PROGRAMMES FOR THE CONTROL AND RESTORATION OF DEGRADED AQUATIC SYSTEMS

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ABSTRACT: The paper focuses on the necessity of the implementation of programmes for *the control and restoration of degraded aquatic systems. Two case studies concerning the utilization of mechanical processes (hypolimnetic aeration and sediment removal) are described. Emphasis is given to the fact that these techniques should be always applied in conjunction with measures related to the management of the watershed.*

INTRODUCTION

The aquatic systems all over the world are, in general, subjected to an intensive degradation of their quality, caused by the discharge of nutrients in excess, contaminants, toxic substances and minerals. The resulting processes of artificial eutrophication and silting can nowadays be easily observed in water bodies of different characteristics, mainly in those located in urban areas. The existence of these problems, which directly affect the different water uses (water supply, energy generation, irrigation, navigation, recreation) leads to the necessity of the implementation of regular programs for the control and restoration of degraded aquatic systems.

This consideration applies particularly to lakes and reservoirs, water bodies which are most susceptible to the negative influences listed above. The strategies usually adopted for controlling the eutrophication and silting of lakes and reservoirs fall into two categories:

a) those concerned with watershed management, such as construction of sewerage systems, wastewater treatment plants and measures for erosion control;

b) the in-lake techniques, which are implemented within the lake or reservoir itself. Examples of these techniques include:

- mechanical processes, such as destratification, hypolimnetic aeration, dilution/flushing, sediment removal, sediment covering and shading;

- chemical processes, such as phosphorus precipitation and inactivation, sediment oxidation and the use of algicides;

- biological processes, such as food chain manipulation.

This paper will focus on the use of two mechanical techniques for restoration of lakes and reservoirs: hypolimnetic aeration and sediment removal.

HYPOLIMNETIC AERATION

Since the main problem caused by the eutrophication of lakes and reservoirs is the strong demand of dissolved oxygen for the mineralization of the biomass formed during the process, it would be reasonable to conclude that the injection of oxygen in the water body would contribute to solve this inconvenience. The first attempts to oxygenate lakes and reservoirs consisted of the injection of compressed air from a pipe or ceramic diffuser located at their bottom. The rising column of bubbles could produce a lake-wide mixing, increasing the algae cell's time in darkness and leading to reduced net photosynthesis. Also the phosphorus release from the bottom of the lake could be inhibited, curtailing this internal nutrient source. This kind of artificial circulation, however, should not be employed in lakes or reservoirs with anoxic hypolimnia: in these cases the thermal stratification would be destroyed through large amounts of oxygen-deficient water, causing frequent fish killings.

An alternative idea was then developed for deep lakes with high values of hypolimnetio oxygen demand. In these cases an air lift device was employed to transport the cold hypolimnetic water, mixed with compressed air (Fig. 1). The air/water mixture did not rise to the lake surface but only up to a certain region in the hypolimnion. The flow then returned to a plane near the bottom, to where it was discharged. Although the air-water contact time was in this case much smaller, this technique prevented the undesirable destratification of the lake.

