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Environmental Protection
Agency

Office of Water
Nonpoint Source Control Branch
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EPA Report to Congress: Water Quality of the Nation's Lakes

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Water Quality of the Nation's Lakes

Nonpoint Source Control Branch
Office of Water Regulations and Standards
Office of Water
U.S. Environmental Protection Agency

1989

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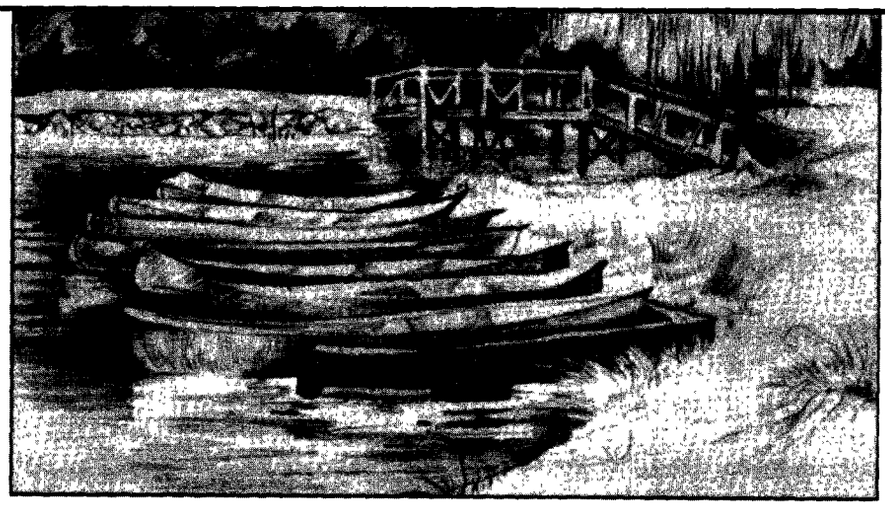


Foreword

Section 314 of the Clean Water Act, as amended by the Water Quality Act of 1987, requires the States to submit to the Environmental Protection Agency, as part of their 305(b) biennial reports, information on the water quality of their lakes, including:

(a) an identification and classification according to eutrophic condition of all publicly-owned lakes in such State;

(b) a description of procedures, processes, and methods (including land use requirements), to control sources of pollution to such lakes;

(c) a description of methods and procedures, in conjunction with appropriate Federal agencies, to restore the quality of such lakes;

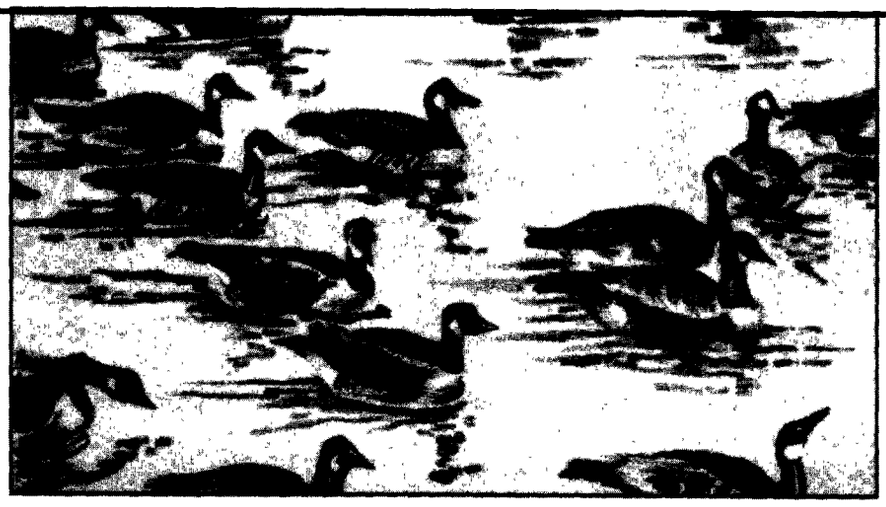
(d) a description of methods and procedures to mitigate the harmful effects of high acidity, including innovative methods of neutralizing and restoring buffering capacities of lakes and methods of removing from lakes toxic metals and other toxic substances mobilized by high acidity;

(e) a list and description of those publicly-owned lakes in such state for which uses are known to be impaired, including those lakes which are known not to meet applicable water quality standards or which require implementation of control programs to maintain compliance with applicable standards and those lakes in which water quality has deteriorated as a result of high acidity that may reasonably be due to acid deposition; and

(f) an assessment of the status and trends of water quality in lakes in such State, including but not limited to, the nature and extent of pollution loading from point and non-point sources and the extent to which the use of the lake is impaired as a result of such pollution, particularly with respect to toxic pollution.

The Act, as amended, further requires the Administrator of the Environmental Protection Agency to transmit to the Senate Committee on Environment and Public Works and House Committee on Public Works and Transportation a report on the status of water quality in our Nation's lakes.

The following report summarizes the information submitted by the States in response to the April 1, 1988 legislative requirements described; where necessary, information developed by EPA supplements the State-reported data. This Report to Congress, therefore, represents the Agency's summary of the water quality of lakes throughout this Nation as currently perceived and documented by the States in response to Section 314.



Executive Summary

Status

The status of water quality in our Nation's lakes has been assessed according to use impairment, threatened uses, and trophic condition (a measure that determines the "aging process" of a lake). Of 12,413,837 lake acres assessed by 34 States, 25 percent were found to be impaired or partially impaired, and 20 percent threatened by pollution. "Threatened" waters refers to those lakes that fully support their designated uses but that may not fully support uses in the future because of anticipated sources or adverse trends of pollution. Approximately 50 percent of 22,000 lakes classified by trophic status were either eutrophic or hypereutrophic (nutrient-rich or "old").

From a national perspective, a statistically-designed sampling framework was not used to estimate the water quality of lakes across the country. Therefore, this report cannot state actual status and trends or classify the trophic condition of the Nation's lakes with statistical confidence. The numbers reported in the 1988 assessments are in many cases incomplete.

Causes of Impairment and Sources of Pollution

States identified 12 specific causes of use impairment in lakes, with nutrients and siltation/turbidity the most significant pollutants. Nutrients are elements, primarily phosphorus and nitrogen, that promote plant and algae growth. Excessive nutrients may increase the productivity of the lake to the point where algal blooms and aquatic vegetation impede recreational activity and diminish the lake's aesthetic value. At the end of their growing season the algae and aquatic vegetation die, and their decomposition consumes dissolved oxygen. Such oxygen depletion results in conditions unsuitable for fish; severe depletion may cause fish kills.

Siltation is the process by which soil or rock is carried by water to a lake and deposited as sediment. As the silt settles, the lake becomes more shallow, often producing conditions that stimulate macrophyte (aquatic plant) growth. Dense vegetation, shallowness, and changes in lake bed/sediment composition adversely affect recreation and fish habitats. The habitat suitable for coolwater sport fisheries may decline or even disappear.

Turbidity is an indirect measure of the transparency (light penetration) of the lake. High turbidity resulting from matter suspended in the water reduces transparency, producing what is often perceived as a "cloudy" condition. High turbidity also inhibits algal productivity and may affect feeding habits of fish and food chain organisms.

States classified the sources of pollution causing use impairment as either point source, nonpoint source, or natural. According to the States, 76 percent of the pollution affecting lakes originates from nonpoint sources, 11 percent from point sources, and 12 percent from natural sources. Agricultural

nonpoint source runoff was the most frequently reported source; however, urban runoff and resource extraction (mining) are major sources in specific areas.

Pollution Control and Lake Restoration

The sources of pollution to a lake, be they point or nonpoint, will determine the approach used to control pollution. Point sources are usually controlled through wastewater treatment and permit programs. Nonpoint sources, because they are diffuse by nature, are best controlled by watershed management.

Once the sources of pollution have been successfully addressed, in-lake restoration may begin. The specific causes of use impairment in the lake will determine the restoration techniques to be used. For example, nutrient inactivation may reduce or eliminate algal blooms, while dredging will deepen a shallow lake, and harvesting can remove rooted vegetation. In this report, lake restoration techniques are organized and explained by six basic objectives: (1) control of algae; (2) deepening; (3) removal of rooted vegetation; (4) improvement of fisheries; (5) acid mitigation; and (6) toxic removal.

