ORGANIC SEDIMENT REMOVAL
THROUGH
MULTIPLE INVERSION

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ABSTRACT

Several researchers have noted increases in benthic invertebrates when water quality is improved (5, 6, 16, 20, 30, 33, 36, 39). The purpose of this paper is to examine sediment removal as a result of these increases in bottom-feeding organisms.

INTRODUCTION

If the bottom waters of an eutrophic lake are oxygenated, the activity rate of anaerobic bacteria rapidly decline. Instead, aerobic bacteria thrive and begin decomposing the organic matter, while iron and other sediments are oxidized (12). This results in a general improvement in water quality, as carbon dioxide is removed by aeration, and anaerobic acids and gases are no longer produced (18, 40).

Macroinvertebrates also take advantage of the newly oxygenated water and feed upon dead organic matter in the sediment as well as upon each other (2, 3, 5, 6, 16, 33). A food web is established, and bottom-feeding fish move into deeper water and feed upon the smaller organisms (10, 11, 12, 21, 39).

This process of sediment removal from lake bottoms occurs regularly in nature when the spring and fall turnovers in northern lakes bring oxygenated waters down to the benthos (24). The use of aerobic bacteria and aeration has been used to decompose sludge in waste treatment plants for many years (4, 14, 29).

For the biological breakdown of organic matter to be successful, however, we have found that highly efficient oxygenation of the bottom waters, coupled with removal of detrimental gases for an adequate period of time is necessary, and the addition of nonpathogenic microorganisms to seed the lake accelerates the removal.

This paper describes the equipment used and gives the results of nine field studies that involved removal of organic muck from natural lake bottoms.

METHODS AND MATERIALS

The Multiple Inversion System[1] used has a microporous ceramic air diffuser which supplies microscopic air bubbles to a central point on the bottom of a cell of lake water up to five hectares in area. These bubbles tend to have very small diameters and, therefore, an exceptionally large, cumulative surface area. As they rise, the surface tension between the air-water interface causes them to pull a maximum quantity of water to the lake surface.

When the bottom water reaches the surface, it spreads out in a thin sheet, eventually flowing all the way to the shoreline. Hydrogen sulfide, ammonia, and carbon dioxide are diffused into the atmosphere by the wind, and oxygen is absorbed.

Earlier tests have shown that a 0.33-hp, Clean-Flo Multiple Inversion System located in two meters of water can move 450,000 liters of water to the surface per hour. This is enough displacement to completely roll over a 4 hectare lake once every 7 days, if the average water depth is two meters.[2]

The Multiple Inversion System duplicates the turnover that occurs naturally in northern lakes each spring and fall, and as cold fronts pass over southern lakes in the winter. Continuous turnover allows nearly complete oxygenation of the bottom waters throughout the year, and a permanent reduction in gases toxic to invertebrates.

To test the possibility that seeding the lake with bacteria would increase the sediment removal rate, four of the test lakes were seeded with nonpathogenic soil-type bacteria (C-FLO)[3] to feed on the sediment and in turn become food for higher organisms (1).

With the exception of Lake Maggiore, sampling locations were selected after a cross-hatched grid was placed upon a map of each lake, and each grid intersection was assigned a numerical value. A random numbers table was used to select 2-11 intersections on each lake where sampling was to take place, depending on size.

A 2.5-cm I.D., 3.2-cm O.D. by 3.7-m long clear plastic tube was gently lowered vertically into the water, making a slow, circular motion 0.1-m in diameter with the bottom end. The tube was marked every 2.5 cm. The tube was lowered until a faint resistance was felt to the circular motion. The mark on the tubing at the water surface indicated water depth to the top of the muck layer. This value was recorded.

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1. Manufactured by Clean-Flo Laboratories, Inc., Hopkins, Minnesota, Patent pending.
2. Laing, R. L. and S. R. Adams, August, 1975. Oxygen transfer constant (K_La) for Clean-Flo aeration/circulation systems. Clean-Flo Laboratories, Inc. 15 p. In-house paper.
3. Clean-Flo Living Organisms (trademark), Clean-Flo Laboratories, Inc. U. S. Patent pending.

The tube was then pushed straight down into the muck until it could not be pushed further. The depth to the water surface was noted. This depth minus the water depth is given as the total depth of the muck. A mark was painted on a permanent structure at the lake shore to indicate water level at the time of the initial test.

RESULTS AND DISCUSSION

Characteristics of the lakes tested, the bottom sediment and a summary of the tests conducted are given in Table 1.