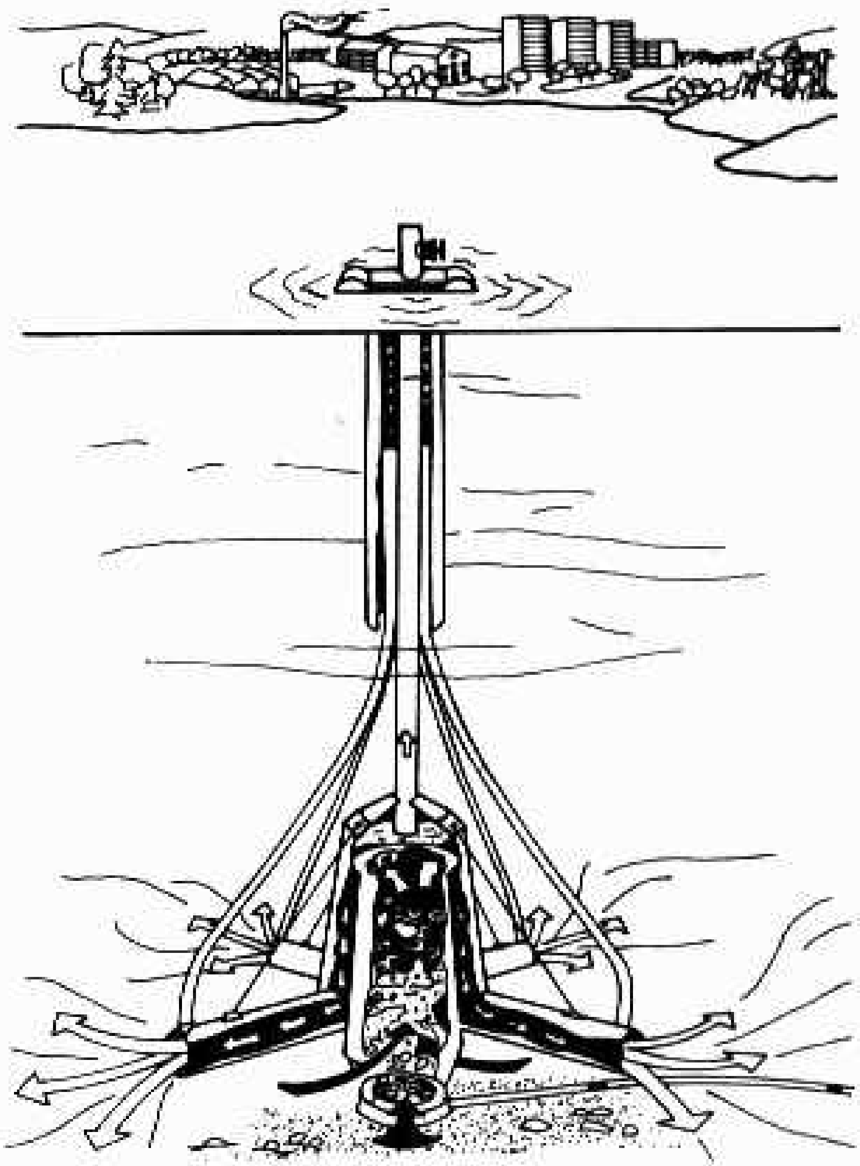


Fig. 1. Hypolimnetic aerator (ATLAS COPCO)

The main parameter for the design, construction and operation of a hypolimnetic aerator is the hypolimnetic oxygen consumption. This can be estimated by observing the rate of oxygen depletion following the period of stratification. The amount of water (Q_{water}) required to balance the oxygen demand is obtained through the division of the total daily oxygen consumption (mgO_2/d) by the input rate of the aerator (mg/l). The air flow (Q_{air}) required to pump water through the aerator is calculated based on the depth of air release and the density of the air/water mixture. For further details see ASHLEY (1985). The ratio between water flow and air flow (Q_{water}/Q_{air}) is known as flow efficiency and usually ranges from 7 to 30.

A case study concerning the use of a hypolimnetic aerator is presented here. Lake Flughafen is situated in the urban area of the city of Berlin, Germany (Fig. 2).