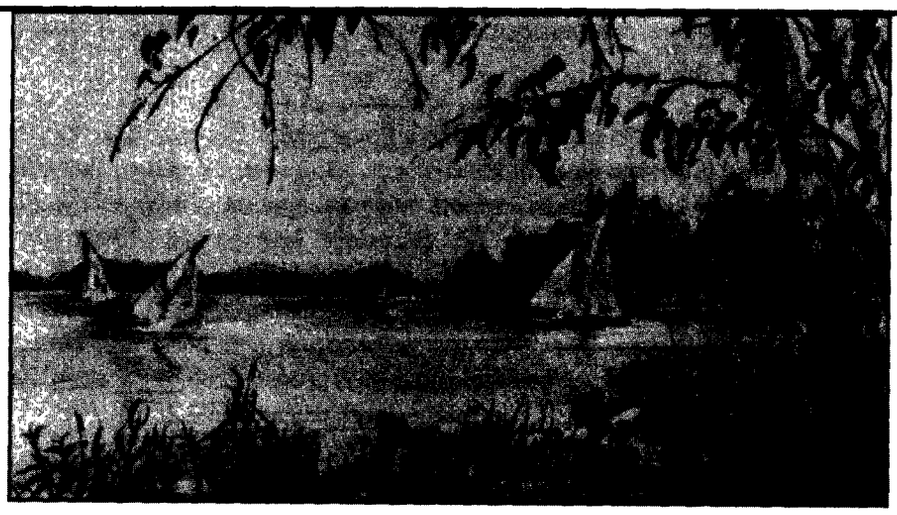
Trends

Information that can be used to define water quality trends in lakes is extremely limited. Many lakes have been sampled only once or twice during the past 15 years and the range of seasonal and annual fluctuations in key parameters is not well documented. To accurately reflect trends in lake water quality, data must be collected consistently over several years. Of the 38 States reporting the water quality of their lakes in 1988, most did not have the baseline data necessary for trend analysis.

In comparison with the 1986 305(b) report, however, the number of lakes considered eutrophic increased more than 10 percent, while the number of mesotrophic and oligotrophic lakes decreased 8 and 7 percent, respectively. This finding is based on more extensive data, with 63 percent more lake acres assessed in the 1988 Lake Water Quality Assessment than by the 1986 305(b) report.

The baseline data therefore are building, and will be further augmented in future 305(b) reports by activities authorized by the Water Quality Act of 1987. Grants made under Section 314 as well as the continuing emphasis on lake water quality assessment will strengthen both the quantity and quality of data on the water quality of this Nation's lakes.

Lakes are being considered as ecological units subject to many factors, and monitored for a number of significant parameters in addition to traditional trophic state parameters. As technical and scientific knowledge of lake systems continues to grow, along with our database of lake water quality information, understanding the changes that are occurring in lake water quality also increases.



Problem Definition

Introduction

In the 1988 Lake Water Quality Assessments, most States identified a lake as "impaired" or "threatened" in terms of designated uses being met, a relatively new concept now generally accepted as the most realistic appraisal process for lake waters. Lake acres that were reported "not meeting" or only "partially meeting" designated uses were considered impaired, although the criteria used to determine impairment vary from State to State according to differing regional expectations of lake water quality.

States also identified their lakes according to trophic condition. Traditionally, the trophic state designation has been used to classify a lake according to its nutrient status. Eutrophication, a general measure of nutrient status, can be viewed as an indication of the lake's natural aging process, the changes that normally occur over hundreds even thousands of years, evolving the lake into a wetland, and finally, dry land (Fig. 1). Although a natural evolution, the eutrophication process can be accelerated by human activities. "Cultural eutrophication" is the term applied to the effects of human activities on water quality (e.g., careless use of detergents, fertilizers, and pesticides, unwise waste disposal, poor mining and construction practices) and result in perturbations that can usually be reversed.

The eutrophication progression can be described by a series of trophic states:

- **Oligotrophic** – clear waters with little organic matter or sediment, and minimum biological activity;
- **Mesotrophic** – waters containing more nutrients and therefore exhibiting more biological productivity;
- **Eutrophic** – waters extremely rich in nutrients, with high biological productivity;
- **Hypereutrophic** – murky, highly productive waters, closest to the wetland status.

General Characteristics of Traditional Lake Trophic Status Classifications

CHARACTERISTICS	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC
Nutrient Level	Low	Medium	High
Organic Matter Content	Low	Medium	High
Biological Productivity	Low	Medium	High
Lake Age	Young	Medium	Old
Water Transparency	High	Medium	Low
Oxygen Depletion Hypolimnion	No	Yes	Yes
Average Depth	Deep	Moderate	Shallow

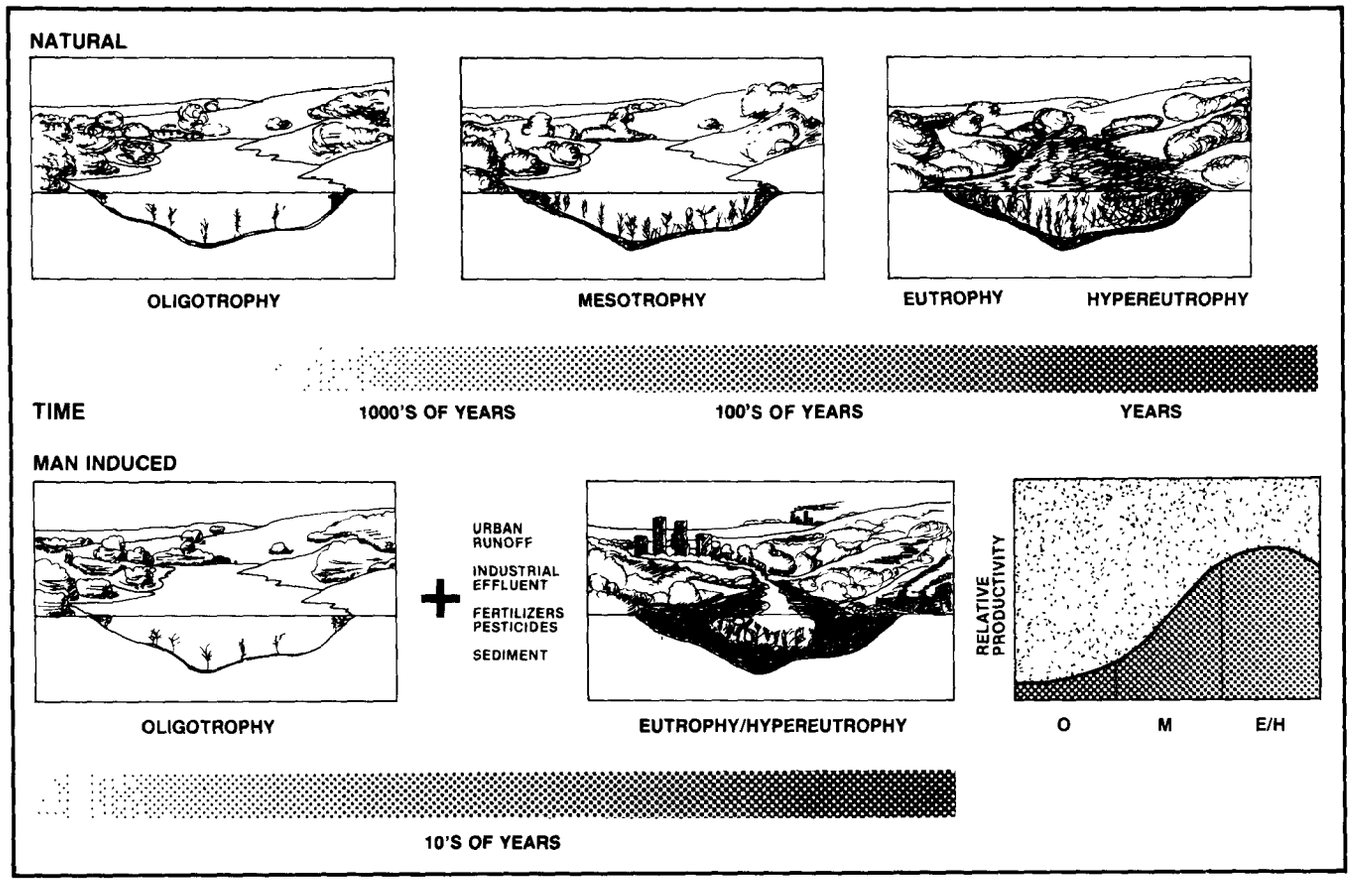


Figure 1.—Above: The progression of natural lake aging or eutrophication through nutrient-poor (oligotrophy) to nutrient-rich (eutrophy) states. Hypereutrophy represents extreme productivity characterized by algal blooms or dense macrophyte populations (or both) plus a high level of sedimentation. The diagram depicts the natural process of gradual nutrient enrichment and basin filling over a long period of time (e.g., thousands of years).
Below: Man-inducted or cultural eutrophication in which lake aging is greatly accelerated (e.g., tens of years) by increased inputs of nutrients and sediments to a lake, as a result of watershed disturbance by man.

