Special Publication SJ 87-SP5

A PRELIMINARY ASSESSMENT OF PHOSPHORUS PRECIPITATION-INACTIVATION AS A RESTORATION TECHNIQUE IN LAKE APOPKA

By

Richard A Baird
Project Manager

ORANGE COUNTY ENVIRONMENTAL PROTECTION DEPARTMENT
2002 East Michigan Avenue
Orlando, Florida 32806

John M. Bateman, P.E.
Department Manager

For the

St. Johns River Water Management District
Post Office Box 1429
Palatka, Florida 32078

September 8, 1987

ACKNOWLEDGEMENTS

The Orange County Environmental Protection Department would like to recognize and thank Dr. Edward R. Pershe for his work on this report.

We also wish to thank all the people whose names do not appear here but were involved in the preparation of this document.

ABBREVIATIONS

P....................................phosphorus

Al...................................aluminum

PO_4..............................phosphate

mg...................................milligrams

L....................................liter

ha...................................hectare, 2.47acres

m....................................meter

<....................................less than

>....................................greater than

Table of Contents

I. Introduction

Lake Apopka in northern Orange County is the largest lake in the Upper Oklawaha River, and the largest tributary to the St. Johns River. Covering an area of approximately 12,510 ha (31,000 acres) or 51 square miles, and having an average depth of about two meters, the lake drains northward to Lake Beauclair through the Apopka-Beauclair canal (4, 13).

For a number of years, Lake Apopka has received heavy loadings of nutrients, nitrogen and phosphorus, from bordering muck farms, citrus groves, wastewater treatment plants, and various non-point sources. Prior to 1947, the lake had clear water, supported no algal blooms and was a fisherman's paradise. In the late 1940's and early 1950's, the first algal blooms were observed, rooted aquatic vegetation began to disappear and game fish populations declined (16).

At the present time, Lake Apopka is highly eutrophic with a constant algal bloom. Rooted aquatic vegetation and bass have practically disappeared from the lake, and rough fish, shad and gar, now dominate the lake's waters (16).

Over the past decades, various methods have been proposed to restore the lake to its former condition. One method proposed is the chemical treatment of the water with aluminum compounds, to precipitate the phosphorus and consolidate the sediment.

In September 1986, the St. Johns River Water Management District employed the Orange County Environmental Protection Department to conduct an assessment of phosphorus precipitation-inactivation as a restoration technique in Lake

Apopka. Phase I of the project involves conducting a review of the literature to determine whether further exploration of this restoration technique is warranted.

The purpose of this report is to present the data, findings, and pertinent details of projects that have utilized chemical precipitation of phosphorus as a lake restoration technique. It represents the latest information available from a computer search of pertinent references conducted in October 1986. The computer search was conducted by the University of Central Florida Library Information Network and Exchange System. The library used the DIALOG Information service Inc. which accessed thirteen data base systems. We provided the following key words;

Lake, Reservoir, Alum, Treatment, Phosphorus, and Precipitation. Using these keywords in the thirteen data base systems there are over 850,000 references available. We then chose three combinations of those keywords; Treatment with alum, phosphorus precipitation, and lake or reservoir and alum treatment or phosphorus precipitation.

These combinations resulted in the previously referenced 133 citations.

After reviewing them and preparing the annotated bibliography found in appendix A, we now have 111 citations. We feel that the references used in the report constitute those studies which are most closely related to the Lake Apopka situation.

Table I-1. A Chronology of Lake Apopka. (From Proposed Work for Apopka Pilot Project 2/86)

Year(s)	EVENT
1922-1927	Sewage discharges from Winter Garden begin
1924	Waste water discharges from fresh fruit preparation begin
1942	Drainage water discharges from muck farms begin
1942-1947	Expansion of muck farms
Sept. 1947	Hurricane destroys large amount of submerged vegetation
Oct. 1947	First algae bloom 35% of fish are game fish, 20% are gizzard shad
1948	Waste water discharges from citrus concentrate production begin, herbicide treatments of water hyacinth begin, Apopka-Beauclair Canal opened, 57% of fish are game fish
1948-50	Disappearance of rooted aquatic vegetation, frequent algae blooms, ten-fold increase in fish population, game fish 69%
1951	Average annual gross income of fish camps about $37,000
1952	Control structure placed in Apopka-Beauclair Canal and water level stabilized at 55.5-67.5 ft. msl
1956	21 fish camps
1957	Gizzard shad 82% of fish population, selective poisoning of shad (3.5 million pounds)
1958	Selective poisoning of gizzard shad (10 million pounds)
1959	Selective poisoning of gizzard shad (6.5 million pounds)
1962	Shad 30% of fish biomass; game fish 50%
1962-1963	Fish kills due to gas embolism
1965	9 fish camps, average annual gross income about $11,000
1970	AGizzard shad 82% of fish population
1971	Experimental gravity drawdown, alligator, turtle, and fish mortality attributed to bacteria (Aeromonas)
1976	4 fish camps
1977	Citrus processing waste water discharges end
1980	Sewage discharges end
1981	Final report of University of Florida indicates continuing eutrophication

II. Some Aspects of Phosphorus Precipitation-Inactivation

The purpose of phosphorus precipitation and inactivation in lake restoration is to lower the lake's phosphorus content by removing phosphorus from the water column and retarding any release of phosphorus from lake sediments. Aluminum sulfate (alum), sodium aluminate, or a mixture of both, is added to the water column to form a precipitate of aluminum phosphate or colloidal aluminum hydroxide to which certain phosphorus fractions are tightly bound.

Aluminum is the element most often chosen for phosphorus precipitation and inactivation because it complexes and forms polymers which are apparently inert to redox changes such as occur in an anoxic hypolimnion. The phosphorus that is bound in such a way remains so, in contrast to iron complexes, which releases phosphorus as the redox potential falls during the development of anoxia. In addition, the aluminum complexes are highly efficient in the entrapment and removal of particulate and inorganic phosphorus, and are apparently nontoxic to aquatic biota at the pH and dosage required to effect the desired phosphorus removal (3).

When alum or sodium aluminate is added to water, the solution pH dictates the form of hydrolyzed aluminum species that results. Settleable, polymerized aluminum hydroxide predominates between pH 6 and 8, aluminate predominates above this range, and trivalent aluminum below it.

The removal of inorganic phosphorus is primarily dependent on the reaction pH and phosphorus concentration. In general, high inorganic phosphorus concentrations (>1 mg P/L), such as those encountered in wastewater treatment, and low pH favor the formation of $AlPO_4$. Theoretically, under these conditions and in the presence of excess phosphorus, the removal of one mole of phosphorus as $AlPO_4$ would require one mole of aluminum. In practice, however, Al/P ratios for maximal removal during conventional wastewater treatment are often greater than unity (11).

At lower inorganic phosphorus concentrations (<1 mg P/L), and higher pH, OH^- competes with PO_4^{-3} for aluminum ions thus favoring the formation of aluminum hydroxide-phosphates. Under these conditions,maximal phosphorus removal occurs at Al/P molar ratios which are much higher than those used in wastewater treatment, ranging from 5.5 to 7.5 (11).

Dissolved organic phosphates are removed with considerably less efficiency, presumably because of their complex molecular structure and chemical characteristics. If the objective of alum treatment is to reduce phosphorus to limiting concentrations in a lake, failure to remove dissolved organic phosphorus could create a significant problem since certain nuisance blue-green algae can produce phosphates, an enzyme which will release inorganic phosphorus from any organic phosphates and cause algal blooms (7,14).

Once deposited, aluminum hydroxide floc provides continued phosphorus control. The phosphorus-trapping effectiveness of the floc layer will depend on the amount of aluminum present, pH, the concentration of phosphorus, and the rate at which phosphorus is supplied to the floc either through sedimentation or ground water seepage (6). Such control may last at least 5 years if nutrient diversion is complete (1).

Iron and calcium salts are not suitable as phosphorus precipitants/inactivants in lake restoration. Lake sediments, covered by an oxidized microzone which traps phosphorus by precipitation with hydrated iron oxides, will release phosphorus when the dissolved oxygen content of the hypolimnion falls and causes the reduction of ferric hydroxide and other iron complexes.

The use of calcium additions to lakes to obtain effective phosphorus removal requires pH values above those found in natural waters and thus may cause damage to the biota.

No standard set of procedures can be prescribed for successfully treating lakes with alum. However, the following factors must be taken into consideration when undertaking such projects:

(1) Dose of chemical to be applied
(2) Chemical form
(3) Depth or point of application
(4) Application procedures
(5) Season of the year
(6) Side effects of treatment
(7) Lakes best suited for this Restoration Technique.

A. Chemical Dose

Determination of the alum dose is dependent on whether the purpose of the treatment is to remove phosphorus from the water column or to control the release of phosphorus from sediments. In either case, jar tests must be employed.

If the primary objective is to remove phosphorus from the water column, the dosage is determined by jar tests in which aluminum salts are added until a desired phosphorus removal is obtained. Little attention is given to the quantity of the floc that is deposited on bottom sediments. The laboratory determined dosage is then used directly to calculate the amount of chemical to be used on a lake volume basis. Usually the dose of aluminum chosen is small enough so that drastic shifts in pH and residual dissolved aluminum (RDA) do not occur.

If, in the second approach to dose determination, the goal is to obtain maximum application of aluminum to the bottom sediments in order to obtain long term control of internal phosphorus recycling. Phosphorus removal in the water column is only a secondary consideration (1,2,18). Again, laboratory jar tests are used, however, the dosage is determined by using changes in pH and residual dissolved aluminum (11). The "maximum" dose which will produce an acceptable pH and RDA concentration is then chosen.

A "maximum" dose is defined as that dose above which the dissolved aluminum concentration exceeds .05 mg Al/L. This is the concentration that has been shown to be safe for rainbow trout (11). It has been widely adopted as a criterion by virtually all authorities.

Basically, samples of lake water are taken from different depths to insure that all alkalinity conditions are represented. The samples are treated with chemical to ascertain the relationship between RDA, alkalinity and chemical dose, following which the dose for the entire lake is computed.

An alternate approach would be to add both alum and sodium aluminate at the same time and determine the proper proportion of chemicals to maintain a pH at which the RDA does not increase. When aluminate is used alone, the pH will rise. This can be avoided by neutralizing the aluminate with hydrochloric acid (HCl) before addition to lake water where the alkalinity is below 100 mg/L as $CaCO_3$.

B. Chemical Form

Nearly all treatments have used liquid alum or sodium aluminate applied to surface or hypolimnetic waters with extensive mixing. Dry alum does not form a floc as well as liquid alum and is less effective. If dry alum is the only form available, it can be mixed in tanks to form a slurry before application.

C. Depth of Application

The depth or point of application is directly related to the treatment objective. When phosphorus removal from the water column is desired, surface treatment is utilized. When the goal is to control the release of phosphorus from sediments, a hypolimnetic application is usually employed (1,2,9,17).

Most of the pre-1974 projects employed surface application, however, since that time, hypolimnetic applications have been favored because control of phosphorus release from sediments quite often is the primary objective. It should be noted that surface application is far less costly than hypolimnetic, and may be just as effective in controlling phosphorus release from sediments if sufficient chemical is added.

D. Application Procedures

Methods of applying aluminum salts to lakes have remained remarkably similar over the years. In the basic application system, dry alum is mixed with water on board the applying vessel. The prepared slurry is then pumped through a distribution manifold suspended behind the craft just below the water surface. Using liquid alum eliminates the equipment that is required to process dry alum.

While some designs have employed dispensing manifolds fixed to the rear of boats or barges, more recent designs have used a frontal distribution system to take advantage of the mixing and spreading action produced by barge pontoons and the propellers of the motor (14).

Particular care must be exercised when applying two chemicals at the same time, such as when adding sodium aluminate and aluminum sulfate to soft water lakes (alkalinity below 100 mg/L as $CaCO_3$), or when applying ferric alum and dry aluminum sulfate to small ponds. In such cases, the chemicals must be pumped separately because contact prior to release in water would clog equipment with the precipitate that would be formed. Ferric alum has been added to lakes by simply placing blocks of it in the water, suspended by floats, and allowing it to dissolve. When the blocks dissolved, they were replaced (14).

Most of the equipment used for application purposes has been designed to apply an even dosage for surface coverage or to add alum to the hypolimnion. It is also intended to make the work less tedious and expensive. An alternative procedure would be to spray the alum over the lake surface using a pump and a hose with a nozzle. This could save on manpower and equipment costs, however, several serious problems could arise, including localized lethality due to high aluminum or hydrogen ion concentrations from uneven distribution of chemical, and poor mixing leading to locally heavy amounts of floc (10).

E. Season of the Year

The optimum time for application is dependent upon the objective of the treatment. If phosphorus removal is the objective, then early spring would be ideal because most of the phosphorus in the water column at this time of the year is inorganic and almost completely removable by floc (11).

In summer months, a large fraction of the total phosphorus is in the particulate and dissolved factions which are efficiently removed with aluminum. The main source of phosphorus to the water column of many eutrophic lakes during the summer is internal phosphorus release. While there are biotic sources of internal phosphorus, much of it probably comes from anaerobic sediments and phosphorus must be controlled there to achieve limitation of algal populations (7,9).

If control of phosphorus release from sediments is the objective, then time of application does not appear to be critical. However, a late fall treatment would find most benthic insects dormant or at a low rate of activity (12).

F. Side Effects of Treatment

The chemistry of aluminum in water is complex and no generalization about toxicity can be applied to taxonomic or habitat-related groups (3). Moreover, residual dissolved aluminum is pH dependent and some waters could receive large amounts of aluminum before the residual dissolved aluminum became sufficiently high to be toxic. Therefore reports of safe dose limits are of limited value.

Several investigators have reported an apparent absence of negative effects on fish or benthic invertebrates after full-scale lake treatments. A review of a number of laboratory studies on aluminum toxicity collectively seem to indicate that a dissolved aluminum concentration below .05 mg Al/L will have no harmful effects on *Daphnia magna*, rainbow trout, *Salmo gairdneri*, or chironomid larval *Tanytarsus dissimilis* (12). Mortality to fish in acid environments seems to be due to a combination of aluminum and low pH. Aluminum is most toxic to fish at pH 5.0 (15).

Aluminum toxicity does not appear to be a significant problem as long as pH is controlled and/or the residual dissolved aluminum is not allowed to reach levels in the area of .05 mg Al/L. The long-term effects seem to be small, at least to most benthic invertebrates which live directly in the aluminum-enriched sediments. In areas where lakes have low alkalinity and acid rainfall is significant, lowering of lake pH could occur years after an aluminum treatment causing a sudden increase in residual dissolved aluminum and possible toxic effects to lake biota (12).

G. Lakes Best Suited for this Restoration Technique

Aluminum treatment of lakes has been successful in reducing the phosphorus concentration and improving the trophic state in nearly every case. Treatment areas up to 120 ha, doses up to 936 metric tons, and treatment effectiveness up to 12 years have been reported. There have also been some limited successes as well as some clear failures. Problems have been caused by insufficient doses, inadequate mixing, or insufficient diversion of incoming nutrients (3,11,19).