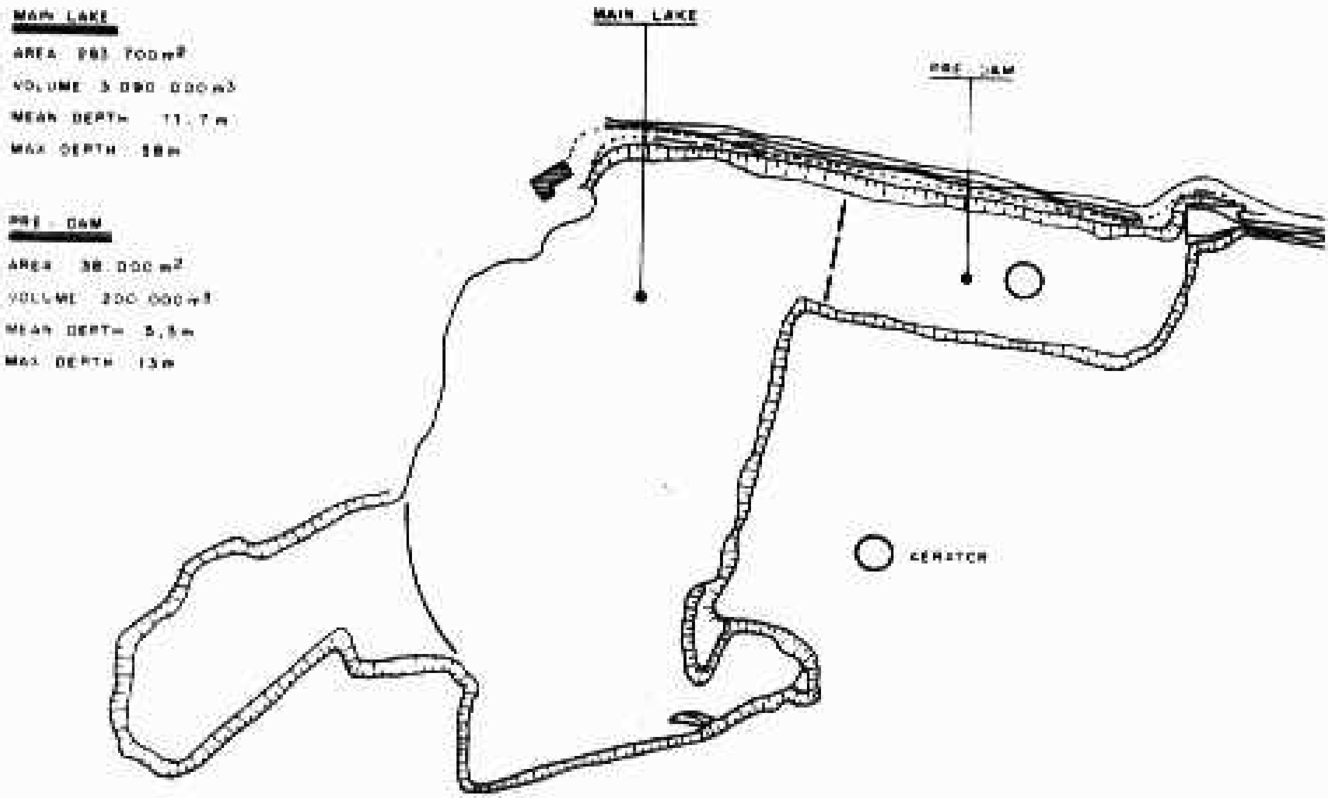


Fig. 2. Lake Flughafen

The lake was monitored at monthly intervals during the period March 1986 to November 1988. The relevant information regarding the design of the hypolimnetic aerator is given in Table 1.

It can be seen that maximum hypolimnetic oxygen consumption occurred in the period April-May 1987, just before the onset of the thermal stratification. For the design of the aerator a safety factor of 50% was introduced. Thus:

$$223\ kg/d \times 1.5 = 335\ kg/d$$

An equipment that could deliver 350 kgO_2/d was chosen. For lakes and reservoirs situated in temperate climates the mean oxygen consumption of 1 $g/m^2.d$ can be usually adopted. In order to achieve the maximum efficiency the aeration should start before the period of highest oxygen consumption.

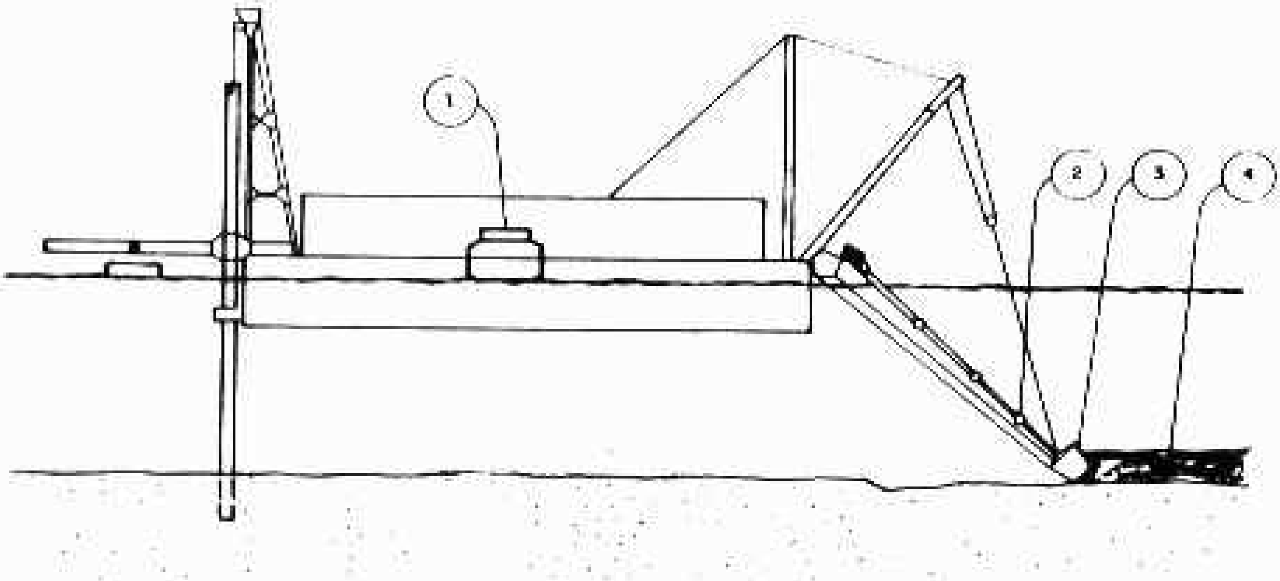
Table 1. Oxygen consumption in Lake Flughafen (SPERLING, 1989)