Dystrophic is also a lake classification but not necessarily a part of the eutrophication progression. Dystrophic systems are often low in nutrients yet highly colored with dissolved humic organic matter (sphagnum bog).

The trophic state of a lake is most commonly determined by using Carlson's Trophic State Index (TSI). This index was developed from the interrelationships of summer transparency (clarity of the water as measured by the Secchi disk), epilimnetic concentrations of chlorophyll *a*, and total phosphorus. The TSI values range between 0 and 100 with increasing values indicating more eutrophic conditions.

When considering the results of the TSI calculations, one should keep in mind the assumptions on which the Carlson formulae are based: (1) Secchi transparency is a function of phytoplankton biomass; (2) phosphorus is a factor limiting algal growth; (3) total phosphorus concentration is directly correlated with algal biomass. Therefore, Carlson's TSI may not be applicable to lakes where suspended solids are a major source of turbidity, when nitrogen is the factor limiting algal growth (as is the case in Delaware and many southern U.S. lakes), or when total phosphorus does not correlate with algal biomass.

To compensate for these inadequacies, several States have developed other ways to determine the trophic status of lakes. For example, Indiana measures seven parameters in addition to the three used for Carlson's TSI: dissolved phosphorus, organic nitrogen, nitrate, ammonia, dissolved oxygen, plankton, and light transparency.

Trophic State and Lake Uses

Although changes in lake water quality may be tracked by monitoring for trophic state, experience has shown that the trophic state of a lake does not always define its use. Some States believe that advanced eutrophication does not necessarily eliminate a lake's

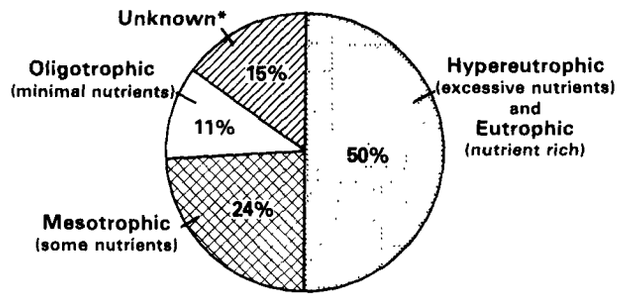
designated recreational uses, nor is an oligotrophic lake always best for recreational activities. These States have recognized this apparent disparity between positive recreational uses and the negative connotations associated with eutrophic conditions, adjusting the ways they determine trophic status to reflect desired use (such as warmwater fishing) and public perceptions in addition to measurable physical, chemical, and biological parameters.

A eutrophic condition, therefore, is not necessarily "bad" in terms of using the lake, nor are eutrophic or mesotrophic conditions necessarily abnormal or outside of ecological expectation based on lake and watershed characteristics. For example, most lakes assessed in Iowa and Nebraska either fully or partially support designated uses, even though all 114 Iowa lakes are classified as eutrophic, and 22 of 23 Nebraska lakes evaluated are either eutrophic or hypereutrophic. However, as the aging process accelerates (usually because of cultural eutrophication), the lake and its watershed require greater management to maintain the lake's designated uses.

Table 1 summarizes the trophic status of lakes as reported by the States. The total number of lakes listed is the number assessed, not the total number of lakes in the State. The assessments were done by in-lake monitoring and evaluation (based on professional judgement, lake uses, known pollution sources, and other subjective information). One problem with accumulating and interpreting the data presented from the States is that the data are collected in a variety of ways: most states have not performed a complete census on their lakes and there is no indication as to why the lakes they assessed were selected. If the lakes were assessed in response to a problem or public complaint, or based on easy accessibility, rather than on random selection, there is probable bias in the reported information. It is likely that the more remote and/or pristine lakes are underrepresented in some State assessments.

Given the limitation on the data compilation, the States reported that 50 percent of all lakes assessed for trophic status were either eutrophic or hypereutrophic (Fig. 2); 24 percent, mesotrophic; 11 percent, oligotrophic; and less than 1 percent, dystrophic. Trophic status for the remaining 15 percent assessed was unknown.

Of the total acres assessed in 34 States, 25 percent were reported as impaired and 20 percent were considered threatened (Table 2). The States used different criteria in developing the categories of "impaired" and "threatened"; therefore, the results should not be compared among States. Of the States that reported, New Jersey did not indicate impairment (because of insufficient monitoring data), but did list its total 51,000 lake acreage as "threatened."



* assessed for something other than trophic state

Figure 2.—Lakes in each trophic status classification as reported by States for all U.S. lakes assessed (%).

States are becoming increasingly aware that eutrophic condition is to be considered in the context of lake and watershed history, characteristics, and uses; not negatively, but comprehensively to show the overall condition of the lake. Determining whether a lake is supporting designated uses helps the lake manager or concerned individual assess the lake's "health." That assessment also may point to potential problems that can be averted to protect the future health of the lake.

Causes of Use Impairment

States identified 12 specific causes of pollution in lakes with impaired uses (Table 3). Nutrients and siltation/turbidity were two significant pollutant groups. These factors play principal roles in determining a lake's trophic state. For example, Minnesota reported that 75 percent of its citizen complaints concerned eutrophication, usually identified as algal blooms and directly related to excessive nutrients. Algal blooms were also reported as a problem in North Carolina. Siltation is a concern in South Dakota, where several lake restoration projects have been designed to remove sediment.

Nutrients are elements, primarily phosphorus and nitrogen, that promote growth, especially that of plants and algae. Excess nutrients may increase the productivity of the lake to the point where algal blooms and aquatic vegetation impede recreational activity and diminish the aesthetic value of the lake.

Siltation is the process by which particles of soil or rock are carried by water to a lake and deposited as sediment. Turbidity is an indirect measure of the transparency (light penetration) in the lake; high turbidity results from matter suspended in the water

Table 1. – Trophic status report.

STATE	LAKES ASSESSED	OLIGO-	MESO-	EU-	HYPER-	DYS-	UNK*-
AL	35	4	16	11	0	0	4
AR	71	0	59	4	0	0	8
CT	160	34	78	17	0	0	31
DE	31	0	0	31	0	0	0
DC	3	0	1	0	0	0	2
FL	91	57	19	13	0	0	2
ID	554	0	55	499	0	0	0
IL	412	2	25	239	146	0	0
IN	404	75	144	67	0	118	0
IA	114	0	0	114	0	0	0
KS	193	0	68	125	0	0	38
KY	92	14	27	51	0	0	0
MD	59	2	13	44	0	0	0
MA	478	133	289	56	0	0	2,381
MI	682	98	367	217	0	0	0
MN	12,034	1,203	3,009	7,822	0	0	0
MS	127	0	0	33	0	0	94
NB	23	0	1	12	10	0	0
NV	9	1	4	4	0	0	0
NH	415	161	172	82	0	0	0
NY	3,340	85	132	84	0	0	3,039
NC	144	11	21	25	9	8	70
ND	216	0	0	216	0	0	0
OK	74	5	49	8	12	0	0
OR	204	46	78	69	11	0	0
PA	37	1	29	7	0	0	0
PR	18	0	3	14	0	0	1
RI	54	4	41	9	0	0	0
SC	41	0	0	40	1	0	0
TN	119	21	33	55	10	0	0
UT	127	33	44	50	0	0	0
VT	–	19	72	28	0	11	589
VA	248	20	49	120	0	1	58
WA	140	58	24	45	0	0	13
WI	2,153	605	746	802	0	0	0
TOTALS	22,902	2,692	5,668	11,013	199	138	6,330

*Unknown means these lakes were either not assessed or not assessed for trophic status.

states not listed in the table either did not report the information or reported in a way that was inconsistent with the format of the table.

Table 2. – Impaired and threatened lakes.