Lakes best suited for treatment would appear to have most of the following characteristics:

(1) Adequate alkalinity. In lakes having high alkalinities (>100 mg/L as $CaCO_3$), large quantities of aluminum sulfate can be added before the pH falls sufficiently to cause the appearance of dissolved aluminum. Mortality to fish in acid environments seems to be due to a combination of aluminum and low pH (3,12,15).

(2) Sufficient depth. Alum may not be appropriate for shallow lakes, especially those with macrophyte problems because the clarified water often enhances the development of macrophytes. Also, successful treatment of shallow, polymictic lakes has been thought to be unlikely because it is believed that the floc would be readily dispersed and relocated during severe weather. Some shallow lakes and reservoirs circulate continuously from top to bottom (5,20).

(3) Low phosphorus/hydraulic retention time. Lakes having low phosphorus/hydraulic retention times will usually show the

beneficial results of chemical treatments within a reasonable time frame (18).

Table II-1. gives a selection of lakes that have been treated to remove phosphorus as a form of lake restoration. One important observation from this table is the number of lakes similar in size and depth to Lake Apopka, that would be three. There is no data on the long term results of alum treatment and none were any where near the size of Lake Apopka.

Table II-1. Summary of Phosphorus Inactivation/Precipitation Treatments (EPA, 1981)

Lake	Chemical-Physical Data	Date	Chemical and Dose	Objective and Site of Application	Duration of Effectiveness	Cost	Side-Effects
1. Dorrdrecht Reservoir Netherlands Peelen (1969)	No Data*	1962	2 g Fe^{+3}/m^3	P removal. Surface	No Data	No Data	No Data
2. Langsjon Lake Stockholm, Sweden Jernelov (1970)	A_o = 35 ha V^o= 6.5 x 10^6 m^3 z = 3.0 m max	4/68	4.7 g Al/m^3 Granular alum	P removal. Surface	Unknown	No Data	None Reported
3. Lötsjön Lake Stockholm, Sweden Hellstrom (1979)	A_o= 6 ha V^o= 1.2 x 10^5 m^3 z = 3.0 m max z = 2.0 m pH = 8.0 polymictic	1968 1969 1970 1974 1975	3.2-7.7 g Al/m^3 Granular alum	P removal. Surface	1-6 months	No Data	None Reported
4. Horseshoe Lake Manitowac Co., Wisconsin J. O. Peterson et al. (1973)	A_o = 8.9 ha V^o= 3.6 10 10^5 m^3 z = 16.7 m max x = 4.0 m Alk = 218-278 mg/l pH = 6.8-8.9 dimictic	5/70	2.6 g Al/m^3 Liquid alum	P removal. Surface	2-3 years	$101/ha for alum 12 man-days for applic. 1.33 man-days/ha	None Observed
5. Cline's Pond Corvallis, Oregon Sanville et al. (1976)	A_o = 0.4 ha V^o= 9600 m^3 z = 4.9 m max z = 2.4 Alk = 30-50 mg/l pH 7.0-7.7 monomictic	4/71	10 g Al/m^3 Liquid sodium aluminate and HCl	P removal and control of P release. Surface	1 year	$420/ha	None Reported
6. Fishery Ponds Waterville, Minn. Bandow (1974)	A_o = 0.4 ha V^o= 0.6 x 10^5 m^3 z = 2.1 m max z = 1.5 m Alk = 150 mg/l pH = 8.0	5/71 6/72 6/73	8.4 g Al/m^3 4.2 g Al/m^3 5.6 g Al/m^3 Liquid alum	P removal. Surface	Unknown	No Data	None observed to fish and zooplankton
7. Söndra Hörken Grangesburg, Sweden Ahling and Raghall (1973) Dunst et al. (1974)	A_o = 15 ha z^o= 22 m max	1971	160 tons Granular alum	P removal. Surface	2 years	No Data	None Reported
8. Braidwood Lagoon Braidwood, N.S.W. May (1974)	z = 0.9 m max pH = 6.3	7/71	10.7 g Al/m^3 Liquid alum 31 g Fe^{+3}/m^3 Dry ferric alum	P removal and control of P release. Alum to surface, iron to pond bottom	Unknown	No Data	None Reported

Table II-1. (cont.)

Lake	Chemical-Physical Data	Date	Chemical and Dose	Objective and Site of Application	Duration of Effectiveness	Cost	Side-Effects
9. Snake Lake Villas—Oneida Cos. Wisc. T. Wirth and R. P. Narf (unpub.)	A_o = 5.0 ha z = 5.5 m max Alk = 50 mg/l dimictic	5/72	9.0 g Al/m^3 Liquid alum and sodium aluminate; surface dilutional pumping	P removal and control of P release. Surface	To Present	No Data	None observed to macro-invertebrates
10. Long Lake, Langlade Co. Wisc. T. Wirth and R. P. Narf (unpub.)	A_o = 28 ha z = max Alk = 7 mg/l	5/72	14 gal/m^3 Liquid alum and sodium aluminate at surface	P removal and effect on pH and alkalinity	Unknown	No Data	None observed to macro-invertebrates
11. Reither See Tyrol, Australia Dunst <u>et al</u>. (1974) Findenegg (1972)	A_o = 1.5 ha z = 8.2 m max	5/72	6 g Fe^{+3}/m^3 $FeCl_3$ and hypolimnetic siphoning	P removal. Surface	Unknown	$120/ha	Unknown
12. Powderhorn, Minneapolis, Minn. Dunst <u>et al</u>. (1974)	A_o = 3.2 ha z = 7.0 max	8/72	Unknown dose Liquid alum	P removal. Surface	Unknown	$563/ha	Unknown
13. Mytajärvi Lahti, Finland Dunst <u>et al</u>. (1974)	A_o = 1.5 ha z = 10.5 m max	4/73	24 g Al/m^3 Granular alum	Unknown objective. Surface (ice)	Unknown	No Data	Unknown
14. Pickerel Lake, Portage Co., Wisconsin T. Wirth and R. P. Narf (unpub.)	A_o = 20 ha $\underline{z}$ = 4.6 m max z = 3.0 polymictic pH = 8.2 Alk = 110 mg/l	4/73	7.3 g Al/m^3 Liquid alum	P removal. Surface	Unknown	No Data	None observed on benthic macroinverte-brates
15. Welland Canal Welland, Ontario Shannon <u>et al</u>. (1974)	A_o = 74 ha V = 6.2 10^6 m^3 $\underline{z}$ = 9.0 m max z = 9.0 m Alk = 109 mg/l dimictic	5/73	2.5 g Al/m^3 Liquid alum surface	P removal	1 year (end of monitoring)	$204/ha for all equip. and chemicals $161/ha for chemicals 100 man-days for chem. applic.: 1.35 man-days/ha	None observed to zoo-plankton
16. Cline's Pond Corvallis, Oregon Powers <u>et al</u>. (1975)	A_o = 0.4 ha V = 9600 m $\underline{z}$ = 4.9 m max z = 2.4 m Alk = 30 mg/l pH = 7.0-7.7 monomictic	3/74	5 g Zr/m^3 and NaOH $ZrCl_4$	P removal. Surface	Unknown	No Data	None Observed

Table II-1. (cont.)

Lake	Chemical-Physical Data	Date	Chemical and Dose	Objective and Site of Application	Duration of Effectiveness	Cost	Side-Effects
17. Lyngby Sø Sweden Sønnichsen (1978)	A_o = 59 ha V_o = 1 x 10^6 m^3 $\bar{z}$ = 1.69 m pH = 9.0	5/74	2 Doses, 8.6 and 20.2 g Al/m^3 Granular alum	P removal. Surface	Transitory	No Data	Flocculation and possible toxicity to micro-crustacea
18. Calusa Lakes (2) Miami, Florida Haumann and Waite (1978)	A_o = 1.38 ha z_o = 4.3 m max Alk = 46-188 mg/l pH = 7.0-9.2	6/74	1.2 g Al/m^3 Liquid alum	P removal to control macrophytes. Surface	Unknown	No Data	None Reported
19. Morse's Pond Wellesly, Mass. Thompson (unpub. mss.)	A_o = 44.5 ha V_o = 113.6 x 10^5 m^3 $\underline{z}$ = 5.5 m max $\bar{z}$ = 2.6 unstratified	7/74	3.3 g Al/m^3 Liquid alum plus aeration and copper	P removal. Surface	Unknown	No Data	None Reported
20. Dollar Lake Kent, Ohio Kennedy (1978)	A_o = 2.2 ha V_o = 0.86 x 10^5 $\underline{z}$ = 7.5 m max $\bar{z}$ = 3.9 m pH = 6.7-8.6 Alk = 101-127 mg/l dimictic	7/74	20.9 g Al/m^3 Liquid alum	P removal and control of P release. Surface (10% of dose) and hypolimnion	To Present	$504/ha for chemicals 4.3 man-days/ha	None Observed
21. Liberty Lake Spokane, Washington Funk and Gibbons (1977)	A_o = 288 ha V_o = 20.2 x 10^6 m^3 $\bar{z}$ = 7.0 m pH = 6.6-9.3 Alk = 12-65 mg/l dimictic	10/74	0.52 g Al/m^3 Liquid alum rotenone	P removal and interception of P release from delaying macrophytes. Surface	2 years	No Data	None Observed
22. West Twin Lake Kent, Ohio Cooke et al. (1978)	A_o = 34 ha V_o = 14.2 x 10^4 m^3 $\underline{z}$ = 11.5 m max $\bar{z}$ = 4.4 m Alk = 102-149 mg/l dimictic 16 ha treated	7/75	26 g Al/m^3 Liquid alum	Control of P release. Hypolimnion	To Present	$425/ha for chemicals and equip. 0.94 man-days/ha	Decrease in micro-crustacea diversity
23. Lake San Marcos Orville Ball, Assoc., Consultants (unpub. mss.)	A_o = 18.2 ha V_o = 4.3 x 10^5 m^3 $\underline{z}$ = 2.3 m max $\bar{z}$ = 2.3 m pH = 7.3-9.1 Alk = 190-268 mg/l	7/75	6 g Al/m^3 Liquid alum	P removal. Surface	Unknown	$126/ha	None Reported

Table II-1. (cont.)

Lake	Chemical-Physical Data	Date	Chemical and Dose	Objective and Site of Application	Duration of Effectiveness	Cost	Side-Effects
24. Bluff Lake Fox Chain, Illinois Kothandaraman *et al*.	A_o = 37.2 ha V^o= 1.2 x 10^6 m^3 z = 8.2 m max $\bar{z}$ = 3.2 m Alk = 162 mg/l pH = 8.7 dimictic	8/77	6 g Al/m^3 Liquid alum	P removal and control of P release. Surface	Days	No Data	None Reported
25. Medical Lake Medical Lake, Washington Gasperino and Soltero (1978)	A_o = 64 ha V^o= 6.4 x 10^6 m^3 z = 18 m max $\bar{z}$ = 10 m Alk = 750 mg/l pH = 8.5-9.5	8-9/77	12.2 g Al/m^3 Liquid alum	P removal and control of P release. Multiple applications to surface and hypolimnion	To Present	No Data	None Reported
26. Mirror Lake Waupaca, Wisconsin Knauer (1978) (unpub. mss.)	A_o = 5.1 ha V^o= 4 x 10^5 m^3 z = 13.1 m max $\bar{z}$ = 7.8 m Alk = 222 mg/l pH = 7.6 monomictic	5/78	6.6 g Al/m^3 Liquid alum and aeration	P removal and control of P release. Hypolimnion	To Present	1.4 man-days/ha	None Reported
27. Shadow Lake Waupaca, Wisconsin Knauer (1978) (unpub. mss.)	A_o = 17.1 ha V^o= 9.1 x 10^5 ha x = 12.4 m max $\bar{z}$ = 5.3 m Alk = 188 mg/l pH = 7.4 dimictic	5/78	5.7 g Al/m^3 Liquid alum	P removal and control of P release. Hypolimnion	To Present	0.61 man-days/ha	None Reported
28. Annabessacook Lake Winthrop, Maine Dominie (1978 (unpub. mss.)	A_o = 575 ha V^o= 31.1 x 10^6 m^3 z = 12 m max $\bar{z}$ = 5.4 m Alk = 20 mg/l pH = 6.7 dimictic 121.4 ha treated	8/78	25 g Al/m^3 7-10 m contour	Control of P release Hypolimnion	To Present	No Data	None Reported

III. Lake Apopka Morphology

As stated earlier Lake Apopka is a 12,150 ha (31,000 acre) lake with an average depth of 1.5 meters (4,13). This is far larger than any lake previously reported in the literature (5). We intend to address the same aspects of alum treatment in Lake Apopka that were considered for other lakes in part one of this report.

A. Dose of Chemical

As was discussed previously, the intent of the chemical treatment must be determined before discussing dose requirements. For the purpose of our consideration, release from the sediments will most likely be required. However, if the project ultimately involves a drawdown where the muck is effectively consolidated or even removed, then simple removal of phosphorus from the water column is appropriate. We have learned that the most important factors for the receiving water body in determining dose of alum are pH and alkalinity (or hardness). Lakes with alkalinity over 100 mg/L as $CaCO_3$ are best suited to receive large amounts of alum before pH drops to the point where dissolved aluminum becomes a problem (3).

Unpublished data from the Orange County Environmental Protection Department (OCEPD) indicates that, for the past fifteen years, the alkalinity of Lake Apopka water, sampled at the mouth of the Beauclair Canal, has ranged from 109.5 to 140.6 mg/L as $CaCO_3$. During this same time period the pH ranged from 8.1 to 9.3. These values indicate Lake Apopka would be a, theoretically, successful candidate for alum treatment (5).

B. Chemical Forms

The chemical form most frequently used is liquid. However, solid may be the least expensive and it can be mixed to form a slurry before application. The use of polymers may be appropriate if the dose rates determined in Phase II prove to be onerous. The Reedy Creek Improvement District (RCID) used a polymer on one of their lakes to achieve greater floccing (10).

C. Depth of Application

There is no hypolimnion in Lake Apopka. Therefore, surface application would most likely be adequate to control phosphorus from the sediments (10).

D. Application Procedures

Since no body of water the size of Lake Apopka has ever been treated, it is difficult to determine application procedures at this time. However, RCID has had success with a barge system where the alum was applied just below the surface (less than 1 meter). They also had motor boats equipped with pH meters, moving about the application area to ensure mixing (10). The technology of barge application seems well established. The magnitude needed on Lake Apopka will dwarf those efforts on Annabessacook Lake in Maine. Which, as of 1986 was the largest lake ever to be treated with alum at 574 ha (3).

Annabessacook Lake (574 ha) was treated at the hypolimnion level or 8-10m contour level. This amounted to only 121 ha of treatment. Although they had to go slower because of the need for deeper treatment at greater depth, than would be necessary on Lake Apopka it took 18 days to cover 121 ha (3). If their application procedures cannot be improved upon Lake Apopka will take almost 5 years of eight to ten hour days of continuous application to cover its 12,150 ha surface area. RCID using a surface treatment on their Seven Seas Lagoon of 40 acres required 2 days. However, they estimate that one barge can treat about 40 acres in one day (approximately 10 hours). They also estimate their costs at about $300 per acre. Extrapolating out to Lake Apopka the costs would come to almost 10 million dollars (10).