YEAR	MONTH	O_2 – mass (kg)	O_2-consumption (kg/d)
1986	June	8900	
			79
	August	4400	
			37
	September	3300	
			10
	October	3000	
1987	April	12200	
			223
	May	5500	
			107
	June	2300	
			37
	July	1200	
			33
	August	200	
1988	April	17000	
			173
	May	11800	
			153
	June	7200	
			53
	July	5600	
			73
	August	3400	
			23
	September	2700	

SEDIMENT REMOVAL

Sediment dredging is used in order to control the release of algae-stimulating nutrients from lake sediments by removing the layer of the most highly enriched materials. Examples of the use of this technique can be found in BJORK (1988) and MOORE and THORNTON (1988).

Among the several types of dredging equipment, the most common choice consists of a hydraulic dredge equipped with a cutter head (Fig. 3). The sediments are transported as a slurry through a pipeline which traverses the lake from the dredging site to a disposal area.



1 - PUMP
2 - LADDER
3 - CUTTER
4 - SEDIMENT

Fig. 3. Suction dredging (SPERLING, 1991).
1. Pump; 2. Ladder; 3. Cutter; 4. Sediment

A case study concerning the use of this recovery technique is described below.

Lake Pampulha (Fig. 4) is located within the urban area of Belo Horizonte and is considered to be one of the most important tourist