STATE	REPORTED	ASSESSED	IMPAIRED	THREATENED
	ACRES			
AL	504,336	491,566	86,080	–
CT	82,900	37,562	12,389	8,176
DC	377	136	136	0
FL	2,085,120	947,200	637,440	–
GA	417,730	417,730	5,373	140
IL	305,847	183,572	160,641	22,455
IN	104,540	104,540	179	104,361
IA	81,400	80,249	53,448	18,902
KS	175,189	173,911	57,256	116,655
KY	228,385	214,483	35,148	152,544
LA	713,719	517,476	141,141	87,034
ME	994,560	994,560	38,211	–
MD	32,583	17,448	2,610	4,606
MI	840,960	424,021	119,836	161,894
MN	3,411,200	1,435,554	236,845	–
MS	500,000	500,000	18,260	–
MO	288,012	288,012	2,311	–
NE	145,300	85,518	3,214	–
NC	305,367	305,367	11,897	50,330
NH	151,000	149,854	19,146	4,603
NY	750,000	750,000	295,332	29,942
ND	625,503	619,333	48,125	570,170
OH	117,323	90,771	59,835	25,733
PR	11,146	11,146	7,345	1,745
RI	16,520	16,089	1,401	11,425
SC	963,000	410,407	1,165	–
SD	1,598,285	662,532	94,720	548,000
TN	538,657	538,657	86,648	75,828
VT	229,146	227,121	49,206	153,319
VA	161,562	161,089	13,737	–
WA	613,582	156,518	33,684	116,210
WV	23,460	19,171	19,171	0
WI	971,000	971,000	722,000	179,300
WY	411,244	411,244	23,239	146,491
TOTALS	18,398,953	12,413,837	3,095,438	2,485,502

– State did not report this data.

Percent impaired = 25 percent; Percent threatened = 20 percent.

states not listed in the table either did not report the information or reported in a way that was inconsistent with the format of the table.

that creates what may be perceived as a "cloudy" condition. As the material settles, the lake becomes more shallow, often producing conditions that encourage macrophyte growth. If this vegetation becomes too dense, it may affect both recreation and fish habitats. A lake that becomes too shallow may impede recreational activities such as swimming, boating, and fishing.

Metals and inorganics also were identified as significant causes of use impairment in lakes. Metals include cadmium, lead, zinc, copper, silver, iron, and manganese. The largest cause of impaired lake use in North Carolina has been discharges from coal-fired power plants to two lakes (Belews and Hyco), producing excessive selenium levels in these lakes. This selenium contamination has caused a drastic decline in fish population and reproduction in both lakes. Metals (iron and manganese), generated by active and abandoned coal mining, are significant factors affecting lake use in West Virginia.

Mercury is the principal inorganic responsible for impairment in lakes. Mercury contamination has been a problem in northeastern Minnesota lakes, where a study is being conducted to determine the source of the mercury. Most fish can be consumed from 92 percent of the large lakes (greater than 5,000 acres) sampled, but fish cannot be eaten from 1 percent. Of the small lakes (less than 5,000 acres) sampled, some fish can be consumed from 80 percent.

Organic enrichment and low dissolved oxygen (DO) also account for some of the use impairment in lakes. The biological decomposition of organic matter – from agricultural runoff, algae, aquatic vegetation, and/or municipal/industrial discharge – consumes oxygen. If the oxygen is consumed more rapidly than it can be replaced, the oxygen supply may be depleted to the extent that fish are stressed or unable to survive. Of the fish kills reported in Nebraska and Minnesota, 71 percent and 69 percent, respectively, resulted from such conditions.

The presence of pathogen indicator organisms may also restrict the use of

Table 3. – Major causes of pollution in lakes with impaired uses (% acres).**

STATE	NUTRIENTS	pH	SILTATION/BURBIDITY	ORGANIC ENTIRCHMENT/DO	THERMAL MODIFICATION	FLOW ALTERATION	OTHER HABITAT MODIFICATION	PATHOGENS	AQUATIC PLANTS & ALGAE	PESTICIDES	PRIORITY ORGANICS	METALS/INORGANICS	OTHER#
CT	36		15	4				6	22			1	16
FL	7	1	15	15				<1	8			27	27
IL	15		48	19				1	9	4	1	2	1
IN	32	8		22				12		3	7	4	12
KS	<1		<1			<1						100	
KY	19		13									67	1
LA*	33		6	11				27		<1		13	9
MD	99		1										
MN	62										2	36	
MS*	34		33							31		2	
MO		1				75				24			
NH	24	76											
NM	31		16	53			<1						
NY	36	6		<1		12		1		9	36	<1	<1
NC	11		4	10		<1			22			53	
OH	21		23					2	29	2		14	9
OK	23		38	5				<1		9	4	12	10
PR	30	3	20	19			6	7				8	6
RI	19		5					76					
SC				5			74						21
SD			80		<1			14				4	2
VA*	45	10	10	29	2			<1		<1		4	
VT	20	<1	8	5		13		5	49				
WA	69					6		6	1		6	6	6
WV	12	29	20		11							28	
AVERAGE	27	5	15	8	1	4	3	6	6	3	2	15	5

** These numbers represent the relative impact of each pollutant on the use impairment in lakes.

#This category includes primarily unknown toxicity, non-priority organics, and taste/odor problems associated with water supplies.

*Identified no major causes; however, these moderate/minor impacts cause the use impairment in lakes.

states not listed in the table either did not report the information or reported in a way that was inconsistent with the format of the table.

lakes. Tests for fecal coliform bacteria are commonly used as an indicator of human or animal wastes contaminating water bodies. Such contamination often may result from runoff from animal feed-lots, rural or urban areas heavily populated with domestic and/or wild animals, or improperly treated municipal wastewater, including combined sewer overflows. The feces from warm-blooded animals contains many pathogens, some causing disease in humans. Therefore, the presence of fecal indicator organisms in a lake may lead to restrictions being placed by public health officials on contact recreation (e.g., swimming) and fish consumption. The feces from warmblooded animals may also contain pathogens that cause disease and perhaps fish kills. For example, in Kansas most of the reported fish kills can be traced to pathogens from animal feedlots and agricultural runoff.

Impairments caused by thermal modification usually result from warmwater discharges (primarily from some type of cooling process) into a lake or its tributaries. This temperature increase adversely affects the sport fishery that prefers cool water. Reservoir releases or withdrawal of cool bottom water may also limit or destroy the habitat for coolwater fisheries.Flow alteration can impair lakes in various ways. Most typical is either decreasing inflow or increasing outflow, both of which lower the water level. This may limit fish habitat and recreational activities.

Acidic conditions can also adversely affect the fish population of a lake. pH is a measure of the hydrogen ion concentration in the water and is used to indicate acidity or alkalinity. A pH of 7.0 is considered neutral, pH less than 7.0 is technically acidic, and pH greater than 7.0 is alkaline. According to the National Acid Precipitation Assessment Program (NAPAP), most fish populations tolerate pH levels between 6.0 and 9.0 without apparent difficulty; significant impact on some species begins at pH = 5.5; serious damage for almost all species occurs below 5.0; and relatively few species can sustain populations in waters below pH = 4.5. The pH at which a State considers a lake impaired may vary depending on various characteristics of the lake and fish species present. The lake's ability to offset changes in pH (buffering capacity) must also be considered since small changes in pH can harm aquatic life.

Although only a few States have assessed the extent of adverse impacts resulting from excessive acidity, it appears that relatively few lakes have low pH values. For example, only 9 lakes with pH values less than 4.5 were reported in Massachusetts and 4 lakes in New Hampshire. New Hampshire also reported 27 lakes with pH between 4.5 and 5.0. Of the 1,000 lakes sampled in Maine, the State reported 50 with a pH less than 5.0, and Wisconsin estimated between 100 and 200 lakes are acidic. However, States indicated that many more lakes are considered sensitive to acidic inputs because of their low buffering capacity. Acidic inputs to a lake may result from precipitation, mine drainage, or naturally decomposing humic material.

Toxic is defined by EPA as any pollutant or combination of pollutants that harms aquatic or terrestrial life or adversely affects human health. Although low dissolved oxygen, pathogens, and acidity may have toxic effects on aquatic life, most States reported their toxic problems in terms of more priority toxicants such as pesticides, organics, metals, and inorganics. Most of these toxicants can accumulate in the food chain and thereby pose a public health problem if contaminated fish are consumed. These toxicants are considered "priority" in that they are listed as such by the Environmental Protection Agency pursuant to Section 307(a) of the Clean Water Act.

Twenty-one States reported the detection of priority toxicants, most often PCBs, pesticides (chlordane, atrazine, alachlor), metals, and mercury. These pollutants were found in lake water, sediment, and fish tissue. Priority pollutants usually are not found statewide, but in specific local areas, where they result from extensive urban or agricultural runoff, mining activities, or industrial point source discharges.

In many instances, levels of priority pollutants warrant fishing bans or consumption advisories such as have been in place for sport fish consumption in Illinois during the past few years. New York also has issued consumption advisories for almost 40 water bodies and banned fishing in the Upper Hudson because of high levels of PCBs in fish. To control fish consumption, fishing at Syracuse's Onondaga Lake was once banned. Even though it is now allowed as recreation, people are warned not to eat their catch.