E. Season of the Year

In Florida it has been said that there are no seasons. However, we do have weather, and plants and animals do respond to it. The spring is rather windy, the summer has thunderstorms every afternoon, the fall has hurricanes (although the few we have had in recent years have not been very impressive), the winter of late has varied from freezing cold to heavy rain falls. The algae blooms have become a year long event especially this year. To generalize about the weather in this area would lead to costly errors. RCID found their barge was easily blown off course on windy days, but windy days helped facilitate mixing (10). In general, trying to select an appropriate time of year to treat the lake may only depend on localized weather conditions.

F. Side Effects

Studies from the early 1970's indicate that Lake Apopka is hypereutrophic (4). Unpublished data from the OCEPD indicate that there are no macroinvertebrates to speak of in the sediments. Recent fish kills have been almost exclusively gizzard shad, an undesirable fish that feeds mainly on algae. Except for the possibility of a high RDA being toxic, there are really no undesirable side effects to treating Lake Apopka.

G. Lakes Best Suited to Restoration

Lake Apopka has several factors that make it a suitable candidate for phosphorus precipitation/inactivation using alum and some combination of polymers. The pH and alkalinity are within the range of successful long term treatments. The alkalinity as mg/L $CaCO_3$ is over 100, making it a hardwater lake. Such lakes can handle the amounts of aluminum needed to seal the sediments thus preventing nutrient recycling. The pH is generally above 8.0. Aluminum is released into the water column from the addition of alum when the pH drops below 5.0-5.3 (3). Therefore, depending on the amount of alum deemed appropriate, it may not be necessary to continually adjust the pH during application.

The depth of Lake Apopka is generally about 1.5 to 1.7 m deep (4,13). There are various holes ranging from about 3 m to 13 m, however they are by no means extensive. (4,16).

Lake Apopka has been described as having a large fetch. The nautical applications of this term refers to the distance across an open body of water over which the wind has blown uninterrupted by land. This unobstructed expanse allows the wind to drive the waves to specific heights given by the formula $h = \sqrt{x}$, where x equals distance in centimeters (20). Using this equation and a fetch of seven miles the theoretical height of a wave on Lake Apopka would be 1.1 meters, just over 3 feet. This is nearly half the average depth of the lake. Although we do not know how severely wind action will affect the floc once it has formed, it has been suggested that wind action will stir up sediments and release phosphorus into the water column (18).

The intent of the treatment will most likely be to seal the sediments. In 1967 it was determined that generally about 2 feet of loose silt are on top of 3 to 4 feet of unconsolidated muck (16). Since that time no scientific attempt has been made to determine the depth of the sediments, until now. Dr. R. Reddy is currently conducting such work. His data will have some bearing on Phase II of this project. Unpublished data from the OCEPD indicates total solids ranging from 285 to 416 mg/L within the top 0.5m of the lake since 1972. None of the literature reviewed identified solids levels in the lakes treated. We believe the muck, silt and suspended solids levels in Lake Apopka will have a significant impact on the amount of alum needed to treat the lake.

IV. Conclusion

Lake Apopka by virtue of its high pH, high alkalinity, would make an ideal candidate for alum precipitation, from a chemical perspective. But given its size, depth, and extent of muck, the prospects for long term success of alum treatment are suspect.

Proceeding to Phase II may answer the question of whether phosphorus cycling from the sediments could be retarded in a lake with an extensive sediment component. It would also allow the accurate calculation of costs for a large scale project. However, it would remain uncertain how well the floc layer could withstand extensive mixing in the whole 12,150 ha of Lake Apopka.

LITERATURE CITED

1. Cooke, G.D., R.T. Heath, R.H. Kennedy, M.R. McLomas. 1982. "Change in Lake Trophic State and Internal Phosphorus Release After Aluminum Sulfate Application." Water Resources Bulletin. v18:4. pp699-705.

2. Cooke, G.D. and R.H. Kennedy. 1978. "Effects of a Hypolimnetic Application of Aluminum Sulfate to a Eutrophic Lake." Verh. Internat. Verin. Limnol. v20. pp485-486.

3. Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1986. "Lakes and Reservoir Restoration." Ann Arbor Science, USA. pp101-131.

4. EPA,US. 1977. "Report on Lake Apopka, Lake and Orange Counties." Prepared by National Eutrophication Survey Staff, US EPA in cooperation with the NERC. Las Vegas,NA.

5. EPA,US. 1981. "Precipitation and Inactivation of Phosphorus as a Lake Restoration Technique." EPA-600-13-81-012. pp13-16.

6. Fellows, C.R. 1978. "The Significance of Seepage in the Water and Nutrient Budgets of Selected Florida Lakes." Master of Science Thesis, University of Florida. (Unpublished).

7. Francko, D.A. and R.T. Heath. 1981. "Aluminum Sulfate Treatment: Short-Term Effect on Complex Phosphorus Compounds in a Eutrophic Lake." Hydrobiologia. v78. pp 125-128.

8. Furman, D. 1978. "Restoration of Lake Apopka." An Unpublished Paper Presented to the Florida Section, ASCE. Annual Meeting, Cypress Gardens, FL.

9. Garrison, P.J. and D.R. Knauer. 1983. "Lake Restoration: A Five Year Evaluation of the Mirror and Shadow Lakes Project at Waupaca, Wisc." Wisconsin Dept. of Natural Resources. Madison, Wisc. EPA Report No. EPA-600/3-83-101.

10. Gorento, G., J. Repoff. 1987. Personal Communication. Reedy Creek Improvement Dist. Lab. Orlando, FL. 32812.

11. Kennedy, R.H., G.D. Cooke. 1982. "Control of Lake Phosphorus with Aluminum Sulfate: Dose Determination and Application Techniques." Water Resources Bull. v18:3. pp389-395.

12. Lamb, D.S., G.C. Bailey. 1981. "Acute and Chronic Effects of Alum to Midge Larva." Bull. of Environ. Contamination and Toxicology. v27:1. pp59-61.

13. Olsen, L.A. and B.J. French. 1976. "Lake Apopka, Florida: Review of the Literature, 1953-1976." Florida Dept. of Environmental Regulation, Office of Lake Restoration and Pollution Recovery, Tallahassee, FL.

14. Peelen, R. 1969. "Possibilities to Prevent Blue-Algal Growth in the Delta Region of the Netherlands." Vaerh. Internat. Verein. Limnol. v17. pp763-766.

15. Peterson, S.A., W.D. Sanville, F.S. Stay, C.F. Powers. "Laboratory Evaluation of Nutrient Inactivation Compounds for Lake Restoration." JWPCF. v48:5. pp 817-831.

16. Schneider, R.F. and J.A. Little. 1969. "Characterization of Bottom Sediments and Selected Nitrogen and Phosphorus Sources in Lake Apopka, Florida." US Dept. of Interior, Fed. Water Pollution Control Administration, Southeast Water Laboratory, Athens, GA.

17. Smeltzer, E. 1986. "Lake Morey Restoration Project." Interim Progress Report. Vermont Department of Water Resources and Environmental Engineering. Waterbury, VT.

18. Sonzogni, W.C., P.C. Uttomark, G.E. Lee. 1976. "A Phosphorus Residence Time Model: Theory and Application." Water Resources Bulletin. v10:5. pp429-435.

19. Welch, E.B., J.P. Michaud, M.A. Perkins. 1982. "Alum Control of Internal Phosphorus Loading in a Shallow Lake." Water Resources Bulletin. v18:6. pp929-936.

20. Wetzel, R.G. 1975. Limnology. W.B. Saunders & Co. Philadelphia, PA. p95.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

1. Argo, David G. 1971. Polyelectrolyte Conditioning of Alum Sludge, Master's Thesis. 94p.

Lime sludges, one from a phosphorus precipitation process and one from an excess lime color removal process were conditioned with various polyelectrolytes, analytical tests included specific resistance, COD, total and volatile solids, pH, and zeta potential. Polyelectrolyte conditioned and unconditioned samples were applied to bench-scale sand beds to determine the effect of conditioning on gravity dewatering and air drying. Specific resistance was determined to be an effective control parameter, and it was reduced significantly only by anionic polyelectrolytes. Sludges so conditioned produced a porous, open floc structure, principally through chemically bridging, which facilitated gravity draining and air drying. Adequate polymer dispersion was required, but excess turbulence destroyed the floc structure. pH was shown to have no detectable effect, whereas the effects of varying solids concentrations were quite noticable. An average cost of $934 per million gallons of sludge treated was reported, a figure low enough to justify the economic feasibility of the process. (Lowry-Texas)

2. Aulenbach, D.B. 1976. Chemical Interactions in a Eutrophic Lake. FWI Report 76-6. 41p.

Interrelationships among carbon dioxide, oxygen, light penetration, iron, phosphate, ammonia, nitrate nitrogen, silica and predominant algal forms were correlated with the presence or absence of oxygen and with biological productivity in eutrophic Saratoga Lake in eastern New York. The lake receives raw, partially and fully treated sewage effluents and agricultural runoff from the watershed and from an influent stream. The hypolimnion is devoid of oxygen during summer stratification and there is a marked oxygen deficiency below the 6 m level in the epilimnion on calm days. To reduce the trophic level, one proposed step was diversion of sewage effluents; however only 26% of the nitrogen and 17.5% of the phosphorus is contributed by the watershed's effluents and the influent creek contributes 1.36 mg/l of N and 0.3 mg/l P, thus diversion would not reduce these nutrient levels sufficiently to control the nuisance algae. Other alternatives considered were reaeration, phosphorus precipitation by chemicals and addition of silicon on the premise that diatoms would supplant the blue-green algae. Cost estimates of alum, lime, ferric chloride and sodium silicate were compiled, based on the present 116,000 kg P/yr input and projected loading of 95,300 kg P/yr after completion of the sewage treatment plant and effluent diversion. The least costly lake renovation approach would be an air reaeration system representing $130,000 capital costs and $11,000 for annual operation. (Auen-Wisconsin)

3. Baumann, P. 1982. Restoration of the Central Lakes: Baldeggersee, Hallwilersee, and Sempachersee. Wasser, Energie, Luft, Vol 74: p. 13-14.

Methods of restoring the eutrophic central Swiss lakes Baldeggersee, Hallwilersee, and Sempachersee are described, using as an example a four-step plan developed for Sempachersee. The principal cause of eutrophication is phosphorus; the annual phosphorus load of Sempachersee is 15 tons (7 tons from wastewater treatment plants and urban and rural areas not served by these facilities, 7 tons from agricultural areas, and 1 ton from the atmosphere and precipitation), whereas it should lie below 4 tons. The first stage of the plan is directed toward urban areas, where wastewater treatment plants with phosphorus precipitation are in use. The boroughs are obligated to ensure that all households are hooked up to the sewers, while the cantons are responsible for monitoring the quality of treated wastewater released into the lake. Rural areas, dealt with in stage two of the plan, often release raw or partially treated wastewaters containing phosphorus to the lake. The discharge points must be located and treated individually for the agricultural areas (stage three), as assessment was made in 1979 of agricultural pollution of the lake's catchment area with emphasis on phosphorus, and in 1981 all farmers in this area received general and individually oriented information on this subject. The fourth stage concerns measures conducted within the lake: aeration, artificial circulation in winter, and extraction of 1.1 cu m/sec of polluted water from a depth of 80 m. None of these measures are yet in effect. (Gish-FRC)

4. Bannink, B.A. 1979. Hydrobiological Consequences of the Addition of Phosphate precipitants to Inlet Water of Lakes. Public Works Dept. 14 (1-2). p 73-89.

In 3 model reservoirs (Lund, 1975) a method reducing bluegreen algal blooms in lakes was studied. Fe or Al were added to inlet waters for chemically binding the inflowing P. The research program, started in 1975, includes intensive monitoring of many chemical and hydrobiological variables, the determination of water and mass balances and since 1977 measurements of primary production rates with 14C. In this paper only the results found in 1977 are discussed. An attempt is made to describe quantitatively how growth rates and changes in biomass are interconnected and how phosphorus changes these variables. In all reservoirs a large discrepancy was observed between the actual rate of increase in the algal population and the relative production rate. The latter appeared to be higher by one order of magnitude. The relative death rate due to grazing can account for the large difference between these growth rates only when selective grazing of zooplankton on phytoplankton is assumed. It can be concluded that treatment of inlet water with AVR, an Al salt, is unsuccessful in reducing algal development. Treatment with iron sulphate may be successful, but a reduction of the relative growth rates was not observed. The effects of grazing of zooplankton and Dreissena polymorpha need further investigation.

5. Barnard, J.L. 1975. Nutrient Removal in Biological Systems. Water Pollution Control. Vol 74. No 2. P 143-154.

Purely biological methods of nutrient removal are discussed. Removal of nutrients may be due to sludge synthesis or to wastage and the amount is dependent to a large degree on whether the assimilated nutrients in the waste cellular material are returned to the aeration basin. Fixed-media denitrification and suspended media denitrification systems are detailed. A modified activated sludge plant to remove nitrogen through nitrification/denitrification was developed, called the Bardenfo Process. In this method the need for methanol addition is eliminated but the basin size must be increased. Nitrates are used as a source of oxygen, and less sludge, which is more stable, is produced by a long solids retention time (SRT). If the Bardenfo Method were applied to an extended aeration plant, costs would include partitions and an additional pump for recycling mixed liquor. These costs would be offset by savings in power due to no necessary increase in the basin size. Phosphorus precipitation in the final clarifiers of some activated sludge plants to which no chemicals have been added has been attributed to several factors. It seems that phosphate removal is greater with a low MLSS in the aeration basin and a low SRT. It has also been postulated that an increased pH is responsible for precipitation of phosphate. It was concluded that additional research is necessary to provide for better biological systems of nutrient removal without the use of expensive physico-chemical methods. (Kramer-Firl)

6. Bateman, J.M. 1977. Restoration of Water Quality in Lake Weston, Orlando Florida. J Aquat Plant Manage. 15 p. 69-73.

Lake Weston, an 11.3-ha, 15-m deep eutrophic lake in Orlando, Florida (USA), was polluted primarily by effluent from a waste treatment plant. It was treated with aeration equipment and a non-toxic, soluble Ca compound to make P unavailable for plant assimilation. Results were compared to Lake Lovely, a control lake in which sewage was upgraded but no treatment given, and Lake Lawne, which received alum treatment, dredging and draw-down.

7. Beer, C. Hetling, L.J. 1974. Nitrogen Removal and Phosphorus Precipitation in a Compartmentalized Aeration Tank. EPA. 17050 Edl. 23p.

With a view to the importance of the activated sludge process in the New York State Water Pollution Program, the State of New York embarked in 1968 on a research and development program in the area of activated sludge. It was hoped that results of that program might help to operate existing activated sludge plants more efficiently and, perhaps, to develop modifications that could be incorporated in these plants for achieving greater removals of contaminants. It was also hoped that processes could be developed that would influence the design of plants not yet on the drawing board. As a vehicle for the research and development program drawn up, it was decided to construct an experimental sewage treatment plant that would serve one of the State's institutions, the Coxsackie Correctional Facility. A modification of the biological nitrogen removal process described by Wuhrman (W70-04764) was combined with the phosphorus removal process based on the addition of ferric chloride to the aeration tank of the activated sludge system as described by Thomas and Wildi (W73-07465). Good results were obtained in treating approximately 95,000 gallons per day of institutional sewage. A compartmentalized aeration tank (11 compartments) was used with arrangement for aerobic treatment after denitrification and before final settling. The required ferric chloride addition for phosphorus elimination was much less than the stoichiometric requirement. (Poertner)

8. Beer, Carl. Hetling, Leo J. Wang, Lawrence K. 1975. Full Scale Operation of Plug Flow Activated Sludge Systems. E.I. Monthly. 49p.

