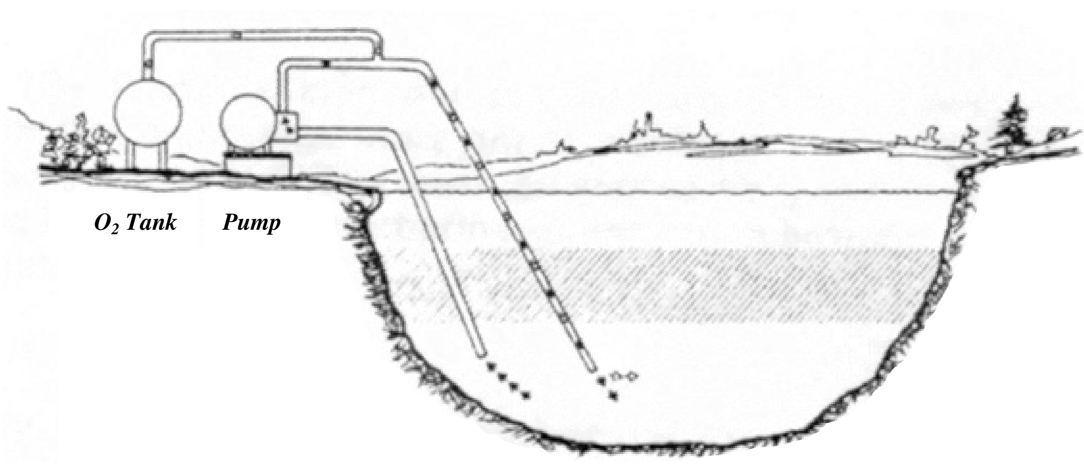

Figure 6. Side-Stream Pumping (S.S.P) (Fast, [9] and Fast et al. [10])

Many authors compared the fees of three types of hypolimnion aerators, and found out that the conception of total air ascension has the exploitation fee the much less and the higher efficiency. The **S.S.P** has a much smaller capital cost (Fast [9]).

In 2002, Marc Beutel exposed a comparison between the hypolimnetic aeration systems. He focused on the associated costs and the effect on the water quality (Beutel [11]).

Table 4 shows the costs as well as the advantages and the inconveniences of the different oxygenation systems

Table 4: Oxygenation systems (Beutel [11])

System (reference)	Capital cost	Operational cost	Advantages	Disadvantages
Pure oxygen submerged chamber	$1 million	$ 850	Very high oxygen transfer efficiency. Oxygen discharged horizontally over sediment-water interface. System efficiency independent of lake depth	Need for a submerged pump and chamber.
Deep pure oxygen U-tube	Not reported	$ 1.000	Low operating cost compared to on shore chamber. System efficiency independent of lake depth.	Need to construct 175-foot deep U-tube. Pumping involved.
Diffuse deep-water oxygenation	$1 million	$ 1.000	No pumping. Good horizontal distribution of oxygen.	Oxygen release above and away from sediment-water interface. System efficiency decreases with lake depth. May impact thermal stratification.
Shallow pure oxygen U-tube	Not reported	$ 1.200	Tube only 20-30 feet deep. System efficiency independent of lake depth.	Pumping involved. Compared to deep U-tube, less oxygen delivered per unit flow through the system.
Bubble plume oxygenation	Not reported	Not reported	By pumping air through the diffusers, it can also be as destratification system.	System efficiency decreases with lake depth. Oxygen released above and away from sediment-water interface. System can impact thermal stratification.
Pure oxygen on shore pressurized chamber	Not reported	$ 3.000	Most facilities on shore. System efficiency independent of lake depth.	High pumping cost.

2.3.2 Compared Effects of Destratification and Hypolimnetic Aeration Systems

Ruane and his co-workers (1977) have compared the two methods of aeration (Table 5) upon application to the Patrick Henry Dam (south of Holston River, USA) (Ruane et al. [13]).

Table 5: Application domain of the different aeration methods for the Patrick Henry Dam (Ruane et al. [13])

Conditions under which the aeration technique must be applied	Destratification		Hypolimnetic Aeration with diffusion	
	Mechanical Pumping	Air Diffusion	Air	Oxygen
Cold water	-	-	+	+
Strong increase in DO	-	-	?	?
Minimal effect on the production of energy	+	+	+	+
Minimal increase in the dissolved nitrogen	?	?	?	+
Small cost	+	+	-	-

Note:
+ indicates a positive effect on the particular aeration method
- indicates a negative effect on the particular aeration method
? indicates an unknown effect for the shown condition

Report

Ruane and his co-workers (1977) reported that the destratification and the hypolimnetic aerations are not applicable to the Patrick Henry dam. They explained that the first method could increase the water temperature and consequently leads to ominous effects on the piscicol live, since the dam is classified as a cold water fishery.