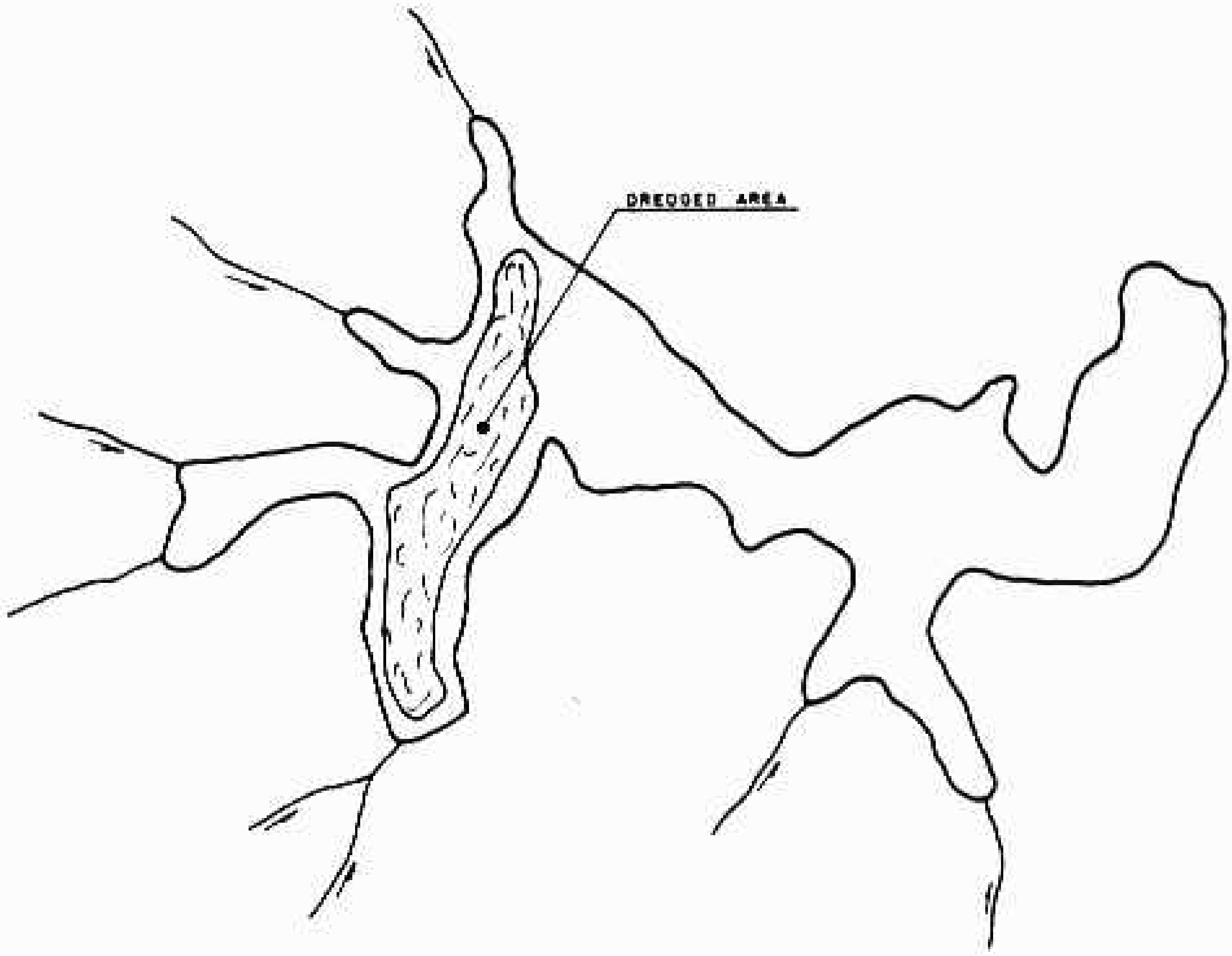


Fig. 4. Lake Pampulha

attractions of the region. It was constructed originally as a water supply, but the degradation of the water quality prevented its further use. Presently Lake Pampulha is suitable only for some few recreational activities.

The lake has an area of approximately 2.6 km^2 and a volume of about 14 million m^3. Its maximum depth is 16 m and the mean depth is 5 m. The drainage basin occupies a significant area of 97 km^2. The relationship between these figures signifies that the reservoir receives a considerable influence from activities developed in its watershed. The main sources of pollution are the discharge of untreated sewage into the lake and the strong erosion of many areas in the drainage basin, leading to a high volume of settling material in the water body.

The fertilization of water due to excess nutrients (phosphorus and nitrogen) results in an accelerated growth of algae and water plants and increased concentrations of organic matter in the water. The consequence is a disruption of the aquatic environment, with risks to public health and to the real objectives for the lake.

Several studies have been conducted by the local authorities in order to recover the limnological quality of Lake Pampulha, but their implementation was obstructed due to political or economic influences. In recent years, the area occupied by algae and macrophytes has been expanding and has caused serious concern, considering the known difficulties involved in controlling eutrophication and settlement in urban lakes. In 1989, the local administration finally initiated a recovery program, which consists of the following basic activities:

- management of the watershed (erosion control, sewage diversion);
- construction of sedimentation basins in the tributaries;
- macrophyte (mainly water hyacinth) removal;
- sediment removal.

The dredging equipment installed at Lake Pampulha was capable of removing 1500 m^3/h of slurry of approximately 80% water. The suction diameter was 16 inches and the pipeline (plastic) had a total length of 800 m. The dredging work consisted of removing the sediment deposited in an area of 34 ha, in order to guarantee a water column height of at least 2 m.

Instead of transporting the material to a final destination place outside the water body, as is usually the case in dredging works, the mud is deposited within the lake itself. The aim of this procedure is to create four islands. These islands are for recreation for the local population and will serve as the site for a field laboratory for ecological studies.

The dredging activity began in April 1990 in a shallow part of the lake which is particularly affected by the settlement of solid materials composed of both mineral and organic particles. Over 1.1 million m^3 of sediment were removed from the lake in the period April 1990 — May 1991.