With a view to the importance of the activated sludge process in the New York State water pollution program, the State of New York embarked in 1968 on a research and development program in the area of activated sludge. It was hoped that results of that program might help to operate existing activated sludge plants more efficiently and perhaps to develop modifications that could be incorporated in these plants, for achieving greater removals of contaminants. This report is a progress report describing efforts to date - October 24 - to develop a simple activated sludge process for nitrogen removal and phosphorus precipitation. A report of somewhat narrower scope was submitted to the New York Water Pollution Control Association in January 1974.

9. Biedermann, E. Bohg, A. 1970. Pre-precipitation of Phosphorus in Heavily Doped Silicon. Appl. Phy. Lett. Vol. 17. p 457-9.

Presently, silicon device technology phosphorus diffusions with high surface concentrations are commonly used for the formation of the emitter areas. Annealing treatments at or below 800 C have been shown to lead to the formation of extrinsic dislocation loops in such areas. A transmission electron microscopic investigation combined with resistivity measurements and profile determinations leads to the interpretation of these loops as a primary step of phosphorus precipitation in the supersaturated lattice.

10. Bole, J.B. Bell, R.G. 1978. Land Application of Municipal Sewage Waste Water: Yield and Chemical Composition of Forage Crops. Journal of Environmental Quality. 7(2), 222-226.

Alfalfa outyielded 4 grass species (reed canarygrass, bromegrass, Altai wildrye, and tall wheatgrass when the forages were irrigated with sufficient lagooned municipal sewage wastewater to meet the evapotranspiration minus precipitation deficit (about 50/cm/yr). The yields were increased and the yield differential between the alfalfa and the grasses was reduced when additional N was added as fertilizer or by doubling the amount of waste-water. The grasses, with the exception of tall wheatgrass, out-yielded the alfalfa when fertilizer was added at the high wastewater level. Since water did not limit growth, yields were controlled by the N supply. Waste-water-N and fertilizer-N were equally effective in stimulating forage production. Nitrogen yield of alfalfa was double that of the grasses with the unfertilized wastewater treatment, and considerably greater than the N yield of the grasses with the other treatments. Nitrogen uptake by all the forages, except tall wheatgrass, exceeded N application by waste water and fertilizer. Phosphorus application, in the wastewater or as fertilizer P, exceed plant uptake. The P content of the forage was unaffected by the treatment. Alfalfa was the most suitable forage crop when the system was operated for optimum utilization of the wastewater. When high levels of wastewater were applied, reed canarygrass removed most of the nutrients while withstanding flooding and higher soil moisture without stands being reduced by winterkilling, as occurred with alfalfa. (AM)

11. Bowen, S.P. 1975. Evaluation of Process Design Parameters for Phosphorus Removal from Domestic Waste Waters by Chemical Clarification. PhD Thesis. 134p.

The increased use of chemical waste water treatment requires the development of optimum values, and a means for their determination, of design parameters. These parameters include the coagulant, dose, pH, flocculation intensity and duration, and sedimentation time. Alum and lime treatments were the subjects of investigations. Coagulation was studied in the treatment of raw domestic sewage by using jar tests and a column flocculation-sedimentation apparatus. Procedures were developed to determine the effect of coagulant dose and pH interaction on the removal of total phosphorus, suspended solids, turbidity, and total organic carbon. Results showed that alum coagulation produces optimum removal at a dose of about 175 milligrams/liter and a pH of 5.9. Small variations produce large alterations in pollutant removal. There was no optimum dosage for lime treatment coagulation and pollutant removal increased as the dose and pH increased. Coagulation at low lime dose, and use of ferric iron as a coagulant aid and sludge recycling were also studied. Studies on the effect of flocculation mixing intensity and sedimentation time on pollutant removal using the above data indicated that flocculation

intensity was relatively unimportant. Overflow rate, dose, and pH for lime and alum produced enough energy to prevent floc settling during flocculation. A lighter, slower floc was produced by alum and alum coagulated water overflow rates must be lower to produce comparable results. Hydraulic variations more easily upset alum floc than lime floc. Alum sludge was more voluminous and more difficult to dewater than that of lime. (Collins-FIRL)

12. Bouveng, H.O. 1973. The Chemical Treatment of Municipal Waste Water. Staedtehygiene, Vol 25. p. 260-261.

The Swedish government has adopted a policy of financing 50 percent of the construction costs of municipal purification plants provided a 90 percent reduction of BOD and of the total phosphorus is achieved. This action has spurred the addition of chemical stages to the mechanical biologic purification plants since this stage has a higher BOD reduction capability. In Switzerland and Finland, simultaneous treatment through chemical precipitation is the most common practice. Incorporation of this phase into the existing purification plant scheme allows for better phosphorous concentration. (Sandoski-FIRL)

13. Brun, C. Patou, P. Parniere, P. 1982. Influence of Phosphorus and Manganese on the Recrystallization Texture Development During Continuous Annealing in Ti-IFS Sheets. Metallurgical Soc of AIME. p. 173-197.

14. Brunskill, G.J. 1969. Fayetteville Green Lake, New York. II. Precipitation and Sedimentation of Calcite in a Meromictic Lake with Laminated Sediments. Limnology and Oceanography. Vol 14. No 6. p. 830-847.

Sediments of meromictic Fayetteville Green Lake, New York, are deposited annually in couplets of light and dark laminae, which probably reflect seasonal differential between precipitation rate of calcite and depostion rate of organic matter. Seasonal measurements of pH, temperature, calcium and titration alkalinity permitted calculation of calcium and carbonate activities. Based upon these data and thermodynamics of carbonate equilibria, detailed method of correcting for existing ion-pair interactions is described which yields estimates of calcite equilibrium activity product (K) and observed ion activity products (IAP) for calcium and carbonate-ion. Ratio, IAP:K, estimates departure from calcite saturation. Values exceeding unity indicating supersaturation. While internally generated calcite supersaturates water column throughout year, IAP:K at surface increases from winter values (2-4) to 6-8 during May-October. Largely due to thermal effects on equilibria. Calcite precipitates massively during May-August, epilimnetic decreases in carbon dioxide indicating precipitation of 230 grams calcite/square meter per year upon bottom within 45-meter contour. Crystals settle 2-4 meters/day, consistent with rates calculated from Stokes' Law for observed particle sizes. Couplet production will probably continue so long as hydrologic and chemical budgets persist, meromictic stability exceeds wind work, and climate provides seasonal thermal differentials.

15. Buergel, P.M. Soltero, R.A. 1983. The Distribution and Accumulation of Aluminum in Rainbow Trout Following a Whole-Lake Alum Treatment. Journal of Freshwater Ecology. Vol 2. No 1. p. 37-44.

Medical Lake, Spokane County, prior to 1977, was subject to high phosphorus concentrations manifested by reduced sediments. Phosphorus inactivation was accomplished by the application of 936 metric tons of alum (aluminum sulfate).

The immediate and long-term effects of an alum treated environment upon the food chain are generally unknown. Because there has been a deliberate alteration in the natural chemistry of Medical Lake by the alum treatment, there is potential for a bioacumulation of aluminum by organisms inhabiting the lake. Because the fish and their prey are dependent upon a habitat potentially higher in available aluminum than neighboring habitats, trout tissues, plankton and water were analyzed for total aluminum concentrations. Statistical comparisons of experimental and control tissues revealed few overall significant differences ($P = 0.05$) in the level of aluminum between alum-exposed and non-exposed fish, but significant differences existed between tissues within a given treatment and age class. (Murphy-IVI)

16. Bulson, P.C. Johnstone, D.L. Gibbons, H.L. Funk, W.H. 1984. Removal and Inactivation of Bacteria During Alum Treatment of a Lake. Applied and Environmental Microbiology. Vol. 48. No. 2. p 425-430.

Flocculation and removal of bacteria were observed during two separate aluminum sulfate (alum) treatments for removal of phosphorus from a eutrophic recreational lake. In addition, die-off and release of bacteria from alum floc were studied in columns under laboratory conditions. Membrane filtration and spread plates were used to determine concentrations of indicator species and total cultivatable bacteria, respectively. During the alum treatment of the lake, 90% of the fecal coliform (FC) population and ca. 70% of the fecal streptococci population were removed from the water column within 72 h. Numbers of FC in the floc on the lake bottom exceeded 2,400/100 ml at 120 h compared with the pretreatment concentration of 30 FC/100 ml. Inactivation of FC in the floc proceeded at a rate of 200 FC/100 ml per 24 h. In a second alum application to the lake, 95% of the total culturable bacterial population was removed from the water column. In a laboratory column study of survival and release rates, over 90% of an Escherichia coli suspension was concentrated in a floc formed at the bottom. E. coli was not released from the floc. The numbers of and survival of E. coli in the floc suggest the probable concentration of other enteric organisms, including pathogens. Thus, the floc poses a potential human health risk if ingested by swimmers or if others use the lake as a potable water source.

17. Bundgarrd, E. Kristensen, G.H. 1984. Nitrification and Phosphorus Removal From Trickling Filter Effluents. Water Science and Technology. Vol. 16. No. 10/11. p 187-200.

Nitrification and simultaneous phosphorus precipitation in a separate activated sludge plant is considered the cheapest alternative for upgrading conventional trickling filter plants. Before upgrading the Herning (Mid Jutland, Denmark) treatment plant (200,000 population equivalents) a 12 month pilot plant expermient was performed. During operation of the pilot plant, important parameters were investigated, such as excess sludge production, sludge properties, and influence of the large part of chemical sludge when combining separate nitrification and simultaneous precipitation. It was found that a stable process could be operated with a bypass of 20-25% settled raw wastewater. Due to improvements in the sludge characteristics simultaneous precipitation with ferrous sulfate improved the effluent quality with respect to both phosphorus, BOD and suspended solids.

18. Burgess, E.L. Nasby, R.D. 1974. Application of the Lifshitz-Slyozov Theory to Precipitation of Phosphorus in Silicon-Germanium Thermoelectric Alloys. Journal of Applied Physics. Vol 45. No 6. p. 2375-2381.

The applicability of the Lifshitz-Slyozov model for predicting phosphorus precipitation rates in the phosphorus-SiGe system is investigated. Model parameters are determined from short-term anneals of less than 2000 h for SiGe alloys varying in silicon content from 67 to 81 at . % and prepared by zone leveling or hot pressing. Using these parameters in the model, resistivity changes are predicted for phosphorus-doped SiGe thermoelectric elements which have been life tested from 4000 to 40,000 h. It is concluded that the Lifshitz-Slyozov model is applicable to the phosphorus-SiGe system. The results can be used to calculate long-term degradation of thermoelectric performance in SiGe alloys due to phosphorus precipitation.

19. Burns, Donald E. Shell, Gerald L. 1973. Physical-Chemical Treatment of a Municipal Wastewater Using Powdered Carbon. EPA #W74-00154. p. 237. EPA-R2-73-264.

A municipal wastewater was treated in a nominal 100 gpm pilot plant by chemical coagulation-precipitation, powdered activated carbon absorption and granular media filtration. Spent carbon was gravity thickened, vacuum filter dewatered and thermally regenerated in a fluidized bed furnace. Solids-contact units were used for chemical treatment and carbon contacting. Ferric chloride, alum or lime were all found to effectively produce coagulation and phosphorus insolubilization. Based on total treatment costs, including sludge disposal, alum treatment was estimated to be the economic choice for Salt Lake City municipal wastewater. Organic removal in the powdered carbon contactors was substantially enhanced by anaerobic biological activity. The use of solids-contact treatment units for carbon contacting resulted in effecting gravity clarification without the use of chemicals. The powdered carbon physical-chemical treatment system produced a treated effluent similar to that expected for biological treatment followed by tertiary treatment for phosphorus removal. Carbon losses of 17 to 60 percent were experienced across the fluidized bed furnace regeneration system. The cause of high carbon losses was identified as ignition of carbon instead of gas which was injected into the fluidized bed to scavenge excess oxygen.

20. Burns, D.E. Shell, G.L. 1974. Carbon Treatment of a Municipal Wastewater. Journal Water Pollution Control Federation. Vol 46. No 1. p 148-164.

The use of powdered carbon for the removal of soluble organics from municipal raw wastewater was evaluated in a Salt Lake City, Utah, pilot plant study. The carbon treatment system included two carbon contactors, a granular media filter, a gravity thickener, and a vacuum filter. Solid contact units were very effective for contacting and removing powdered carbon for chemically treated and gravity clarified municipal wastewater. The two-stage, counter-current contacting was more efficient, (requiring less carbon) than single-stage contacting. The total solids recycle and variable area clarification zone features of the units used were key factors in providing a significant level of biological activity without odor problems and in accomplishing effective removal of carbon solids. Effective gravity clarification of carbon suspensions was achieved at overflow rates of up to 0.8 GMP/ sq ft without the use of flocculation aids. Granular media filtration effectively removed carbon particles from carbon contactor effluent. Alum treatment followed by a two-stage counter-current carbon contacting with

75 milligram/liter dosage would cost $0.83/1000 gal, including chlorination. The predicted plant effluent quality would be considerably better than a secondary biological treatment effluent for all parameters, but particularly for phosphorus and suspended solids. (Merritt-FIRL)

21. Campbell, Terrance L. Reece, Jeff M. Murphy, Timothy J. Drnevich, Raymond F. 1978. Biological Phosphorus Removal at Brockton, Massachusetts. Journal of the New England Water Pollution Control Association. Vol. 12 No 1, p 61-73.

Preparatory to a planned expansion of existing wastewater treatment facilities at Brockton, a pilot plant program was conducted to test the applicability of a biological phosphorus removal process, PhoStrip, to the Brockton wastewater. A high level of phosphorus removal was achieved throughout the program. This process was also shown to be compatible with a two-step nitrification system. The stripper supernatant, a phosphorus-rich stream, is treated with lime to precipitate phosphorus. The lime-phosphorus precipitation is pH dependent and non-stoichiometric.

22. Convery, John J. 1970. Treatment Techniques for Removing Phosphorus from Municipal Wastewaters. EPA Report #W71-07760. Jan 29, 70. p. 44.

Biological uptake, chemical precipitation of soluble phosphorus, and settling or filtration of particulate phosphorus are the major removal mechanisms used in phosphorus removal. At present, chemical precipitation is the most universally applied method. The wide variety of chemical reactions which lead to phosphorus precipitation allows much flexibility of operation to plant operators. In dealing with raw sewage, primary effluent, or secondary effluent the size of the plant, influent waste water characteristics phosphorus discharge standard, and the types of other processes used in the treatment train must all be considered. In addition to phosphorus removal, higher levels of BOD and suspended solids removals are customarily obtained when some type of phosphate reduction mechanism is employed. Each of the mechanisms described here have been analyzed both with respect to technological and economic feasibility. Costs ranged from 13 cents/1000 gallons for two-stage lime treatment of 1 mgd to achieve 97% removal, to a potential low of $.015/1000 gallons using waste pickle liquor to achieve a reduction of 80%.