Results of the tests are shown in Table 2. Significant removal of shoreline sediment was accomplished in all cases. Sediment depths at the diffusers themselves were also strongly affected and 18 m diameter craters in the sediment often were the result of Multiple Inversion. All test sites were far enough from the diffusers that cratering was not a factor.

With the exception of Bennett Lake, all seeded lakes had microorganisms added immediately after initiation of the Multiple Inversion systems. Bennett was not seeded for six months, and the results include the time during which it was not seeded.

The tests on Lake Maggiore sediment were made by the City of St. Petersburg, Florida. In Lake Maggiore, the amount of data available for investigation made a linear regression analysis feasible. Several other statistical models were also evaluated using a multiple regression technique. None of the models were subjected to statistical tests because of failure to pass an examination of the residuals. However, the linear regression is still a good descriptive tool to use on the data. These results showed that 49 to 82 cm of sediment were removed per year, at the test sites.

It should be noted that the most rapid sediment removal occurred in the four lakes receiving C-FLO.

While these results show a definite removal of sediment, several shortcomings are apparent in the method used. Of foremost concern is the amount of force used to push the tube down to hardpan. From site to site, depending upon the type of sediment present, the penetration of the tube possibly could give a false indication of hardpan depth.

It would also be useful to correlate sediment removal with quantity of benthic bacteria, invertebrates, and vertebrates. This is a difficult task, however, because the consuming organism could be microbes, bottom-feeding macroinvertebrates, or temporary invaders such as bottom-feeding fish. Organisms such as midge larvae would be plentiful at certain periods, and then metamorphose, and leave the environment. Such analysis is beyond the scope of this study.

A further shortcoming is lack of ability to find identical control lakes, so that Multiple Inversion alone could be tested in one lake, and Multiple Inversion plus C-FLO in the other. Since all lakes vary in their influent, size, water quality, and type and depth of sediment, one must limit the study to controlled laboratory tests only, which is too far removed from a natural

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4. Laing, Guy A., June, 1980. Organic Sediment Removal in Lake Maggiore. Clean-Flo Laboratories, Inc. In-house paper.

environment for meaningful results. Thus, while the use of bacterial seeding in four studies seemed to accelerate sediment removal, this conclusion could only be confirmed after a more extensive program in which lakes were tested with and without seeding. In the tests conducted, the type of sediment does not appear to affect removal rates, but contaminants such as pesticides and heavy metals should influence results (26, 27). This same phenomenon was discovered by Hargrave (1).

In lakes having a layer of unconsolidated ooze over organic sludge, both declined simultaneously. In Lochlin Pines, while 12.5% of the ooze was removed, 43% of the sludge and peat underlying the ooze was removed.

While the method used is obviously lacking in closely controlled, supportive data, the results are subjectively gratifying, and should warrant further study. One can now walk 200-300 meters eastward from the west shore of Lake Maggiore on solid sand, where prior to the tests, one would be immersed to the waist in foul-smelling organic sludge. This observation conforms roughly to sediment contour lines in the lake derived by the test method of this paper.

For many years, as a result of reviewing the available literature, we have been of the opinion that the following processes were taking place as a result of multiple inversion. First, the result of the oxygenation of the water should make the bottom sediment an adsorbing material that would adsorb nutrients from the water column. Second, the result of oxygenation of the benthos would revive an aerobic food web which in turn would cycle the nutrients out of the benthos by the interaction of an aerobic fauna above the benthos. This remains theory and not enough information is available to form a conclusive opinion. Tests on Moore Lake (Table 4) and Lake Maggiore (Table 5) seem to indicate a large increase in sediment phosphorus and nitrogen levels immediately following initiation of the Multiple Inversion system. Then a large decrease in sediment nutrients occurs. The data also seems to indicate a considerable decomposition and resultant compaction of flocculent plant fragments in the aerated sediment (1), accompanied by adsorption of nutrients from the water column (9, 10, 15, 17, 22, 23, 28, 32, 34, 37) and prevention of a release of nutrients to the water column that would be caused by anaerobic conditions (2, 7, 8, 19, 21, 25, 32, 35). This may then be followed by the establishment of a benthic community which cycles nutrients from the sediment into the faunal food web (1).

ABLE 1. Lakes tested, characteristics of bottom sediment, and tests conducted.