In addition, the hypolimnetic aeration with air causes nitrogen oversaturations, and the aeration with oxygen is not promising due the high cost of oxygen (Ruane et al. [13]). The published effects of the oxygenation on the nitrogen concentration have not been consistent. The total nitrogen and total ammonium diminish in some surveys, but increase in others (Vickie et al. [12]). On the base of their survey achieved for the Patrick Henry dam, and using the oxygen diffusion in an aeration turbine, Ruane and co-workers mentioned that most of the economic sources of oxygen may come from the liquid oxygen in the reservoirs provisions instead of the production of gaseous oxygen in this site, because the required oxygen is seasonal, varies largely and is relatively low (Ruane et al. [13]).

In order to increase the content in hypolimnion oxygen, the technique of oxygen gas can be used instead of the air technique. The advantage of the first technique is that the compressor is not necessary, and that the oversaturation with nitrogen cannot be reached (Ruane et al. [13]).

3. COMPARED POSITIVE EFFECTS OF HYPOLIMNETIC AERATION AND DESTRATIFICATION AERATION

3.1 Destratification Aeration Systems

- The destratification is generally effective, especially when the presence of hydrogen sulphide, iron, manganese and other associated conditions with anaerobic water are problematical (Fast [9]).
- The destratification may limit the proliferation of algae, if the mixing is total, and if the lake has a relatively sufficient depth in its euphotic region (Fast [9]).
- Many surveys showed a substantial increase in the distribution of fish depth associated with the destratification (Fast [9]).
- In winter, the destratification system can prevent the fish killing by oxygenation of ice covering the lakes (Fast [9]).
- Sometimes, the destratification can increase the production, by bringing to the surface the nutritional elements regenerated from the hypolimnion, which are not precipitated by the increase of the reduction-oxidation potential or by the $CaCO_3$ (Fast et al. [8]).

3.3 Hypolimnetic Aeration Systems

The hypolimnetic aeration has many advantages on the destratification system. The nutritional elements (nitrogen and phosphorus) are not transported to the epilimnion where they can stimulate the algae proliferation, and the process can preserve a cold water habitat for fishes such as salmon and trout (Vickie et al. [12]). The advantage of hypolimnetic aeration is the aptitude to re-supply dissolved oxygen while preserving the thermal stratification (McGinnis et al. [5] and McGinnis et al. [2]).

The hypolimnetic aeration can increase the diversity of species by the creation of an adequate habitat for cold water fishes such as trout and salmon (Fast [9]).

Sometimes, the hypolimnetic aeration is preferred more than the destratification in the management of the fishery and in the supply of domestic and industrial water, since the total mixing may promote an increase of algae (Fast et al. [8] and Fast [9]).

The hypolimnetic aeration can be also used to prevent winter fish death. The application of this system during the summer yiels to the oxidation of organic materials and reduce then the oxygen demand in winter (Fast [9]).

4. CONCLUSION

This study lets to conclude that:

- The aeration by oxygen limits the nitrogen saturation; in contrast the aeration by air creates it.
- The most efficient hypolimnetic aeration system is the bubble plume diffuser; although an accidental destratification may occur.
- The destratification can be used in winter because the temperature of the lake is not modified. However, the hypolimnetic aeration is used in summer in order to avoid the homogenization of the lake temperature during this period.
- For reservoirs and dams, the summer destratification is not profitable due to the warming-up of the reservoir water which becomes non drinkable.

Nevertheless, some experiments showed that the mechanical aeration is not lasting for the following reasons:

- Duct pipes are frequently plugged by algae, and consequently become difficult to entertain;
- When the mechanical aeration is stopped, the lake rapidly turn out to be eutrophized;

Consequently, and according to the depth and dimension of the exploitations, we can distinguish two kinds of restorations:

- The restoration by destratification appears to be the most adapted to the cold-time season and to small depth lakes or reservoirs having exploitations destined exclusively to the feeding or the irrigation.
- The hypolimnetic aeration suits to deep lakes or reservoirs destined to different exploitations (feeding, irrigation, leisure, etc...), allowing the amortization of the invested fees for the system.

However, it should be noted that the in the case of lakes or reserves destined to fish raising, the hypolimnetic oxygenation permits to avoid the undesired supply of nitrogen coming from the aeration by air, and guarantees the preservation of the fish masses.

We estimate in the present situation of our knowledge and with the subject care, that the best way to fight against the raising pollution of the aquatic middle is to reduce the rate of nitrogen and phosphorus in the loads coming from punctual sources and particularly domestic sewage.

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