Pesticides are chemical compounds used to destroy pests in both agricultural and urban areas. They include chemicals such as chlordane, atrazine, alachlor, dieldrin, DDT, and toxaphene. In Kansas lakes, detectable concentrations of agricultural pesticides (e.g., atrazine and alachlor) were found in 34 percent of the 128 lakes sampled for pesticides. Assessment of fish tissue, a more sensitive indicator than lake water of some toxicants, demonstrates a more widespread effect. Fifty-seven percent of the lake acres assessed in Kansas exceeded the National Academy of Science guidelines for protection of predators, with chlordane, PCBs, dieldrin, and heptachlor the principal causes.

Urban activities have also affected Kansas lakes, with two 1986 intensive lake surveys finding elevated levels of chlordane residue in the edible portion of fish. A correlation was established between high chlordane levels and urban areas.

Priority organics include such chemicals as PCBs, phenols, and dioxin. PCBs are most often reported as a problem in lakes. PCBs are a group of toxic, persistent chemicals used to insulate transformers and capacitators and to lubricate gas pipeline systems. Of the lake acres monitored for toxicants in New York, approximately 20 percent were affected to some degree by PCBs or pesticides, with fish consumption advisories in effect for several lakes because of PCB-contaminated sediments. Ground-based sources such as landfills appear to be the source of these pollutants.

Sources of Pollution

States classified the sources of pollution causing use impairment as either point source, nonpoint source, or natural. Table 4 summarizes these sources by State, with 76 percent originating from nonpoint sources, 14 percent from point sources, and 10 percent from natural sources.

Point sources are defined as discrete conveyance discharges (e.g., through a pipe) and include municipal and industrial discharges and combined sewer overflow. Most nonpoint source pollutants are transported by surface runoff, groundwater, and atmospheric deposition. These pollutants originate from streets, lawns, construction sites, forests, mines, and agricultural lands. Point sources are usually chronic and site-specific in impact, whereas nonpoint sources are episodic and/or diffuse.

An objective definition of "natural" sources of pollution has not been developed; therefore this report relies on the States categorization and is somewhat variable. For example, one

Table 4. – Major known sources of pollution in lakes with impaired uses (%).

STATE	POINT SOURCE	NONPOINT SOURCE	NATURAL	PREDOMINANT CATEGORY
CT	49	20	31	Municipal
FL	12	88	0	Agriculture
IL	4	96	0	Agriculture
IN	58	42	0	Municipal
KS	0	2	98*	Mineral-Intrusion
KY	8	26	66	Lake Sediments
LA	12	87	1	Agric./Urban Runoff
ME	2	98	0	–
MD	3	97	0	Agriculture
MN	27	73	0	–
MS	0	100	0	Agriculture
MO	0	100	0	Flow Modification
NH	0	70	30	Acid Precipitation
NM	0	100	0	Agric./Recreation
NY	6	94	0	–
NC	35	63	2	In-place contaminants
ND	0	100	0	Agriculture
OH	17	83	0	Agriculture
OK	0	100	0	Agriculture
PR	1	55	44	Urban Runoff
RI	0	100	0	–
SD	2	96	2	Agriculture
VA	1	63	36	Agric./Urban Runoff
WA	2	98	0	Agriculture
WV	46	54	0	Resource Extraction/ Industrial
AVERAGE	11	76	12	

* Use impairment in Kansas is identified by the violation of water quality criteria. The criteria established in the state of Kansas do not adequately reflect the agricultural NPS impacts on the lakes. Additional information shows well over 50 percent of the total lake impacts result from agricultural NPS pollution.

states not listed in the table either did not report the information or reported in a way that was inconsistent with the format of the table.

State considered in-place contaminated lake sediments as a nonpoint source whereas another State considered contaminated sediments a natural source of pollution. Generally, mineral intrusion and salinity are considered natural sources of pollution and reflect the geology of the area, except in heavily irrigated sites.

Figure 3 shows how nonpoint sources such as precipitation, surface runoff, and groundwater, plus the natural geology and topography of the land can influence the water quality of lakes. This hydrologic cycle illustrated the balance between water inputs and outputs that influences lake water quality. Inputs include direct precipitation, groundwater, and surface runoff; whereas outputs are surface discharge (outflow), evaporation, losses to groundwater, and water withdrawn for domestic, agricultural, and industrial purposes.

Most States find nonpoint sources of pollution responsible for most of the use impairment in lakes, several attributing 100 percent of the impairment to nonpoint sources. Agricultural nonpoint source runoff was the most frequently reported source. Nebraska observed that "even where domestic point sources are indicated as being partially responsible for this problem, it is suspected that the effect of nonpoint sources would still preclude support of the use if the point sources were eliminated." Vermont reported nonpoint sources "now the most widespread remaining water pollution problem affecting the quality of the State's water."

One notable exception to these observations is shown in Table 4. Kansas attributed nearly all its major lake problems to natural conditions such as low inflow and mineral intrusion that result in violations of the State dissolved oxygen and metal criteria. Kansas measures use impairment based on its water quality criteria, which do not reflect the agricultural nonpoint source impacts on lakes. Additional information showed that well over 50 percent of the total number of lakes affected in Kansas could be traced to agricultural runoff.

Kentucky also considers natural conditions responsible for most of the use impairment in that State's lakes. This assessment reflects the release of iron and manganese from the lake sediments under anoxic conditions. Selenium-contaminated lake sediments are also responsible for use impairment in North Carolina lakes; however, North Carolina considers contaminated sediment a nonpoint source.

Although States use varying criteria to determine whether a lake is maintaining its uses, most causes of pollution in lakes are rooted in nonpoint sources. Even some pollutants identified as occurring naturally or originating from specific causes, often can be controlled as nonpoint sources.

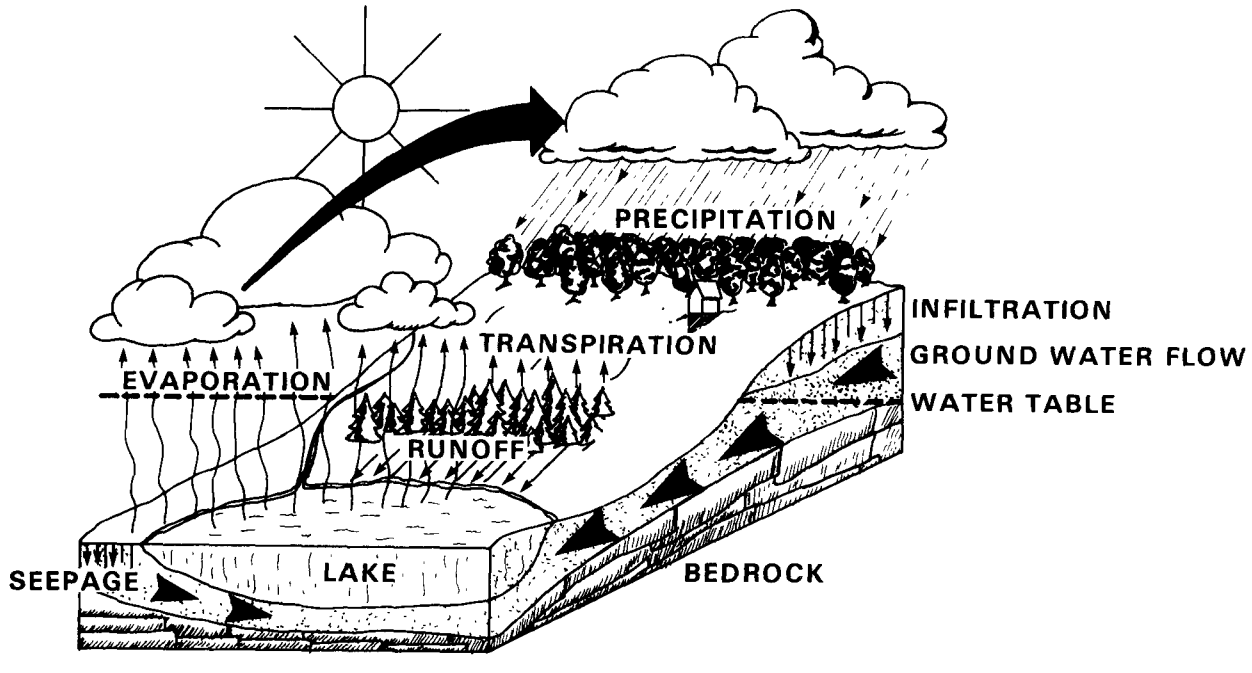


Figure 3.—Hydrologic cycle.