23. Cooke, D.G. Heath, R.T. Kennedy, R.H. McComas, M.R. 1978. Effects of Diversion and Alum Application on Two Eutrophic Lakes. EPA-600/3-78-033. 101 p.

Diversion in 1972 of septic tank drainage away from East and West Twin Lakes, two shallow, eutrophic, dimictic lakes in northeastern Ohio, resulted in prompt return to near-zero fecal coliform levels in groundwater, streams, and lakes. However, phosphorus income failed to decrease to an acceptable level by 1976 due to continued inputs of untreated storm flow and nonpoint urban runoff. Lake phosphorus concentrations remained at typically eutrophic levels. Following an initial reduction in algal standing crop in 1973 there was little subsequent change. In July 1975 addition of a maximum hypolimnetic dose of alum (aluminum sulfate) to West Twin Lake effectively retarded phosphorus release from lake sediments for at least one year, with no adverse side effects observed. East Twin Lake served as a control. The maximum aluminum dose, defined as that above which residual dissolved aluminum concentration exceeds the trout-toleration limit of 0.05 mg/Al/l, was linerly related to alkalinity and could be determined by simple jar tests. Net internal phosphorus loading was only partially reduced by the alum treatment; the untreated upper zone of the lake (specifically the littoral) was apparently a significant internal source of phosphorus. Alum reduced epilimnetic phosphorus concentration and algal standing crop, but both remained at eutrophic levels; cyanophyte dominance was altered to co-dominance of cyanophytes with dinoflaggelates and diatoms. (Lynch-Wisconsin).

24. Cooke, G.D. 1981. In-Lake Control of Nuisance Vegetation: A review of Eight Procedures. Proceedings of a Round Table. Illinois Institute of Natural Resources. Doc #81/06. p 43-55.

Several techniques for restoring lakes are known, and each can provide long-term relief from symptoms, following diversion, if properly selected and applied. Eutrophication causes excessive biological production and decreased lake or reservoir volume. Improvement is possible if the sources of plant nutrients and silt are controlled. Following this, both rooted plants and nuisance algae may be limited by restricting light, preventing their growth by physical barriers or cutting, and controlling the recycling of nutrients from storage in lake sediments. Lake restoration cannot treat symptoms alone, but must include land management to control sources of the problem and in-lake manipulations to give long-term control of plant growth. In-lake restoration methods reviewed in this report are: sediment removal (dredging), aquatic plant harvesting, sediment covering to control nutrient release of rooted plant growth, lake level drawdown, aeration/circulation, dilution/flushing, phosphorus precipitation/inactivation, and biological controls. The report concludes that it is possible to prevent eutrophication of real lakes by planning the development before the lake is built, and that most lakes can be restored to a useful condition that reflects the desired activities of its users. An adequate lake management plan may require resources and time, but it will also give lasting control of eutrophication. (Garrison-Omniplan).

25. Cornwell, D.A. 1975. Recycling of Aluminum Used for Phosphate Removal in Domestic Waste Water Treatment. PhD Thesis. 225p.

A process was developed for the economical recovery of aluminum used as a coagulant for phosphorus removal in domestic waste water treatment. Aluminum-phosphate-organic sludge was used. It was thickened to a solids concentration four times that of raw sludge, and reacted with sulfuric acid to dissolve the aluminum and phosphate. Sedimentation produced a 93% separation. The acidified aluminum was separated from the phosphate by a solvent extraction process using a kerosene solution of alkyl phosphates. The aluminum-rich kerosene phase was contacted with 6N H_2SO_4 and the kerosene:acid volume ratio was adjusted to form a final aluminum concentration equal to that in commercial alum (about 5%). Recovered aluminum was reused as a coagulant in phosphorus precipitation and the kerosene was recycled to the extraction stages. Overall recovery of aluminum was 89-93%. (Collins-FIRL)

26. Cossu, R. deFraja Frangipane, E. Urbini, G. 1981. Biological Denitrification and Simultaneous Phosphorus Precipitation of Sewage in Case of Significant Fluctuations of Polluting Loads. Milan Polytechnic Conf.

27. Dedyo, J. Doan, R. 1981. Reduced Energy Usage with Biolgical Phosphorus Removal. J. Water Pollut. Contr. Fed. Vol 53. No 7. p 1166-1171.

The town of Amherst, N.Y., has under construction modifications to an advanced wastewater treatment plant that include two-step nitrification with oxygen activated sludge, clarification, carbon dioxide stripping, phosphorus precipitation with lime, recarbonation, filtration, and disinfection. Conventional lime sludge handling has included thickeners, classifying centrifuges, and lime recalcination. In 1977, however, a preliminary feasibility study showed that the retrofit of the PhoStrip process for phosphorus removal would save $2 million on a present-worth basis over the original design of the lime precipitation system.

28. Diamadopoulos, E. Benedek, A. 1987. Aluminum Hydrolysis Effects on Phosphorus Removal from Wastewaters. Journal of the Water Pollution Control Federation. Vol 56. No 11. p 1165-1172.

The role of aluminum hydrolysis products in phosphorus precipitation under conditions usually met in practice is reviewed. The effect of aluminum hydrolysis on other parameters such as settling rate, supernatant suspended solids concentration, and sludge filtrability was also addressed. The removal of organics by the hydrolysis products of aluminum was compared with the removal of phosphates. Chemical precipitation was brought about through complex formation. The degree of phosphorus removal depends on the degree of hydrolysis of the coagulant and its concentration, the presence and the concentration of other ions, and the pH. For conditions usually found in practice, the higher the basicity, the smaller the ability of the coagulant to precipitate the phosphates. The most important factors affecting the optimum pH range were the Al:P ratio, the OH:Al ratio, and the presence and concentration of other ions. The presence of sulfate had a beneficial effect on the removal, especially at lower pH values. With domestic wastewaters, the various coagulants gave results similar to those in synthetic wastewater. The efficiencies, however, were smaller because of the presence of condensed phosphates and other ionic species. The hydrolysis of aluminum also affected the supernatant suspended solids concentration, the settling rates, and the dewaterability of the sludge. The pH, the nature, and the dosage of the coagulants affected the removal of organics from an industrial wastewater. The removal of organics by aluminum does not follow the same pattern as the removal of phosphorus. This indicates that a complexation and precipitation mechanism alone cannot be adequately applied to explain the observed trends. (Baker-IVI)

29. Dirickx, I.J. 1981. A Century of Water for Antwerp. Aqua, No 3. p 10-13.

Although the City of Antwerp recognized a need for public water treatment works as early as the cholera epidemic of 1866, it was not successful in establishing a system until 1881, when 7,000 subscribers consuming 2.3 million cu meters a year were served. The distribution system slowly expanded to the 1980 level of 124 million cu meters of water per year and 142,000 subscribers. The water is abstracted from the Albert Canal or the Nete Canal and enters five large storage reservoirs with a total capacity of 2.7 million cu meters. Treatment plants include Notmeir-Walem (165,000 cu meters per day): alum treatment aeration, and sand filtration; Notmeir (220,000 cu meters per day): chlorination, alum and activated silica, dual bed filtration, ozonation, and activated carbon treatment; and Oelegem (135,000 cu meters per day): pumping and purification. (Cassar-FRC)

30. DiStefano, Thomas R. Tu, King-Ning. 1973. The Physics of Interface Interactions Related to Reliability of Future Electronic Devices. IBM Thomas J. Watson Research Center. Report #TR-2;AFCRL-TR-74-0194.

The reliability of semiconductor-insulator interfaces-(Impact ionization model for dielectric instability breakdown; Phosphorus precipitation of Si/SIO2 interfaces); Band structure and switching in insulators-(Optical properties of allotrophic forms of SiO2; Structural transformations as observed by TEM during electrical switching in amorphous Ge-Te); Instabilities associated with metal-glass Interactions-(Analysis of thin film structures with nuclear backscattering and X-Ray diffraction; Reactions of thin metal films with Si or SiO2 substrates).

31. Douglas, D.J. Murray, D.A. Halliday, M. Greene, J. 1978. Correlation Between Exchangeable Phosphorus and Sedimentary Pigment in Some Irish Lakes. Proceedings: Theoretische und Angewandte Limnologi. Vol 20. p 618-623.

Pigment levels and the exchangeable phosphorus fraction in one-m sediment cores generally correlated well in a study of five eutrophic lakes in the Irish midlands, except in shallow Lough Ramor where submerged aquatic vegetation appears to remove large quantities of phosphorus from sediments, and in Lough Key and the north basin of Lough Gowna where significant iron levels may cause rapid phosphorus precipitation. In addition, Gowna's north basin has low levels of primary production and phosphorus. In Loughs Ennell, Gowna (south basin), and Muckno, all subject to artificial enrichment and showing increases in eutrophication, there was remarkable similarity between exchangeable phosphorus levels and pigment concentrations. The lakes in which this correlation was not evident showed little indication of increased eutrophication. Chlorophyll derivatives and total carotenoids were taken to reflect changing production, with low ratios between the two indicating eutrophic conditions with allochthonous production prevailing, and high ratios indicating greater proportional inputs of allochthonous material. Loughs Ennell and Muckno are highly eutrophic, Lough Key eutrophic, Lough Ramor enriched, and Lough Gowna tends toward eutrophic conditions, especially in the south basin. Exchangeable phosphorus appears to approximate the fraction of phosphorus available to algae at the time of sediment desposition. (Lynch-Wisconsin)

32. Dixon, Kevin L. Hoehn, Robert C. Malone, Jill K. Novak, John T. Randall, Clifford W. 1984. Biologically Induced Variations in the Nature and Removability of THM Precursors by Alum Treatment. American Water Works Association Journal. Vol 76. No 4. p 134.

In most lakes, phosphorus (P) is the nutrient controlling the trophic state. Thus, for effective control of eutrophication, the uncertainty in P-loading should be encoded as a probability density function (pdf). Specifically, the pdf of P-loading Y from non-point agricultural sources was sought by means of an event-based stochastic model. P-loading events were triggered by precipitation events (X sub 1, X sub 2, T), in which X sub 1 was the rainfall amount, X sub 2 the duration, and T the interarrival time between events. (X sub 1, X sub 2) were dependent random variables, while T was assumed to be exponentially distributed. The precipitation even causes runoff, which carries dissolved P into the lake with a concentration C sub 1 and sediment yield, Z, which carries fixed or sorbed P into the lake in a fraction C sub 2 of Z. Seasonal loading of P was calculated by adding random numbers of random variables. The model accounted separately for dissolved P and sorbed P. explicit expressions were given for the mean and variance of each type of P-loadings. The case study of a sub-watershed of Lake Balaton, Hungary, was used to illustrate the Methodology. Precipitation data, empirical rainfall-runoff-sediment yield relationships, and a small number of observations of events were used to calibrate the model and to estimate the means and variances of loading per event and per season. Then, a simulation method was used to estimate complete pdf of these random variables. Use of the model for alternative methods of controlling P-loading was discussed briefly, as well as the economics of control. (Sims-ISWS)

34. Env Canada Research Report. 1976. Effluent Polishing by Filtration through Activated Alumina. Env Canada Research Report. 39. Apr. 76.

Special report effluent polishing for phosphorous removal by use of activated alumina columns at the Oakville, Ontario, water pollution control plant was investigated. Phosphorus levels of 0.1 mg/l or less were obtained by this process, depending on the flow rate and the feed phosphorus concentration. The process is estimated to be more economical for desired effluent phosphorus concentrations below 0.5 mg/l than alum treatment alone is.

35. Eisenreich, S.J. 1976. Organic Phosphorus in Lakes. National Technical Information Service. Ph.D. Thesis. 191 p. [31]

The chemical factors controlling the removal of particulate phosphorus (PP), organic phosphorus (Po) and inorganic phosphorus (Pi) from lake waters by aluminum hydroxide have been investigated. Aluminum hydroxide has large adsorption capacity for Pi in distilled and lake water environments (250-280 micro-g P/mg Al). Optimum P removals occurred at low (<4) and high pH (>9-10), and were minimum in the pH range normally encountered in natural waters. The adsorption of Pi and model Po species by amorphous AL-hydroxide was studied over the equilibrium concentration range of 8X 10-7 to 1 x 10-4 M under normal lake pH conditions using the Langmuir adsorption isotherm. The interactions of natural and model Po compounds with aluminum hydroxide lead to the belief that the fraction of native Po which is not responsive to alum treatment consists of a heterogeneous component formed by the association of biologically produced Po and native Pi with inorganic and organic matter in the lake water and not identical to Po compounds normally isolated from aquatic organisms. Solution composition cannot alone account for the lack of Po removal with alum. The non-responsive nature of the Po component is most likely a result of steric, structural or localized ionic aberrations. The ultimate success of lake rehabilitation by alum treatment depends primarily on three factors: (1) the effective immobilization of Pi and Po in the water column; (2) the inhibition of P regeneration from the sediments by covering with a layer of Al-gel; and (3) the limitation of P inputs from external sources. The lake should be treated at spring or fall overturn when Pi is the predominant P form to achieve maximum P removals. A simplified method for the analysis of total P (TP), total dissolved P (TDP) and dissolved reactive P (DRP) in multiple water samples has been developed.

36. Environmental Protection Agency. 1971. Process Design Manual for Phosphorus Removal. EPA, Technology Transfer Manual. 195 p.

The discharge of phosphorus-containing wastewater into the surface waters of the United States, has contributed to their over-fertilization and eutrophication. As a result, efforts are now being made to remove phosphorus from wastewater. This manual discusses phosphorus removal methods that have been found effective and practical for use at treatment plants. All the methods included involve chemical precipitation of the phosphorus and removal of the resultant precipitate. Precipitants include salts of aluminum and iron, and lime. The practical points of addition are before the primary settler, in the aerator of an activated sludge plant, before the final settler, or in a tertiary process. Included in the discussion of each treatment method is a description of the method, pilot or full-scale performance data, equipment requirements, design parameters, and costs. This information should be of value to designers, municipal officials, regulatory agencies, city planners, and treatment plant operators. (Brunner-EPA)

37. Environmental Canada Research Report. 1976. Effluent Polishing by Filtration Through Activated Alumina. Env Canada Research Report 39. Vol 1. 60 p.

Special report effluent polishing for phosphorus removal by use of activated alumina columns at the Oakville, Ontario, Water Pollution Control Plant was investigated. Phosphorus levels of 0.1 mg/L or less were obtained by this process, depending on the flow rate and the feed phosphorus concentration. The process is estimated to be more economical for desired effluent phosphorus concentrations below 0.5 mg/L than alum treatment alone is.

38. Environmental Science and Technology. 1976. Surveying America's Lakes. Environmental Science and Technology. Vol 10. No 9. p 862-864.