AKE	LOCATION	SURFACE AREA (ha)	MAX.WATER DEPTH (m)	MAX.THICKNESS OF SEDIMENT (m)	NUMBER OF TEST SITES	TYPE OF SEDIMENT	% VOLATILE WEIGHT 1/	% WATER 2/	FREQUENCY OF TESTS (days)	DURATION OF TESTS (days
ochlin Pines	Oakland Co., MI	2.6	3.0	0.6	6	Ooze, muck, peat	--	--	42	42
aterfowl (ZOO)	Cleveland, OH	1.6	1.2	1.2	2	duck fesque	49.1	43.1	30	90
ennett	Roseville, MN	6.1	2.4	9.2	7	peat	74.2	72.5	183	548
obinson	Copake, NY	38.9	9.2	1.2	12	muck	--	--	335	335
aggiore	St. Petersburg, FL	153.8	3.1	5.8	10	ooze, muck	58.5	76.6	30	669
annon	St. Louis Park, MN	15.4	1.2	27.5	9	peat	--	--	183	365
rystal	Robbinsdale, MN	32.4	10.7	4.6	11	muck	50 3/	62.0 3/	365	930
win	St. Louis Park, MN	3.2	1.4	0.8	5	muck, peat	--	--	183	365
ost	Plymouth, MN	8.1	1.8	0.9	3	muck	--	--	480	480

1/ By weight of dry sample.

2/ By weight.

3/ Approximate.

Table 2. Organic Sediment removed in nine lakes using Multiple Inversion. Lakes underlined received C-FLO.

LAKE	hp	hp/ha	REMOVAL RATE cm/yr
Lochlin Pines	0.5	0.19	91
Waterfowl (Zoo)	1.0	0.63	81
Bennett	1.0	0.16	49
Robinson Pond	15.0	0.39	38
Maggiore	15.0	0.10	49-82
Hannon	1.5	0.10	28
Crystal	3.3	0.11	24
Twin	1.0	0.31	17
Lost	0.5	0.06	11

TABLE 3. Bottom water chemistry values before and after the test period (mg/l). All lakes experienced periodic oxygen depletions before Multiple Inversion was initiated.

LAKE	DISSOLVED OXYGEN		AMMONIA		CARBON DIOXIDE		HYDROGEN SULFIDE	
	Before	After	Before	After	Before	After	Before	After
Lochlin Pines	10	12	0.3	0.3	6	0	0	0
Waterfowl	10.5	8	0.3	0.05	5.5	8	0.1	0.01
Robinson	1.0	10.5	3.2	0.4	30	22	--	--
Maggiore	9.7	6.0	0.16	0.08	0.6	0.0	0.9	< 0.05
Hannon	12	12	0.4	0.1	7.5	--	0.00	0.00
Crystal	0	13.5	20	0.2	50	10	4.8	< 0.01
Twin	2	11	1.8	0.18	10	0	0.06	0.00

Table 4. Moore Lake phosphorus profile taken in 1977 after Multiple Inversion was initiated on the east side in 1976. Data taken by E. A. Hickok and Associates, Wayzata, Minnesota. The west side was not treated.

Sediment depth, cm	Wt. Dry Sediment, gm East Basin	West Basin	Mg/gm P Dry Sed. E. Basin	W. Basin	Total P, mg E. Basin	W. Basin
0-2.5	0.73	1.2	3000	2150	2.19	2.58
2.5-5.0	10.1	4.6	2170	1900	21.92	8.74
5.0-7.5	15.4	1.6	2150	1760	33.11	2.82
7-5.10.0	16.8	5.5	2050	1610	34.44	8.86
10.0-12.5	16.7	5.8	1890	1570	31.56	9.11
12.5-15.0	19.7	6.2	2350	1280	46.30	7.94
15.0-17.5	16.3	5.4	1940	1360	31.62	7.54
17.5-20.0	22.6	--	900	--	20.34	--
		mg P in core of 17.8 sq. cm -			221.5	47.4

Table 5. Lake Maggiore sediment nutrients. Data taken by Haines Testing Laboratory, Inc., Clearwater, Florida in 1973, and by the Dept. of Environmental Affairs; City of St. Petersburg in 1977 and 1978.