Pollution Control and Lake Restoration

Introduction

The source of pollution to a lake will determine the approach used to protect or restore lake uses. Point sources are usually controlled through permit restrictions on wastewater discharges. Nonpoint sources, because of their diffuse nature, are best controlled by effective watershed management. As point sources are brought under control in most areas, the impact of nonpoint sources becomes more visible and relevant.

The 1986 305(b) Water Quality Inventory found that 76 percent of use impairment in lakes resulted from nonpoint source pollution; this 1988 report confirms that assessment, also finding 76 percent of the impairment caused by nonpoint sources. The 1988 State data on which this report is based reflect, however, assessments of 63 percent more lakes than were surveyed for the 1986 Inventory.

Once the sources of pollution have been successfully addressed, in-lake restoration activities may be appropriate. Lake restoration works only when all parties concerned cooperate in its design and implementation. In developing restoration plans for specific lakes, EPA Regions work with a number of State and Federal agencies, among them the local Soil and Water Conservation District, the Agricultural Stabilization and Conservation Service County Committee, the Soil Conservation Service, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, the U.S. Army Corps of Engineers, and any other organization involved with lakes.

Pollution Control

■ **Point Sources.** Over the past 20 years, the States have made great strides in controlling point sources of pollution through National Pollutant Discharge Elimination System (NPDES) permits, State permits, construction of wastewater treatment facilities, and industrial pretreatment programs.

Wastewaters from cities, industries, businesses, and homes comprise a source of pollutants affecting lake water quality. Wastewaters receive different treatment based on the water quality needs of the receiving stream. Treatment levels are generally referred to as primary, secondary, and advanced.

Primary treatment plants used by municipalities and industry generally remove about 35 percent of pollutants on the average; secondary treatment around 85 percent. Neither primary nor secondary treatment removes phosphorus and nitrogen (which significantly affect lakes) except as these nutrients are attached to solids. Large cities and manufacturers use advanced wastewater treatment plants to remove these nutrients.

Small-scale systems, including septic systems (which can also act as nonpoint sources) may be used by communities and individual property owners. The effects of these small waste disposal systems on water quality depend on their location: the soil characteristics, groundwater tables, usage conditions, and slope of the terrain.

Effective operation and maintenance are key factors in assuring that waste disposal systems avoid degrading water quality. No matter how large or small the system – whether it serves a city of millions or a household of two – it must be properly installed and operated, and maintained on a regular schedule.

■ **Nonpoint Sources**. Daily, natural, and routine human activities – be they on the lakeshore or many miles upstream in the watershed (the land that drains into the lake) – contribute nutrients, sediment, and other pollutants to a lake, principally as runoff from streets, construction sites, forests, mines, and agricultural land. Effective control of nonpoint sources could prevent lake water quality problems, eliminating the need for costly restoration projects. The approaches that can be taken to reduce or eliminate nonpoint source pollution are discussed in the following paragraphs.

Best management practices, commonly referred to as BMPs, are designed to prevent or reduce the quantity of pollution entering a lake. BMPs have been successfully applied to control the potential nonpoint source pollution associated with many land uses, including agriculture, silviculture, construction, mining, and urban activities. Among these BMPs are conservation tillage, integrated pest management, animal waste management, porous pavements, road and skid trail management, land surface roughening, stormwater management, bank stabilization and riprapping, lakeshore management, sedimentation traps, runoff diversions, redesigned streets and parking lots, and detention/sedimentation basins. Knowledge developed by activities authorized under Section 319 of the Water Quality Act will significantly increase citizens' ability to control nonpoint sources of pollution. In addition, various Department of Agriculture programs, such as the Conservation Reserve Program, play an important role in addressing agricultural sources of lake pollution.

A growing number of communities protect lakes with regulations and ordinances that require BMPs to prevent problems caused by erosion and pollution. In the State of Washington, for example, the community of Mountlake Terrace regulates construction to minimize its contribution to nonpoint source pollution. Where possible, planned development within a lake's watershed can limit the entry of pollutants into a lake.

Pollution control also is often brought about by local opposition to activities that may degrade a lake, prompting direct State or local agency intervention. Throughout the Nation, citizens are forming lake associations to protect, manage, and restore their lakes. These associations often promote local ordinances that restrict land use activities to control pollution. For example, Kentucky's mining regulations contain a petition process that allows land in a lake's watershed to be declared unsuitable for mining. Such a petition process has been used to protect the water quality of Cannon Creek Lake in Kentucky.

State Programs

Several States have enacted legislation and set up lake management and nonpoint source pollution control programs. Although a few programs have a regulatory component, they are predominantly voluntary and are based on cost sharing, incentives promoting good land management, technical assistance, and information/education.

South Dakota controls nonpoint source pollution through a combination of regulatory and voluntary measures that focus on their major nonpoint source problem: agricultural runoff. The South Dakota Erosion and Damage Control Act regulates and permits "any land-disturbing activities within the State which result in soil erosion and sediment damage." Also, the State's Surface Water Quality Standards specify eight parameters that can be considered indices for nonpoint source pollution. Examples are (1) suspended solids likely to be associated with most agricultural land-disturbing activities, (2) total dissolved solids and conductivity associated principally with irrigation return flows, and (3) coliform bacteria associated with livestock operations. The State notes that its water quality standards are inadequate for documenting the impact of agricultural runoff.

Slightly more than half of the States use a regulatory approach to control pollution through site-specific criteria and lake water quality standards. These standards are derived largely from professional judgement and literature values, with monitoring data also used. Washington, which has long had standards, modified them in 1988 to establish both a site-specific nutrient (total phosphorus) criterion for Long Lake Reservoir and criteria for toxic substances. Also, in 1988, Washington began taxing tobacco products to fund water pollution control programs. Up to 20 percent of the $45 million generated each year is earmarked for nonpoint source control; another 10 percent, for protection of lakes and rivers. In reality, lakes benefit from both funds because of the close connection between lake water quality and nonpoint source pollution.

Some States have established State lake management programs designed specifically to protect, enhance, and restore their lakes. Among them are Maine, Indiana, Illinois, Massachusetts, New York, New Jersey, South Dakota, Connecticut, Florida, Minnesota, Idaho, North Dakota, New Hampshire, Ohio, Wisconsin, North Carolina, and Michigan.

The Illinois lake program is a good example of a comprehensive State lake management program. The major program components include monitoring, lake classification to guide decisionmaking, development and implementation of lake/watershed management plans for public lakes under the Federal Clean Lakes Program, and education, technology transfer, technical assistance, and coordination.

Since the program began in 1977, the Illinois Environmental Protection Agency (IEPA) has compiled assessment information and baseline water quality and sediment data under Illinois' Ambient Lake Monitoring Program (ALMP). The ALMP defines trends in significant lakes and diagnoses lake problems, evaluates progress in pollution control/restoration programs, and updates the State lake classification system.

More than 700 volunteers have participated in monitoring 250 lakes under Illinois' Volunteer Lake Monitoring Program (VLMP), which, in addition to increasing citizen knowledge and encouraging local involvement, gathers fundamental information on the State's lakes. A historic data baseline is being developed, as are lake protection and management plans.

The IEPA has also developed a lake classification/needs assessment that can be used to establish protection, monitoring, and technical assistance priorities, rank watershed land treatment projects, plan for recreational use, and screen candidates for Clean Lakes Program assistance.

Educational and technical assistance to citizens, lake managers, and local government officials promotes a better understanding of Illinois' lake ecosystems and encourages comprehensive management of these resources.

Several States have acted to reduce the precursors of acid precipitation through emission control programs. For example, New York was the first State to mandate reductions in emissions that contribute to acid precipitation (State Acid Precipitation Control Act, 1984). The State is now proposing to formally adopt the Federal New Source Performance Standards for emissions of oxides of nitrogen.

Michigan has also acted to reduce emissions. From 1974-86, sulfur dioxide emissions from stationary sources in the State were cut by 82 percent with all sulfate emissions standards met by 1987.

Both New Hampshire and Vermont believe that reducing out-of-State emissions must be the first step in addressing the effects of acid precipitation in their States. Pointing out that 99.9 percent of the pollutants responsible for the damage in the State originate outside its borders, Vermont said that the problem will not be solved by treating the symptoms without treating the causes.

Lake Restoration

Lake restoration corrects lake problems, using ecologically sound principles to improve the lake on a long-term basis. To successfully restore lake water quality, the source of the problem must be identified and appropriate control measures then implemented.