Preliminary results from a eutrophication survey of America's lakes are reported along with an example of how some lakes may be restored to higher quality. According to the National Eutrophication Survey, approximately 80% of the lakes and reservoirs in the eastern United States are eutrophic. Shagawa Lake, adjacent to the city of Ely, Minnesota, is an example of a eutrophic lake that has been partially restored by the removal of the algal growth-promoting nutrient phosphorus. The lake originally became eutrophic as a result of the city of Ely discharging its municipal wastewater into it. The installation of a tertiary treatment system at the city's waste water treatment plant resulted in more than 99% removal of phosphorus from the effluent and a decline in eutrophic activity of Shagawa Lake. The effluent flowing into the lake contains only 0.05 milligrams/liter of phosphorus. Although the lake is in the process of repairing itself, it has not yet reached equilibrium, probably because of feedback mechanisms involving internal sources of phosphorus which may be retarding the restoration process. However, the project has demonstrated that phosphorus levels as low as 0.05 milligrams/liter can be achieved through lime precipitation. (Kreager-FIRL)

39. Francko, D.A. Heath, R.T. 1981. Aluminum Sulfate Treatment: Short-Term Effect on Complex Phosphorus Compounds in a Eutrophic Lake. Hydrobiologia. Vol 78. No 2. p 125-128.

Previous studies have demonstrated that hypolimnetic application of liquid aluminum sulfate (alum) may accelerate lake reclamation by removing phosphorus from the water column and by sealing anoxic sediments to reduce the release of nutrients. This study was designed to investigate the effectiveness of alum applications to the hypolimnion in removing various complex phosphorus compounds occurring in eutrophic lakes. These complex phosphorus compounds include phosphomonoesters, polyphosphates, and ultraviolet-sensitive phosphorus compounds. Alum was applied to the hypolimnion of West Twin Lakes, a culturally eutrophic hardwater lake in northeastern Ohio. Orthophosphate was effectively removed from the lake by this treatment, but complex phosphorus compounds were not. Potentially available phosphomonoesters comprised a considerable proportion of the complex phosphorus fraction in the lake water both before and after the alum treatment. Most of the complex phosphorus compounds remaining in the lake water after the alum treatment were capable of releasing orthophosphate on treatment with alkaline phosphatase. These results indicate that aluminum sulfate treatment may be ineffective in removing all biologically available phosphate compounds from the lake water. Further research is required to determine the overall applicability of alum treatment as a nutrient inactivation method. (Carroll-FRC)

40. Francisco, Donald E. Strauss, Martin Dempsey, Brian A. 1976. Phosphorus Removal with Alum from Secondary Effluent. Journal Water Pollution Control Federation. Vol 48. No 8. p 2002-2006.

This investigation was designed to determine under controlled conditions whether tripolyphosphate was significantly hydrolyzed; whether the amount remaining affected phosphorus precipitation with alum; whether precipitation was affected by pH; and whether increased calcium hardness affected phosphorus precipitation with alum.

41. Funk, William H. Gibbons, Harry L. Bailey, Gary C. Mawson, Simon Gibbons, Maribeth. 1982. Preliminary Assessment of Multiphase Restoration Efforts at Liberty Lake, Washington. EPA-600/3-82-005

Liberty Lake is a 288 ha body of water located in Eastern Washington. In 1974 an alum treatment of the lake, aimed at late summer and fall release of phosphorus, successfully demonstrated the need to control internal cycling of nutrients (especially phosphorus) as well as surface and subsurface input. Macrophytes growing in rich sediments acted as nutrient pumps releasing phosphorus above the floc layer. This event-as well as flushing of the bird refuge and marshland to the south of the lake and continued input of septic tanks-overcame the alum treatment within three years. The three-year respite marked the first period in 10 years to be free of bluegreen algae problems. Long term restoration efforts began in 1978-79 with sewering of the lake periphery.

42. Ganczarczyk, J. Hamoda, M.F.D. 1973. Aerobic Digestion of Organic Sludges Containing Inorganic Phosphorus Precipitates: Phase I. Environment Canada Research Report. No. 3 p. 71. J 1973.

Three series of laboratory batch and semi-continuous experiments were carried out at 20C on the aerobic digestion of activated sludges containing aluminum salts or ferric salts used for phosphorus precipitation. Treatment responses measured were digested sludge characteristics, such as volatile solids destruction, oxygen uptake, settleability, and dewaterability, and supernatant characteristics, including total organic carbon, soluble nutrients, and suspended solids. The only variable that was controlled for all experiments was the sludge hydraulic detention time. The aerobic digestion of conventional activated sludge was not affected to any significant degree by the presence of ferric of aluminum precipitates.For both the control and chemically precipitated sludges an aeration period of 10 to 15 days was required for stabilization. Release of soluble organic carbon and nutrients during the aerobic digestion of activated sludges was not altered appreciably in the presence of the chemical precipitates. At the higher chemical dosages there was a reduction in nutrient release in the supernatant. Dewaterability and settling characteristics of control and chemically precipitated digested sludges did not differ significantly. (Sandoski-Franklin)

43. Garrison, P.J. Knauer, D.R. 1983. Lake Restoration: A Five-Year Evaluation of the Mirror and Shadow Lake Project Waupaca, Wisconsin. EPA-600/3-83-010. 100 p.

Mirror and Shadow Lakes, small seepage lakes in central Wisconsin, had experienced cultural eutrophication as a result of storm water drainage. Storm sewers were diverted from the lakes in 1976 and in 1978 aluminum sulfate was applied to enhance the recovery rate by reducing internal phosphorus loading from the sediments. Mirror Lake was artificially circulated to prevent low winter oxygen concentrations and increase spring oxygen concentrations. Storm sewer diversion reduced external phosphorus loading from 58-65 percent for both lakes while the aluminum sulfate application reduced inlake phosphorus concentrations from 90 mg/cu m and 55 mg/cu m in Mirror and Shadow Lakes respectively to 20-25 mg/cu m. Diversion of the storm sewers resulted in a decrease in epilimnetic phosphorus and nitrogen concentrations. Increased algal productivity and biovolume as a result of urban drainage after storm events were eliminated following storm sewer diversion. With the greatly reduced sediment phosphorus release following the alum treatment there was a decrease in spring algal community size and a shift from a community dominated by Oscillatoria agardhii var. to a more diverse community. Annual primary production was reduced 38 percent in Mirror Lake with the depth profiles shifting to those representative of mesotrophic lakes. Phosphorus and nitrogen sedimentation rates were reduced 55 percent and 28 percent respectively resulting in a decrease in the amount of these nutrients being recycled. The zooplankton community numerical size was reduced as the algal production declined.

44. Gilbert, Jerome B. Culp, Gordon L. Salo, John E. 1980. Las Vegas Bets on a Sure Winner. Water & Wastes Engineering. Vol 17 No 9. p 16.

Technical feature to protect the quality of Lake Mead and Las Vegas wash in Nevada, six water treatment alternatives and three wastewater treatment plants in the Las Vegas Valley were analyzed. The treatment plants and the treatment alternatives are described. Studies on cost-effectiveness, functional limitations, environmental impact, and energy-efficiency of the treatment alternatives are discussed. The low lime treatment mode should be used initially at area treatment facilities because of its proven dewatering characteristics, and the alum treatment mode should receive further testing.

45. Ginn, Thomas C. Grieb, Thomas M. Porcella, Donald B. Lorenzen, Marc W. 1981. Limnological Survey of Layfayette Reservoir. EPA-600/3-81-009 127 p.

Layfayette Reservoir is located in Lafayette, California, approximately 20 miles east of San Francisco. The reservoir is an emergency standby water supply and recreational facility. The purpose of the project was to monitor selected chemical and biological characteristics of the reservoir in order to evaluate limnological conditions before the implementation of restoration measures (hypolimnetic aeration in conjunction with alum treatment). These studies were conducted for a period of 15 months from April 1978 to June 1979.

46. Gray, Albert C. Jr. Gerber, H. Bruce. Paul, Paul E. 1976. Activated Sludge Process with Alum Addition and Heat Treatment. Journal Water Pollution Control Federation. Vol 48. No 1. p 163-178

Following the study and evaluation of a number of treatment process combinations that would provide the degree of treatment mandated by the Pennsylvania Department of Environmental Resources, a treatment scheme involving the high-purity oxygen activated sludge system was recommended. The recommended treatment process includes degritting, flocculation, and primary sedimentation, activated sludge using high-purity oxygen; phosphorus precipitation by the addition of alum following oxygenation; secondary sedimentation; disinfection by chlorination; gravity thickening of primary, waste activated, and phosphorus sludges; thermal conditioning of sludges; and vacuum filtration, steam drying, and incineration of thermally conditioned sludges. The recommended system will afford a high degree of treatment and provide for complete disposal of sludges while minimizing the additional space required for biological treatment units.

47. Gromiec, M. Valve, M. Liponkoski, M. 1982. Nutrient Removal from Waste Waters by Single Sludge Systems. Tech Res Cent Finl Res Rep 1-126.

Environmental impacts of nitrogenous compounds in wastewaters discharged into aquatic environments are presented. Technology for removal of N from wastewaters is reviewed. Emphasis is given to the single sludge systems for N removal and their performance in different countries. Nitrification and denitrification kinetics, and state-of-the-art mathematical models for these processes are described. A single sludge nitrification-denitrification system with intermittent aeration combined with simultaneous precipitation of P with FeSO4 was tested. Experiments were performed in a technical scale plant at the Suomenoja Research Station, Espoo (Finland). A dynamic mathematical model was proposed for this process. The model consists of differential equations, written for NH3 and nitrate N, biochemical O2 demand, alkalinity, dissolved O2 and heterotrophic and nitrifying organisms. A computer program for solving these differential equations was developed and computer simulations were performed to show the effects of variables on the performance of the process. The computer program was a useful tool for determining the operational strategies for the process. Technical considerations for the process are given.

48. Gujer, Willi Boller, Marcus. 1978. Basis for the Design of Alternative Chemical-Biological Waste Water Treatment Processes. Progress in Water Technology. Vol. 10 No.6 p 741-758.

Conventional and pre-precipitation primary treatment in combination with simultaneous precipitation and conventional activated sludge processes have been operated in parallel in semi-technical scale. Experimental results are evaluated in order to yield design information for alternative chemical-biological wastewater treatment processes for organic carbon removal, nitrification and phosphorus removal. Data regarding nutrient mass flow, sludge production and sludge thickening characteristics, biological kinetics and phosphorus precipitation is given for an integrated design of primary-secondary processes. Achievable residual concentrations of collective and specific water quality parameters are expressed in statistical terms.

49. Giles, M. 1980. Chemical Treatment Solves Tannery Waste Problems. Industrial Wastes. 26(2) p 30-31.

Manufacturing leather hides for sporting equipment necessitates treatment of a variety of pollutants in the wastewater treatment facility at the Gunnison Brothers Tannery in Girard, Pennsylvania. Approximately 33,000 gpd of non-uniform wastewaters are treated with chemicals and specialized flexible waste treatment equipment. The 2 types of wastewater treated are tannery and finishing mill wastes, which contain lime, hair and other protein, grease and fatty acids, and numerous acids and dyes. A batch-type system is used in the wastewater facility because composition of the wastewater to be treated changes often due to the seasonal nature of the tannery's business. Jar tests are performed each day to determine how the influent will be treated because of the non-uniformity of wastewaters. Aluminum sulfate (alum) is used for clarification of water and for the reduction of SS, proteins, oil and grease, and BOD. The company uses =800 mg/l of alum as aluminum slufate, in conjunction with 10 mg/l Separan AT273, an anionic polyelectrolyte. The effluent SS can be reduced to 5 mg/l with alum treatment. After flocculating, settling, and clarifying, the wastewater is disinfected and discharged into Brandy Run, a tributary of Elk Creek, which feeds into Lake Erie. A pilot study is under way to replace the existing system with a more efficient facility to meet proposed EPA guidelines. (FT)

50. Hamm, A. 1981. Input Control of Nutrients by Technical Measures. Water Supply. Vol 1. No 1. p 207-215.

The paper deals with the amount of P-load from point sources and the reduction of phosphorus in detergents as it is now intended by the German law. Measures of sewage diversion were first estabilished at the lakes Tegernsee and Schliersee in Baveria. The development of these lakes till today is shown. If complete sewage diversion is not possible, chemical precipitation of sewage should be used. The different treatment systems are described. The second aim of chemical flocculation in sewage is to improve the efficiency of treatment concerning organic substances and other pollutional factors. Further reduction of P in sewage with effluent values lower than 1 mg/l can be achieved by sand filtration, activ-alum-treatment, flocculating filtration and other advanced treatment techniques.

51. Haumann, D. Waite, T.D. 1978. The Kinetics of Phosphate Removal in Small Alkaline Lakes by Natural and Artificial Processes. Water, Air and Soil Pollution. Vol 10. No 3. p 291-213.

Decreasing phosphorus (P) levels in the water column by alum treatment was highly efficient (40.8% per day) in two small artificial lakes located on a golf course in southwest Miami, Florida. Experiments September 1972-August 1974 defined rates and mechanisms which maintain low P levels, determined average nutrient uptake mechanisms and benthic macrophyte uptake capabilities, and discovered if P removal by filter-alum with sediment sealing would be sufficient to inhibit macrophyte growth. Benthic macrophytes communities use high P levels from the water column rather than from sediments. Applied P fertilizer removal rates adhere closely to two consecutive first-order reactions. Phase I, or the first few days, corresponds to high P removal rates whereas Phase II removes P at slower rates. Natural physicochemical mechanisms remove 79.7% to 97.6% P during Phase I, however, highest per-diem removal by natural processes is 11.1%. Natural removal mechanisms consist of phosphate absorbed to dispersed calcite surface areas with slow transmutation to hydroxyapatite. Phase II P removal results primarily from hydraulic flushing and primary productivity. Filter-alum application removes P from solution at four times natural process rates through enmeshment, absorption, and isomorphic replacement of OH- by phosphate anions in a poly-metallo-hydroxy polymer. (Danovich-Wisconsin)

52. Herode, S. 1984. The Eutrophication of Lake Balaton: Measurements, Modeling and Management. LIMNOL. TRAV. ASSOC. INT. LIMNOL. THEOR. APPL.Vol 22. No 2. p 1087-1091.

In order to study the response of this lake to different nutrient loads a complex dynamic model, and a simple empiric one have been constructed. It seems that to avoid strong algal blooms in the first basin the phosphorus load must be reduced to one sixth of the present level. A more sensitive response is hoped in the less eutrophicated basins. The effects of different management alternatives/sewage diversion, phosphorus precipitation, pre-reservoirs/are discussed.