Measurement, mg/g	8/31/73 ave.	9/15/73 ave.	7/12/78
Total P	6.5	773	3.8
Ortho P	5.8	343	--
Chloride	444	--	--
Total Diss. Solids	1120	--	--
TKN	24.1	2315	45.0
Organic N	--	1068	--
Nitrate N	0.11	54	--
Nitrite N	0.03	1	--
Ammonia N	21.1	1363	0.017
Total N	24.2	2370	--
pH	7.63	--	--
Specific Conductanice, μ mho	1830	--	--
Alumninum	--	--	1880
Arsenic	Neg.	--	--
Barium	--	--	28
Beryllium	--	--	0.56
Cadmium	--	--	0.84
Chromium	Neg.	--	6.0
Cobalt	--	--	3.4
Copper	Neg.	--	7.6
Iron	--	--	150
Lead	Neg.	--	34.9
Manganese	--	--	30
Mercury	Neg.	--	--
Molybdanum	--	--	3.0
Zinc	Neg.	--	22
Fluoride	--	--	0.2

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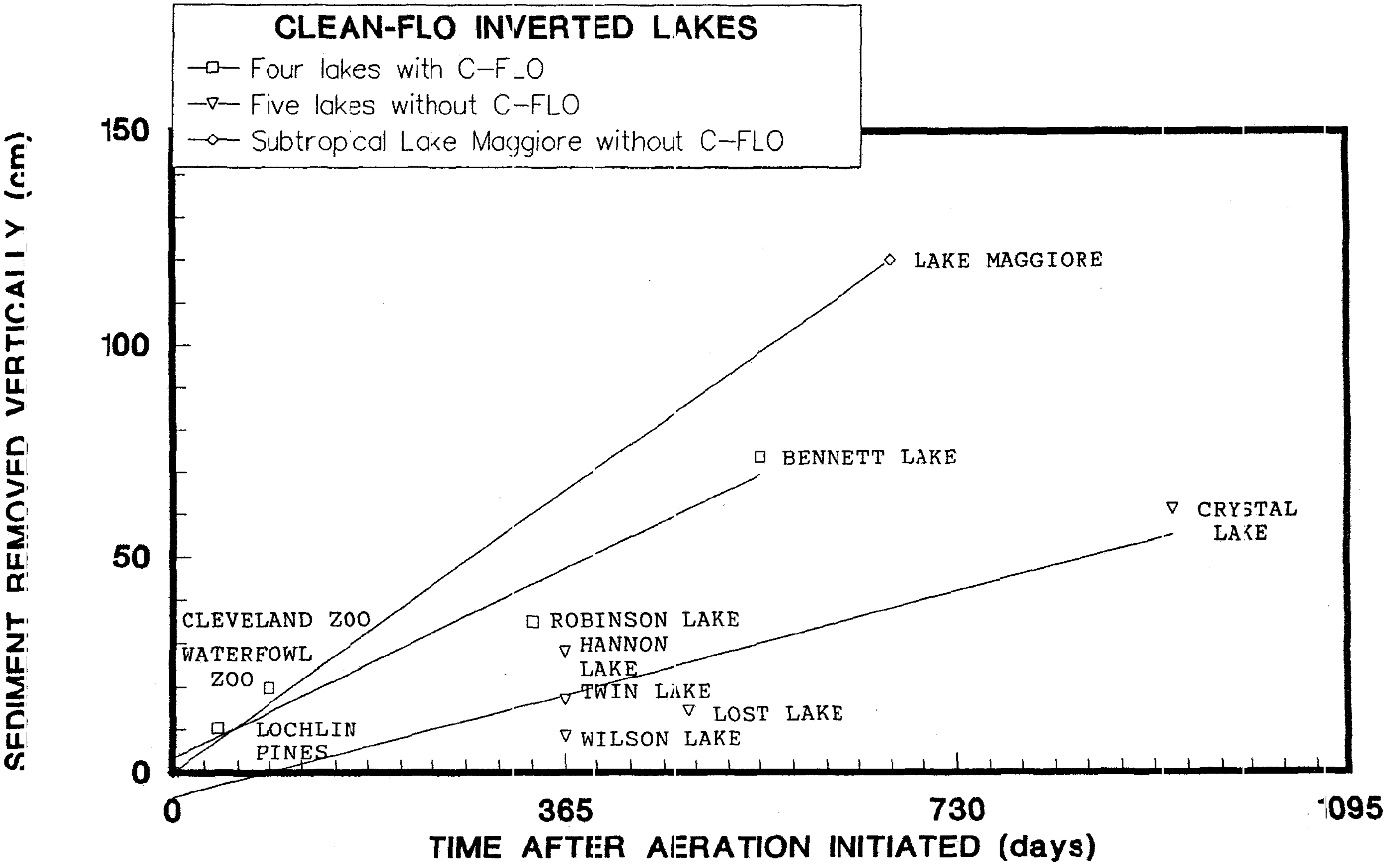
ORGANIC SEDIMENT REMOVAL

Northern Lakes Compared to a Subtropical Lake
Linear Regressions



ORGANIC SEDIMENT REMOVAL
CLEAN-FLO INVERSION ONLY

Two Northern Lakes Compared to a Subtropical Lake