A lake problem is usually best controlled when addressed in its watershed by the procedures described previously in this Report. After the sources of pollution have been eliminated or reduced to the appropriate level, some in-lake measure such as sediment removal can also restore water quality for long periods of time. Others – alum treatment, for example, – restore water quality on a short-term basis to reduce loss of user days while watershed controls are being put in place. Unless the source of pollution is addressed, in-lake restoration efforts become repetitive and costly.

Before restoration can begin, a thorough diagnostic study of the lake must be completed to determine the cause of the problem, as well as the feasibility both of restoration itself and of the proposed restoration techniques. A technique that works well for one lake may not be appropriate for another. The existing lake and watershed conditions and characteristics are key factors in a successful restoration project, and influence the potential for improvement in various lakes. In areas with high precipitation and easily erodible soils that contain excessive nutrients or organic materials, a lake can be improved only minimally, and will probably never be transparent and pristine. Therefore, the best attainable water quality should be determined before deciding on the feasibility of restoration and the appropriate restoration techniques.

Restoration techniques for lakes continue to be developed. The lake restoration demonstration projects in the mid-1970s pioneered many techniques that have since been refined. The principal restoration techniques briefly described here are explained more fully in the Lake and Reservoir Restoration Guidance Manual (LRRGM) published by

EPA in response to legislative mandate to compile information about restoration techniques for public use. Further information on lake restoration will be available to the public in technical updates to the LRRGM.

The States that have reported lake restoration activities are summarized in Table 5. These lake rehabilitation techniques are designed to improve the lake; not all of them necessarily target the source of the problem.

As mentioned previously in this Report, excessive nutrients and siltation caused significant impairment of use in lakes. Nutrient input to lakes encourage macrophyte growth and algal blooms. Also, as explained previously, the decomposition process of algae and plants consumes oxygen, possibly lowering the dissolved oxygen to a level that stresses or even kills fish. Sedimentation may also stimulate algal and macrophyte growth by providing a suitable substrate for macrophytes and transporting the necessary nutrients. Sediment input to a lake can also reduce its depth – impeding boating and other water recreation.

Because nutrients and sedimentation have been recognized as major causes of lake use impairment, the restoration techniques described in this Report focus on abating their adverse effects, and are presented according to the problems they cause. Also, as required by the legislation, techniques to mitigate the effects of acidity and toxics on lake water quality are discussed in this Report.

Restoration techniques, therefore, are presented in the following categories (Table 6):

1. Control of nuisance algae,
2. Deepening to eliminate shallowness,
3. Removal of nuisance rooted vegetation,
4. Improvement of fisheries,
5. Acid mitigation,
6. Toxics removal.

Control of Nuisance Algae

■ **Phosphorus precipitation and inactivation:** Precipitation removes phosphorus from the water column; inactivation controls phosphorus release from the sediments. Alum (aluminum sulfate) is most frequently used because phosphorus binds tightly to its salts under most conditions, creating a floc that settles out, leaving the water clear. If enough alum is added, a layer of aluminum hydroxide will settle to the bottom, preventing phosphorus release. However, the lake should be deep enough to prevent resuspension of sediments that precipitated via alum addition. This technique is most effective on lakes where nutrient inflow has been diverted, and has been proposed for both Delevan Lake, Wisconsin, and Hills Pond, Massachusetts.

■ **Sediment removal:** Controls nutrient release from sediments by removing the layer of the most highly enriched materials. In this procedure, a dredge (several types exist) loosens the sediment, which is then transported as a slurry through a pipeline to a remote disposal area. Although the residue may (if it does not contain toxic material) be used as fill or fertilizer, the costs of dredge spoil disposal can be high. In small lakes, however, draining the lake and removing sediments may be economically feasible. Sediment removal can be effective, as demonstrated on Lilly Lake in Wisconsin and Lake Lansing, Michigan. Care must be taken in depositing the sediments, so as not to adversely affect adjacent wetlands.

■ **Dilution and flushing:** The nutrient concentration is lowered by introducing nutrient-poor water from another source, thus starving the algae. Large amounts of additional water also can flush the algae from the lake faster than they can grow. This technique is limited by the availability of water from an outside source and the rapid rate of algal growth. Therefore, few examples exist, with Moses Lake, Washington being a notable exception. At this lake, water from the Columbia River was diverted through the lake, producing dramatic improvement.

■ **Biological controls:** Plant-eating fish and plant pathogenic organisms can be introduced into a lake to control nuisance aquatic vegetation. Grass carp, a non-native species originally imported from Malaysia in 1962, can control, even eradicate plants within several seasons. The Little Pond, Maine Clean Lakes Project successfully used this technique to control algal blooms. Six insect species imported by the U.S. Department of Agriculture under quarantine are being used in the South to control alligatorweed and water hyacinth. The introduction of non-native species should be used with caution and with a comprehensive understanding of the native species/community interactions. Significant negative environmental impacts, for example, reduction/elimination of native and/or desired species resulting from over-competition of non-native species, are a possibility.

■ **Aquatic macrophyte harvesting:** Vegetation is mechanically cut and removed from the lake. This

Table 5. – Lake rehabilitation technique

STATE	NUTRIENT MANAGEMENT	PHOSPHORUS PRECIPITATION/INACTIVATION	SEDIMENT REMOVAL/DREDGING	DILUTION/FLUSHING	BIOLOGICAL CONTROLS	AQUATIC MACROPHYTE HARVESTING	ARTIFICIAL CIRCULATION	HYPOLIMNETIC AERATION	FOOD CHAIN MANIPULATION	CHEMICAL CONTROLS	DIVERSION	SEDIMENT BASIN/TRAP	DRAWDOWN	SHADING/SEDIMENT COVER	SEDIMENT OXIDATION	HYPOLIMNETIC WITHDRAWAL	INTRODUCTION OF NON-NATIVE SPECIES
CT	X		X	X		X				X			X			X	
DE			X														
FL	X	X		X	X				X								
GA											X	X	X				
IL	X		X	X		X	X	X		X	X	X	X				
IN	X	X	X	X		X	X	X			X	X	X	X		X	
IA			X														
KS			X		X			X									
ME	X	X		X				X		X	X						X
MD			X								X	X					
MA	X		X			X	X			X	X	X	X			X	
M	X	X	X		X	X	X		X		X	X	X		X	X	
MN	X	X	X	X	X	X			X	X	X	X	X			X	
M			X								X						
M			X									X					
N											X						
N									X		X	X					
NH			X							X	X		X				
NJ			X							X		X	X				
NY	X	X	X	X		X	X				X	X	X				
ND			X								X					X	
OH	X		X		X		X					X					
OK			X								X	X					
PA			X														
RI		X	X			X				X							
SD			X								X	X					
TX			X		X												
VT		X				X				X	X						
VA	X						X				X	X					
WA		X	X	X	X	X				X	X						
W	X		X	X		X	X		X	X	X	X	X				

states not listed in the table either did not report the information or reported in a way that was inconsistent with the format of the table.

Table 6. – Lake rehabilitation techniques by restoration objectives.

TECHNIQUE	CONTROL NUISANCE ALGAE	ELIMINATE EXCESSIVE SHALLOWNESS	REMOVE ROOTED PLANTS	IMPROVE FISHERIES	ACID MITIGATION	TOXICS REMOVAL
Phosphorus Precipitation Inactivation	X					
Sediment Removal/Dredging	X	X				X
Dilution/Flushing	X					X
Biological Controls	X		X			
Introduction of Non-Native Species				X	X	
Aquatic Macrophyte Harvesting	X		X			
Artificial Circulation	X			X		
Hypolimnetic Aeration	X			X		
Food Chain Manipulation	X			X		
Chemical Controls	X		X	X	X	X
Diversion	X	X				
Sediment Basin/Trap		X				
Drawdown/Waterlevel Management			X		X	
Shading/Sediment Cover			X			X
Sediment Oxidation	X		X			
Hypolimnetic Withdrawal	X					
Nutrient Addition					X	

procedure reduces the oxygen stress and fish kills associated with decaying vegetation. Harvesting also increases open water and improves aesthetics. However, harvesting must be repeated regularly, and does not completely address eutrophication over the long term, because it only reduces nutrient loading from sediments and does not eliminate external nutrient loading to the lake. In some cases, such as Lake Hopatcong, New Jersey, and Blackhawk Lake, Iowa, it does remove significant amounts of nutrients. Harvesting may not be appropriate in some situations because it can stimulate growth and reproduction in some plant species.

■ **Artificial circulation:** Circulation mixes the lake waters, eliminating thermal stratification. It may control algal blooms by introducing dissolved oxygen to the bottom, thereby inhibiting phosphorus release from the sediments. This technique has been used on Hampton Manor Lake, New York.