53. Hilson, M.A. 1978. Treatment of Mixed Raw Waters. Institution of Water Engineers and Scientists Journal. p. 537-545

The wastewater treatment processes selected for the Lancashire Conjunctive Use Scheme (LCUS) at the Catterall site are described. The scheme will in its present stage of development increase the resources of the Authority by 135 ML/d and is based on the conjunctive use of the upland source of the original Flyde Water Board Area, consisting of Stocks and Barnacre reservoirs, with river water from Wyre and Lune rivers together with groundwater from an extension of the original borehole system. The existing treatment plants incorporated into the scheme are those at Stocks and Barnacre reservoirs and the borehole softening plant at Broughton. A new river water treatment plant of about 280 ML/d is to be constructed. The borehole water treatment capacity is also to be increased 80 ML/d. For borehole water treatment, a straightforward dealkalinization ion-exchange plant was selected. This type of plant has a relatively low capital cost, but a high running cost, depending on reagents used. The plant consists of 5 dealkalinization units each capable of softening 10 ML/d to 0 alkalinity for a final hardness of about 10 mg/l. Up to 4 of these units will be on-line at any one time, with the 5th unit regenerating. A control room houses necessary equipment to control the future river water treatment plant and various other facilities, e.g., mess rooms and workshops. Jar tests indicate that alum coagulant will likely give the best overall river treatment results. A coagulation-sedimentation-filtration process produced satisfactory treated water under all conditions of river water quality. Dissolved air flotation instead of sedimentation in the treatment scheme was also sufficient. The main problem of plant control will arise from the fact that the optimum pH value for coagulation will vary as the proportion from the 2 rivers varies. It is not anticipated that any difficulties will be encountered during periods of change-over from river water to borehole water.

54. Hoehn, Robert C. Dixon, Kevin L. Malone, Jill K. Novak, John T. Randall, Clifford W. 1983. Biologically Induced Variations in the Nature and Removability by Alum Treatment of Reservoir Trihalomethane Precursors. Proceedings AWWA Annual Conference. p. 1093-1118.

The objectives of this study were to compare, during part of the algal growing season, the solubility-class distributions of organic matter dissolved in a reservoir, organic extracellular products (ECP) of algae produced in situ during carbon 14 (14C) uptake studies of primary productivity, and trihalomethane (THM) precursors included in the pool of dissolved organic compounds in the lake water. Additional objectives include relating, if possible, any variations in lake water THM formation potential to variations in algal and bacterial population densities within Claytor Lake near Pulaski, Virginia and to algal activity determined by in situ evaluations, and determining whether there would be seasonal variations in the effectiveness of alum treatment for removing THM precursors and other dissolved organic compounds from the lake water. Experimental methods and procedures are described. The following conclusions are presented: hydrophobic-neutral organic compounds comprised the majority of the organic matter indigenous to the lake, as well as that produced by algae in 14-C-uptake studies; algal and bacterial metabolic activity in a lake significantly alters the THMFP of lake water, though such effects can be identified best only if diurnal studies are undertaken; there were no consistent relationships between either the algal or bacterial population densities and the 7-day THMFPs of lake water collected on a grab-sampling basis; and alum coagulation reduced THM precursors by about 50 percent, and its effectiveness did not appear to be altered by variations in algal or bacterial population densities in the lake.

55. Huang, Ju-Chang Tsai, Kuo-Chun. 1978. New Design Criteria for the Aerobic Digestion of Sewage Lime Sludge. Progress in Water Technology. Vol 10. No 1/2. p 615-631.

This study was undertaken to establish a set of design and operation criteria for the aerobic digestion of sewage lime sludge which was produced from phosphate precipitation in primary clarifiers. The aerobic digestion study was carried out at 20C. Special emphasis was placed on the evaluation of various parameters pertinent to the optimum process design and operational control for such a digester. The minimum solids detention time required in the digester is about 10 days. The air requirement for the digester is 60 scfm/1000 cu ft of digester volume. Following digestion, the VSS reduction is no more than 15 to 20 per cent, which is equivalent to only 2 to 4 per cent of the total sludge solids originally present in the raw lime sludge. However, the digested sludge is readily settleable for easy decantation and thickening. The sludge is also readily dewaterable by either drying beds or mechanical means. The dewatered sludge is suitable for ultimate disposal on land without creating any odor nuisance. The digested sludge supernatant and filtrate are low in P and COD, their values being less than one half of those commonly found in domestic sewage.

56. Hultgren, J. Hultman, B. 1981 Swedish Experiences in the Field of Phosphorus Removal. Europaeisches Abwasser- und Abfallsymposium EAS 5th. Publ by Sesellschaft zur Foerderung der Abwassertechnik, St. Augustin, Ger p 535-546. 1981.

57. 1980. International Trends in Water Management. Effluent and Water Treatment Journal. Vol 20. No 11. 0 538-540.

The importance of national measures for controlling water pollution becomes evident when one considers international rivers such as the Rhine. Considerable interest is appearing in the development of models that permit predictions to be made of the effects of installing or improving wastewater treatment facilities at different locations within the system. Studies have also been made of algal blooms in various lakes, attributed to sewage effluent. Alum treatment has been used to remove phosphate from the effluent in some cases. The importance of urban stormwater as a source of nitrogen and phosphorus and the availability of these potential nutrients for the growth of algae in an area where stormwater is the major contributor to eutrophic conditions has also been examined. A study on groundwater quality was performed because of the potential public health hazard caused by nitrates derived from septic tank leaching systems contaminating groundwater taken for public supply. Each of these various studies is viewed from the viewpoint that the interactions of many variables affect the water quality, leading to the conclusion that the subject of water management must concern itself with these interacting variables. (Baker-FRC)

58. Jackson, T.A. Kipphut, G. Hesslein, R.H. Scnindler, D.W. 1980. Experimental Study of Trace Metal Chemistry in Soft-Water Lakes at Different pH Levels. Canadian Journal of Fisheries and Aquatic Sciences. Vol 37. No 3. p 387-402.

The biogeochemistry of Hg, Zn, Co, Fe, Mn, Cr, V, Th, Ba, Cs, As, and Se in two soft-water lakes of the Canadian Shield was investigated by means of carrier-free gamma-emitting isotopes introduced into limnocorrals in which the pH of the water was varied from 6.8 to 5.1. The residence times of the radionuclides in the water were determined, and the partitioning of the nuclides among different metal-binding agents in the water and sediments was studied with the aid of membrane filtration, dialysis, solvent extractions, and fractionation on Sephadex columns. Metal behavior varied systematically with metal properties. Metals of high crystal field stabilization energy, high electroegativity, or small ionic radius were most readily scavenged by greater than 0.45 micrometer suspended particles and dispersed colloids in the water, disappeared most rapidly from the water column, and were preferentially accumulated by sedimentary binding agents, including organic substances. Which property of a metal had the dominant effect on metal behavior depended on environmental factors, such as the ambient pH and the nature of the binding agents. Thus, Hg was removed fairly rapidly from the water at pH 6.7-6.8 owing to its high electronegativity but was removed more slowly than any other metal at pH 5.1 owing to its large ionic radius. Acidification of lake water to pH 5.1 interfered with accumulation of Hg and other metals by organic ooze, probably owing in part to interference with the deposition or formation of the complexing agents with the 265 nm absorption band. Acidification also lowered the concentration of NaOH-extractable colloidal phosphate in the ooze but had no effect on HaOH-extractable orthophosphate content. (Sims-ISWS)

59. Kainrath, P. Krauth, K. Maier, W. Wagner, R. 1984. Pilot Scale Studies on Enhanced Biological Phosphorus Removal in an Activated Sludge Treatment Plant with Nitrification and Predenitrification. Zeitschrift fur Wasser und Abwasser Forschung. Vol 17. p 245-251.

In activated sludge treatment the enhanced biological removal of phosphorus from domestic sewage is possibly an alternative to the established method of phosphorus precipitation with ferric, aluminum or calcium salts. However it is not yet clear, whether or not this method might be practicable in Central-Europe with the wastewater and temperature conditions existing there. The results of experiments in a pilot-scale activated sludge treatment plant are presented the influence of the composition of the influent, the retention time in the various basins, the variation of the organic sludge load and the seasonal profiles were investigated in ten different experimental periods during the past two years. The process design was also changed during the investigations in order to examine the influence of the system configuration. The aim of these experiments, which are still in progress, is to investigate the possibilities for the technical realization of the method presented.

60. Kannan V. Job, S.V. 1980. Diurnal Depth Wise and Seasonal Changes of Physicochemical Factors in Sathiar Reservoir India. Hydrobiologia. 70 (1-2). p 103-118.

The various physico-chemical factors such as rainfall, depth, water spread, temperature, dissolved O2, pH, redox potential, alkalinity, total P, nitrate, kjeldahl N and dissolved organic matter were studied both diurnally and seasonally and depth-wise during April 1977 - March 1978. Consideration of physico-chemical factors indicates that they are interrelated. The main characteristics of Sathiar clearly indicate that it is highly eutrophic.

61. Kavanaugh, M. Eugster, J. Weber, A. Boller, M. 1977. Contact Filtration for Phosphorus Removal. Journal Water Pollution Control Federation. Vol 49. No 10. p 2157-2171.

Pilot studies on the use of granular media filtration for removal of particulate phosphorus and organic carbon following mechanical-biological treatment are presented. Objectives of the studies were to examine the effects of filter media design, filtration rate, and chemical addition on the performance of granular media filters used for phosphate removal following precipitation; and to evaluate process feasibility of contact filtration for municipal wastewater treatment. The study concluded that contact filtration was a viable alternative to coagulation/sedimentation or flotation, but the permissible influent filter solids concentration was dependent on the individual situation. The addition of a polyelectrolyte such as a non-ionic polymer was necessary to increase the shear resistance of flocculant solids to produce adequate solids retention. Solids removal with the three-layer and two-dual-media filters was greater than 95% in runs of approximately 6 hr. Removal efficiencies were increased with an increase in the upper:lower medium depth ratio which produced a decrease in the time-averaged rate of headloss increase. Inverse relationships were observed between filtration rate/break through time and the time to exhaust available head. Sand, anthracite, and pumice comprised the media used in the three-layer filter, and sand-anthracite and sand-Magnofilt were used in the dual-media filters. Of the media tested the porous granular solids, pumice and Magnofilt, exhibited lower solids capacities than anthracite at a given filtration rate and size fraction. (Schulz-FIRL)

62. Kavanaugh, Michael C. Krejci, Vladimir Weber, Toni Eugster, Jack Roberts, Paul V. 1978. Phosphorus Removal by Post-Precipitation with Fe (III). WPCF J. Vol 50. No 2. p 216.

Technical report the post-precipitation method of phosphate removal in domestic waste treatment was examined. The principle design parameters controlling the performance of post-precipitation with iron (III) as the precipitant/coagulant were elucidated. Predictive models for phosphorus precipitation with (III), flocculation of precipitated solids, and solids/liquid separation in a sludge blanket clarifier were developed and evaluated. The type of initial mixing devices tested did not have a significant effect on phosphate removal. Solids/liquid separation was the critical unit process controlling total system performance. The equilibrium precipitation model gave values of residual dissolved phosphate that agreed with experimental values. The shear coagulation model adequately described turbidity removal, and the steady state filtration model of suspended solids removal in a sludge blanket clarifier correlated well with actual system performance. The models can serve as a basis for design and data evaluation of pilot scale waste treatment systems.

63. Kayser, R. Boll, R. Teichgraeber, B. 1985. Development of a Control Scheme for Simultaneous Phosphorus Precipitation. IAWPRC Workshop. p 715-719.

A closed circuit control scheme using the phosphate concentration of the mixed liquor as the control parameter was developed. It was tested in bench scale plants for simultaneous phosphate precipitation and as an addition to biological phosphate removal. In order to avoid over-or under-dosing, the precipitant may be dosed proportional to the wastewater flow or even better proportional to the phosphorus loading rate (wastewater flow rate times phosphorus concentration).

64. Kennedy, R.H. Cooke, G.D. 1982. Control of Lake Phosphorus with Aluminum Sulfate: Dose Determination and Application Techniques. Water Resour. Bull. Vol 18. No 3. p 389-395.

The phosphorus precipitation/inactivation technique is a procedure to remove phosphorus from the water column and to control its release from sediments in order to achieve P-limiting conditions to algal growth. Aluminum salts have been used in advanced wastewater treatment to remove phosphorus and this technology was extended to lake rehabilitation. Guidelines for dose calculation and application are provided in this report. The dose determination suggested here allows maximum application of aluminum to bottom sediments and thus emphasizes long term control of phosphorus recycling. Dose can be calculated directly from the alkalinity of the water to be treated. Alum may also be used to meet other restoration objectives including the treatment of problem flows and the reduction of particulate concentrations.

65. Kubersky, E.S. 1986. Effects of an Alum Treatment on a Softwater New-Jersey Lake USA. Bull. N J Acad Sci. 31 (1).

66. Kumar, H.D. Rai, L.C. 1978. Zirconium-induced Precipitation of Phosphate as a Means of Controlling Eutrophication. Aquat. Bot. Vol 4. No 4. p 359-366.

A potentially promising method of controlling eutrophication by means of zirconium oxychloride, a chemical precipitant for phosphate, is described. Zirconium oxychloride precipitates phosphate and limits algal growth at fairly low concentrations (100 ppm) at a pH range of 2-11. At this concentration, ZrOCl(SUB-2) does not seem to be harmful either to the tested fish or algae.

67. Lamb, D.S. Bailey, G.C. 1981. Acute and Chronic Effects of Alum to Midge Larva (Diptera: Chironomidae). Bulletin of Environmental Contamination and Toxicology. Vol 27. No 1. p 50-67.

In view of the increasing use of alum to precipitate phosphorus in highly eutrophic lakes, the acute and chronic effects of alum to Tanytarsus dissimilis, important fish food organisms, were determined. Acute tests used alum concentrations of 80, 160, 240, 320, 400, 480, 560, 720, and 960 mg/liter. Chronic test solutions contained 10, 80, 240, 480, and 960 mg/liter of alum. In acute tests there was no apparent effect of alum on either second or third instar T. dissimilis at doses between 80 and 960. Mortalities in the chronic assay were found at all alum doses. Fifty percent mortality was reached with 480 mg/liter at four days. The 50% mortality time for 80 and 240 mg/liter was between 8 and 10.5 days. At 960 mg/liter, 50% of the larvae were dead after 23 days. Heavy alum floc at 960 mg/liter appeared to cause a stress by impeding movements and feedings. Possible chemical and physical toxicity of alum must be considered when planning lake treatments. A well planned alum treatment will avoid adverse effects on the benthic insect population. (Small-FRC)

68. Lee, G. Fred. 1973. Effect of Eutrophication on Raw Water Quality and its Control. Am Chem Soc, Vol 13. No 1. p 90-91.

Excessive growths of algae and aquatic weeds which are associated with eutrophication result in tastes and odors, shorter filter runs, higher chlorine demand, and higher color in the raw water. While water treatment technology can cope with and in general eliminate these problems, normally treatment of eutrophic water is more expensive. The control of excessive eutrophication requires three approaches. Initial attention should be given to determining aquatic plant nutrient that limits or can be made to limit aquatic plant growth in the water supply. The central program should try to limit this nutrient inflow to the water supply. The second approach uses in-lake nutrient control such as aeration and mixing, alum treatment, selective withdrawal, etc. The third approach involves the use of toxic chemicals which are designed to kill the excessive aquatic plants using herbicides and algicides. The current trend today is to place greater emphasis on approaches one and two and de-emphasize approach three.

69. Likens, G.E. Loucks, O.L. 1977. Analysis of Five North American Lake Ecosystems. III. Sources, Loading and Fate of Nitrogen and Phosphorus. INT. 573 Vol 20. p 568-573.