The lake was monitored twice weekly during the period of dredging. Sampling points were located in the water body (two points), one next to the dredging equipment and one at the final disposal place. Considering the very high potential for serious negative impacts on the lake and surrounding area due to dredging, the monitoring was directed towards an evaluation of the effects of sediment removal on the aquatic environment. The data, related to the conditions of the main parameters in the area studied during the sampling period, can be summarized as follows:

— temperature (measured directly): oscillated as a consequence of climatic variations;

— dissolved oxygen at the surface (Winkler's technique): showed considerable variations, including values above saturation; near the dredging equipment the concentrations were usually low;

— dissolved oxygen at the bottom (Winkler's technique): during the stratification the hypolimnetic region was anaerobic; when the lake circulated, the saturation ranged from 10 to 30%;

— conductivity (measured directly): both in the water body and near the dredge ranged from 200 to 300 μS/cm;

— transparency (Secchi disk): the maximum value (2.0 m) was reached during the winter; the values were usually between 0.1 and 1.0 m;

— turbidity (Hellige turbidimeter): in the water body it ranged from 2 to 120 UNT; values registered near the dredge reached 250 UNT;

— total solids (gravimetry): the concentrations in the water body oscillated from 190 to 400 mg/l; near the dredge the values ranged from 190 to 800 mg/l;

- chemical oxygen demand: showed sharp oscillations, ranging from 4 to 90 mg/l in the water body, and from 10 to 100 mg/l near the dredge;

- biochemical oxygen demand: showed a similar behaviour to COD, with values oscillating from 2 to 40 mg/l in the water body and from 10 to 40 mg/l near the dredge;

- ammonia (colorimetry): the concentrations in the water body ranged from 3 to 20 mg/l, while near the dredge the values oscillated from 3 to 12 mg/l;

- nitrate (Hellige disk): in the water body the concentrations oscillated between 0.5 and 15 mg/l; near the dredge the values ranged from 0.3 to 10 mg/l;

- total phosphorus (method V–Mo): in the water body values up to 0.09 mg/l were registered, while near the dredge the concentrations reached a maximum of 0.2 mg/l;

- metals (spectrophotometry): among the metals analysed (copper, chromium, cadmium and mercury), only the first showed high concentrations (maximum of 0.1 mg/l);

- organic matter in the sediments (colorimetry): ranged in all sampling points from 2 to 3%;

- phytoplankton: the phytoplanktonic density oscillated considerably, reaching sometimes values over 2,000,000 cells/ml for the cyanobacteria *Mycrocystis aeruginosa* at the sampling point near the dredge; in the water body the density of this alga ranged from 10,000 to 1,000,000 cells/ml; the second most frequent taxonomic group, the green algae *Chlorella* sp, showed concentrations ranging from 300 to 700 ind/ml in the water body and from 100 to 1500 ind/ml near the dredge.

The results presented here should be analysed in the light of the existence of a tropical ecosystem. This environment shows metabolic patterns substantially different from temperate lacustrine ecosystems. The high temperatures are responsible not only for elevated recycling rates but also for an intensive nutrient uptake by the algae. Although these nutrients, mainly phosphorus, reach the lake in large quantities through the discharge of domestic and industrial sewage, their concentrations in the water body are not considerably high.

The variation of the dissolved oxygen in the water is to a great extent due to climatic factors. The values were however not low enough to cause a fish kill. The conductivity showed very high values, typical of polluted waters. The total solids' concentration and the turbidity showed a strong dependence on rainfall, and consistently higher values at the dredging sites. Although phosphorus concentrations were not particularly high for tropical lakes, the values for ammonia were indicative of the existence of eutrophic conditions. It was observed that the algal blooms were more frequent in the winter, when the nutrient concentrations were higher as a result of a poorer dilution of the influents.

The information available substantiates the conclusion that dredging has been successful in removing the sediment without causing any significant damage to the aquatic ecosystem. A comparison with the considerable data available from past years shows practically no changes in the ecosystem's characteristics.

FINAL REMARKS

The main conclusion to emerge from this paper is the crucial importance of the implementation of programs for the control and restoration of degraded aquatic systems. The case studies presented here stress the necessity for the development of individual studies, since each water body should be considered as a patient that needs a specific therapy. The use of control and recovery processes should also always take into account measures related to the management of the watershed. Finally, countrywide efforts for the restoration of lakes and reservoirs should employ techniques adapted to tropical rather than temperate systems.

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