■ **Hypolimnetic aeration:** Not intended to destratify the lake (as with artificial circulation), this procedure brings cold hypolimnetic water to the surface of deep lakes where it is aerated by contact with the atmosphere and then returned to the hypolimnion. This technique may be used to maintain a coldwater

fishery in a lake where the hypolimnion is normally anoxic (oxygen-depleted), or to eliminate taste and odor problems in drinking water withdrawn from a cold hypolimnion. The Lake Como, Minnesota, Clean Lakes Project is using this technique.

■ **Hypolimnetic withdrawal:** Very little documentation exists on this procedure designed to withdraw water from the deepest areas of a lake, which may be extremely rich in nutrients. Spiritwood Lake, South Dakota, reduced algal blooms by removing nutrient-rich water from the hypolimnion (in addition to implementing watershed erosion controls). Lake Warramaug, Connecticut, also has had good results using this technique.

■ **Food chain manipulation:** Zooplankton grazing might be used to control algae in the open water of a lake or reservoir. This requires analysis of the organisms that exist within the lake.

■ **Chemical controls:** Perhaps the oldest and most widely used method to manage weeds, herbicides can rapidly reduce vegetation for periods of weeks to months. Chemical control is not a long-term restoration technique because it does not address the causes of the problem, nor are nutrients and organic matter removed from the lake. In fact, nutrients sequestered as plant biomass can be released back into the water column as a result of decay of the plant biomass. This can resuult in phytoplankton blooms. Eola Lake in Florida is using this technique.

■ **Diversion:** This method diverts nutrient-laden water entering the lake into an alternative site, either a treatment plant for waste disposal, or some form of detention basin. The latter may be a settling facility or a natural area such as a wetland. Sewage, septic tank seepage, and runoff containing high levels of nutrients are usually the waters targeted for diversion.

Deepening a Lake

■ **Sedimentation basin:** Designed to hold runoff long enough for sediment to settle to the bottom of the containment structure, sedimentation basins are positioned strategically in the watershed to trap the runoff. This technique is both restorative and preventive. Lake Tahoe in Nevada has used this technique.

■ **Diversion:** Described earlier as a technique for removing nutrients, diversion also can be used to prevent sediments from filling the lake. Diverted water is held in a sedimentation basin for settling long enough for sediments to settle out.

■ **Sediment removal (dredging):** Also described in a previous section, dredging is an effective technique for deepening a lake and enhancing recreational activities such as swimming, boating, etc. However, it should be noted that the presence of some shallow shoreline areas with aquatic macrophytes is important to the habitat and propagation of certain fish species. In the restoration of a shallow lake a balance between the maintenance and enhancement of recreational activities and fish habitat must be recognized to ensure the overall health of the lake ecosystem.

Control/Elimination of Nuisance Rooted Vegetation

■ **Drawdown:** Water is drawn from the lake to expose sediments to prolonged freezing and drying conditions that will kill plants. This procedure also allows repair of dams and docks, sediment removal, and other management practices. However, some plants are not affected by the exposure and in others growth is stimulated. At most, this technique should be employed no more that every two years, to avoid development of resistant weed species and damage to benthic invertebrates. If the lake water level is controlled by a dam, this is an inexpensive technique, although costs will be associated with the loss of the use of the lake.

■ **Shading and sediment covers:** Dyes can be applied to the water to limit light available for plant growth and sediments can be covered to stop such growth. Sediment covers are most effective in small areas where, if properly installed, they can completely eliminate plants. Because they are difficult to place over growing plants, covers are best applied during winter drawdown or early spring.

■ **Sediment removal (dredging), biological controls, macrophyte harvesting, and chemical controls** also are used to control vegetation. These techniques were described previously.

Improve Fisheries

Many of the techniques previously described can be used to improve fisheries, with the selection of the specific technique dependent on the geographic area and characteristics of the lake. For example, in lake systems altered by chemical or biological factors

(e.g., acidity), more acid-tolerant species may be introduced.

The most commonly used techniques to improve fisheries (all described previously) include **drawdown, artificial circulation, food chain manipulation, hypolimnetic aeration, and chemical controls.**

Acid Mitigation

Designed primarily to restore the aquatic ecosystem to a pH level that ensures an adequate and healthy fishery, restoration of an acidified lake involves two basic strategies:

1. Modification of the physical and chemical environment, and
2. Modification of fish populations.

The techniques selected will depend upon the geographic, political, institutional, and economic constraints within which the lake manager operates. Many of the techniques involve liming and the use of alkaline materials.

■ **Modification of the physical/chemical environment:** "Liming" or the addition of other alkaline materials is the most widely used technique for raising the pH in lakes. Lime may be applied to the lake water column, lake sediments, watershed, or feeder streams. Other less commonly used techniques to mitigate high acidity in lakes are changing the land cover, managing reservoir surges, and adding nutrients to alter the lake chemistry. Changing the land cover involves eliminating vegetation that produces acidic litter (e.g., conifers). Reservoir water drawdown and discharge can be altered to prevent the acidic surge that can occur with snow melt and spring rains. Supplying nutrients to a lake increases its biological productivity, thereby increasing the lake's pH and acid neutralizing capability.

■ **Modification of fish populations:** Five restoration techniques are used to modify fish populations in lakes affected by acidity. These include placing limestone gravel in spawning beds, stocking with adult fish, stocking with acid-resistant fish, creating new fisheries, and installing limestone filters in hatchery intakes.

Four eastern States (Maryland, Maine, New York, and Pennsylvania) and Michigan described acid mitigation efforts in the 1988 Lake Water Quality Assessments. Maryland has been working extensively over the past two years in an effort to control acidity by liming streams and lakes.

Approximately 200 surveyed Massachusetts lakes either have been affected or are susceptible to acidic inputs. Massachusetts has one State-funded program that addresses the issue: in the past two years, this program has limed nine ponds. In June 1988, the State published *Acid Rain in Massachusetts*, a volume documenting the current status of the problem and the State's mitigation efforts to date.

Pennsylvania, where State law prohibits discharge of substances to State waters without approval, has adopted a policy of approving the addition of neutralizing agents only as part of a closely monitored experimental project designed to study the effectiveness and costs of liming. Under this policy, one lake (White Deer) has been treated twice with agricultural limestone (aglime).

Toxic Removal

Toxics may be present in a lake either in the water column or in the sediment. The appropriate removal technique depends on the location and nature of the toxic pollutants present. In general, techniques to remove toxics from the water column include:

■ **Dilution/flushing.** Dilution is the introduction of toxic-free water that mixes with the contaminated water and by thus reducing the relative concentration of the toxics in the lake may minimize their adverse effects. Flushing the toxic-contaminated water from the lake may improve the condition of the lake, but may also create a problem downstream.

■ **Chemical treatment and/or pH adjustment.** Under appropriate pH conditions and/or upon treatment with particular chemicals, some toxics will precipitate out of the water column and settle to the bottom of the lake. Although this removes the toxic pollutants from the water column, it may result in a problem with contaminated sediments.

Removal of toxic pollutants from bottom sediments is the focus of the five-year demonstration program authorized under Section 118(c)(3). Knowledge gained from this program should produce new technology to control in-place pollutants. Current techniques to remove or minimize the effects of contaminated lake sediments include:

■ **Dredging.** The most commonly used method to remove contaminated sediments from a lake is by dredging, which loosens the sediment and transports it as a slurry through a pipeline to a remote disposal

areas. Since the dredge spoils are contaminated, the disposal area must be completely contained so that runoff will not recontaminate the lake, another area, or leach into the groundwater. The physical action of dredging may also resuspend toxics in the water column.

■ **Sediment covers.** Contaminated sediments may be covered with materials such as toxic-free sand, gravel, or clay to protect the aquatic life from adverse impacts of recycling toxics in the water column. However, unless the source of contamination is controlled these covers will also become contaminated. Sheeting material, such as a plastic-type liner that is resistant to damage by the toxics present, may also be used to line the bottom of the lake. However, these are difficult to apply over large areas and may slip on steep grades or float to the surface after trapping gases beneath them.

Pollution control and lake restoration are inseparable: it is impossible to truly restore a lake on a long-term basis without controlling the sources of pollution to that water body. Some restoration techniques (such as dredging and chemicals) work for the short term, however, temporarily alleviating the problem while the pollution is being controlled. As the States and their citizens become more aware and involved in protecting and restoring their lakes, they are realizing the need to thoroughly analyze the lake's condition and the options for improving its water quality before beginning restoration procedures.

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