Study of nitrogen and phosphorus budgets in Findley Lake (Washington), Mirror Lake (New Hampshire), and Lake Wingra (Wisconsin) showed that: (1) nutrient input levels generally reflected land use, watershed areas, vegetation, and geology; (2) precipitation inputs were significant and sometimes dominant; (3) lacustrine sediments were a sizable sink for nitrogen and phosphorus; (4) retention times for nitrogen and phosphorus may be determined by factors other than water renewal time; and (5) insect emergence may account for significant loss of nitrogen and phosphorus from lake ecosystems. Patterns of short-term nutrient loading and losses need further study at the ecosystem level. Data were not sufficient to test the hypothesis that lakes in forested watersheds receive the majority of their inputs of nitrogen and phosphorus from direct precipitation and gases, whereas runoff dominates in open grassland or disturbed watersheds. Data for Findley were from 1975, for Wingra averages from 1970-74, and for Mirror averages from 1968-75. Wingra is located in a grassland area and receives urban drainage from Madison, Wisconsin, while Findley and Mirror have forested watersheds. Wingra had by far the largest inputs of phosphorus (0.96 g/sq m/yr) and nitrogen (23.59 g/sq m/yr), but among the lakes proportions added from precipitation, fluvial, and litter sources were remarkably similar. Evapotranspiration was much more important than drainage area size in determining annual fluvial water input to the lakes. (Lynch-Wisconsin)

70. Lord, H.O. 1950. Disposal of Sewage Effluent at Madison, Wis. Sewage and Industrial Wastes. Vol 22. No 1.

An historical account is presented of disposal of sewage effluents at Madison, Wisconsin, from 1884 (when sanitary districts served by public sewers were first developed) to 1950. In 1898, the first sewage treatment began, utilizing chemical precipitation. In 1901, a trickling filter plant replaced the original unit. Activated sludge treatment was inaugurated in 1914. Population growth by 1928 necessitated addition of a second plant and several subsequent modifications. Nuisance conditions have long been attributed to the lakes' over-enrichment with sewage effluents. A committee, appointed by the Governor in 1941, to study the Madison Lakes, proposed that removal of nitrogen and phosphorus from effluents would significantly contriubte to abatement of the nuisance conditions. The Legislature enacted a law in 1943, prohibiting discharge of sewage effluents into lakes (apparently tailored specifically for the Madison area). An order by the State Board of Health, requiring Madison's sewage effluent to be discharged outside the drainage basin, was found unlawful and reversed after judicial review in 1948. The original 1943 law was amended in 1949 to permit exemption from the requirement if adequate treatment was provided. (Ketelle-Wisconsin)

71. Maatta, R. 1981. Experience on Use of Ferrous Sulphate in View of Precipitating Phosphorus in Plants with Extended Aeration. Europaeisches Abwasser- und Abfallsymposium EAS 5th. Publ by Gesellschaft zur Foerderung der Abwassertechnik, St. Augustin, Ger p 547-556. 1981.

72. McComas, M.R. Cooke, G.D. Kennedy, R.H. 1976. A Comparison of Phosphorus and Water Contributions by Snowfall and Rain in Northeast Ohio. Water Resources Bulletin. Vol 12. No 3. p 519-527.

A recorded snowfall of 55.8 centimeters occurred on December 1 and 2, 1974, in Portage County, Ohio. An early winter thaw melted the greater part of the snow by December 22, 1974, and a two-day rain fell from December 23 to December 25. These weather events provided an opportunity to compare snowmelt and rainfall contribution to runoff and phosphorus loading to the Twin Lakes watershed. Phosphorus concentrations of the snow and rain were determined. Six lake inflows and two lake outflows were measured daily for volume and phosphorus concentration. The snow added 217,000 cubic meters of water and 2.2 kilograms of total phosphorus to the watershed. The rain added 74,000 cubic meters of water and 1.6 kilograms of total phosphorus. Total water discharge from the watershed during December was 244,537 cubic meters and total phosphorus output was 20.3 kilograms. The snow privided 49.9% of the discharge and 8% of the phosphorus whereas the rainfall contributed 28% of the discharge and 6% of the phosphorus. These results indicated that, while snow is a significant source of water, it is not a large source of phosphorus. The greatest contribution of phosphorus comes from fine sediment carried by storm runoff. (Henley-ISWS)

73. Miller, Roy D. Ryczak, Robert S. Ostrofsky, Arnold. 1978. Phosphorus Removal in a Pilot Scale Trickling Filter System by Low Level Lime Addition to Raw Wastewater. Army Medical Bioengineering Research and Development Lab. TR-7901. p 59. Jan 1978.

Lime addition to raw wastewater as an upgrading technique can significantly aid a trickling filter plant in producing effluents in compliance with NPDES permit limitations for BOD5, suspended solids and phosphorus. Low level lime addition does not require recarbonation and does not produce the sludges typical of high pH lime treatment schemes. Low level lime addition was studied in laboratory and pilot scale systems. Raw wastewater was treated in a 4.16cu/m/day (1100 gpd) primary clarifier followed by a 2.46 cu m/day (650 gpd) trickling filter system. Lime was added to a rapid mix tank prior to primary clarification at pH levels of 9.0, 9.5 and 9.8 entering the clarifier. Phosphorus precipitation, solid-liquid separation of the insolublizied phosphorus, nutrient levels entering the trickling filter, biological treatment efficiency, sludge production and sludge characteristics were all monitored. Ferric chloride and polyelectrolytes were tested for their effectiveness as flocculating aids in the solid-liquid separation of the insolubilized phosphorus. Results indicate that low level lime addition to raw wastewater in a trickling filter system can provide an effective simple-to-operate, cost-effective method of upgrading a plant to successfully comply with effluent limitations.

74. Mires, J.M. Soltero, R.A. Keizur, G.R. 1981. Changes in the Zoo Plankton Community of Medical Lake Washington USA Subsequent to its Restoration by Whole Lake Alum Treatment and Establishment of a Trout Fishery. J. Freshwater Ecol Vol 1, No 2, p 167-178.

The application of 936 metric tons of alum to eutrophic Medical Lake, Washington in 1977 interrupted the lake's internal P cycle, lowering its trophic status. Observations of the zooplankton community were made before, during, and for 3 yr following the restoration. A decline in percent composition of rotifers with a corresponding increase in crustaceans has occurred both in response to the altered trophic status and as a result of coexploitive interactions within the community. The Rotifera numerically comprised approximately 90% of the zooplankton standing crop prior to the restoration but only 43.5% of the standing crop in 1980. The Crustacea (i.e.,Cladocera and Eucopepoda) collectively comprised 9.9% of the total standing crop in 1977 increasing to 56.5% in 1980. Indices of species diversity also indicated a trend toward a more diverse zooplankton community with less annual variability. Following the alum treatment, apprx. 31,000 fingerlings of rainbow trout (Salmo gairdneri) were introduced into the lake over a 3 yr period. The predatory pressure exerted by the trout has also influenced the zooplankton community as indicated by a decline in the Chaoborus density in conjunction with a shift in cladoceran composition and smaller individuals of mature Daphnia.

75. Morgan, W.E. Fruh, E.G. 1972. An Investigation of Phosphorus Removal Mechanisms in Activated Sludge Systems. EPA-R2-72-031. 146 p.

The magnitude of two phosphorus removal mechanisms, metabolic uptake and chemical precipitation with calcium, in activated sludge systems were investigated using synthetic substrates representative of actual wastewaters. Using completely mixed continuous flow laboratory activated sludge units with operating conditions that precluded significant precipitation of phosphorus, normal growth defined as constant 85 to 90 percent carbon removal occurred above 0.9 to 1.0 percent sludge phosphorus (influent COD:P Ratio of 670:1). Between 1.0 and 1.6 percent (influent COD:P ratio of 220:1) a storage zone existed with all phosphorus present utilized, and above 1.6 percent a variable saturation zone occurred with an upper limit near 3.0 percent. An alkaline phosphatase bioassay verified qualitatively the normal growth phosphorus requirement and storage zone, but did not define the upper limit of the saturation zone. An acclimated activated sludge unit with a substrate containing 2 mm calcium, 0.4 mm phosphorus, 0.8 mm magnesium and 2.5 mm bicarbonate attained a maximum of 3.7 percent sludge phosphorus after 39 days of operation at pH 7.6. A similar system with the addition of 1 mg/l fluoride attained 4.6 percent sludge phosphorus. An increase in magnesium to 2.0 mm had little effect on phosphorus precipitation. Alkalinity was implicated to exert both a kinetic effect as well as an effect on residual soluble phosphorus in calcium-phosphorus systems. The presence of soluble organics also was shown to be inhibiting with increasing concentrations. (EPA Abstract)

76. Murphy, C.B. Jr. Hrycyk, O. Gleason, W.T. Field, R. Fan, E. O'Brien and Gere Engineers. 1977. Single P/C Unit Removal of Nutrients from Combined Sewer Overflows. Journal Water Pollution Control Federation. Vol 49. No 2. p 245-255.

An investigation, beginning with a pilot scale program and concluding with demonstration-scale facilities, was conducted to determine design criteria for the construction of a system to remove nutrients from combined sewer overflows. The unit developed was a high rate combined process using primary screening, in-line alum addition and coagulation, and contact with clinoptilolite. Alum dosages which produce an aluminum:phosphorus molar ratio of 1.2 to 1.8 removed 90-95% of the phosphorus. Phosphorus removal was not enhanced by excessive alum treatment. Polymer doses for removing solids depended upon the level of solids in the overflow wastewater and on the solids generated by the alum. This system could be used to partially treat lake and reservoir tributaries with an algae problem during dry weather conditions, and to treat receiving streams immediately following a storm. Ammonia removal depended upon the NH3N concentration in the influent, the volume of clinoptilolite used, and the wastewater application rates. Ammonia removals of 0.36 meq/gram (5.0 milligrams NH3N/gram of clinoptilolite) were achieved. Three contractors in a series are necessary to optimize the use of clinoptilolite. This system is ideal for conditions where treatment of a point source combined sewer overflow discharge is necessary, where space limitations do not allow conventional treatment, and where conveying wastewater is impractical. (Collins-FIRL)

77. Nishi, K. Antoniadis, D.A. 1986. Observation of Silicon Self-interstitial Supersaturation during Phosphorus Diffusion from Growth and Shrinkage of Oxidation-Induced Stacking Faults. J. Appl. Phys. Vol 59. No 4. p 1117-1124.

The effects of phosphorus diffusion on the growth and shrinkage of oxidation-induced stacking faults (OSF) has been studied in the temperature range from 950 to 1100 degrees C. By using Wright etch on angle-lapped samples, OSF size dependence on depth has been obtained. OSF grow faster or shrink slower with increasing phosphorus dose, thus indicating a self-interstitial supersaturation, moreover, it was found that this supersaturation is not the result of phosphorus precipitation. Silicon self-intersititial concentration normalized to its equilibrium value has been calculated from the OSF kinetics and was compared with time, phosphorus dose, and temperature. It was found that the intersititial supersaturation increases with phosphorus dose and decreases with annealing time. At the same phosphorus deposition condition, the interstitial concentration decreases with increasing temperature. Normalized diffusivity at the profile tail, assuming a pure interstitialcy phosphorus diffusion mechanism, yields values approximately twice as high as those calculated from OSF kinetics. Possible reasons for this discrepancy are discussed.

78. Nobili, D. 1982. Coherent Precipitation and Solubility of Phosphorus and Arsenic in Silicon. The Electrochemical Society. Vol 32-4. p 189-208.

79. Ockershausen, R.W. 1980. Waste Water Treatment for Phosphorus Removal. Water and Sewage Works. Vol 127. No 8. p 40-41.

Ten years of experience in removing phosphorus from waste water by alum precipitation shows that this has been successful in several cities. Avon Lake, Ohio, in the Great Lakes Drainage Basin, was one of the first cities to remove P on the continual basis. Phosphorus removal was 90% with alum and zero without. The Richardson, Texas, plant removes 96.8% of P (initial concentration 12 to 15 mg per liter), using a dosage of 150-160 mg alum per liter. Warren, Michigan removes 83.9% P with alum treatment, and Windsor, Ontario, 86.5% total P, 91.1% orthophosphate, and 95.4% dissolved orthophosphate. (Cassar-FRC)

80. Oliver, B.G. Lawrence, J. 1979. Haloforms in Drinking Water: A Study of Precursors and Precursor Removal. American Water Works Association Journal. Vol 71. No 3. p 161-163.

Haloform concentrations in water samples were measured by GC using a modified headspace technique. Samples were chlorinated to the 10 mg /L level with sodium hypochlorite and allowed to rest 24 hr. Primary and secondary effluents from sewage treatment plants showed that reaction with Cl produced very little chloroform (CHCl3)-1-4 mug/L-despite high TOC of =15 mg/L. To assess the importance of low molecular weight methyl ketone precursors, 3 natural water samples were reduced in volume from 1000 ml to 100 ml, and then diluted back to 1000 ml with ultradistilled water. The haloform production during chlorination was then compared with that of the original untreated sample at pHs of 7 and 11. There was virtually no difference in haloform production in the sample pairs at pH 7, and a maximum difference of only 15% in the pH 11 samples. Chloroform produced from solutions of fulvic and humic acids increased rapidly with Cl concentrations ==10 mg/L and then leveled off. Time plots showed a steady increase in CHCl3 production =24 hr. Both acids yielded about the same amount of CHCl3 at the same concentration. In raw water samples from plants in the Great Lakes Basin and Canada, the only haloforms produced in significant quantities were CHCl3 and bromodichloromethane, with CHCl3 the most prevalent. Filtration of the samples through 0.45-mu filters reduced the haloform levels by 5% in most cases. Alum treatment, followed by sand filtration, removed =2/3 of precursors. Chlorination of treated water, in most cases, yielded quite low haloform concentrations. (FT)

81. Ostoja, P. Guerri, S. Negrini, P. Solmi, S. 1984. The Effects of Phosphorus Precipitation on the Open Circuit Voltage in N/Sup +/P Silicon Splar Cells. Sol. Cells Switzerland. Vol 11. No 1. p 1-12.

The emitter recombination current, which limits the open circuit voltage in silicon solar cells with heavily phosphorus doped shallow emitters, depends on the junction fabrication procedures. The physical properties which influence the emitter recombination current include not only the surface recombination velocity (which can be controlled by appropriate surface passivation techniques and optimized front metal coverage factors) but also the bulk emitter lifetime. It is shown that the bulk emitter precipitation phenomenon that causes reduced values of the open circuit voltage. Junction fabrication procedures which result in the suppression of the precipitation phenomenon and experimental data which demonstrate the importance of this effect are presented and discussed.

82. Peterson, J.O. Wall, J.P. Wirth, T.L. Born, S.M. 1973. Eutrophication Control: Nutrient Inactivation by Chemical Precipitation at Horseshoe Lake, Wisconsin. Wisconsin Department of Natural Resources. Technical Bulletin. No 62. 20p.

A demonstration of phosphorus inactivation by chemical precipitation was conducted in eutrophic Horseshoe Lake, Wisconsin, to determine suitable techniques, document effects of the precipitating agent on water chemistry and the algal community of the lake, and determine application costs and benefits or improvements that may accrue. Alum (aluminum sulfate) was used as a method representing an extrapolation of advanced waste treatment technology where phosphorus is removed by precipitation, sorption, and physical entrapment and sedimentation in a flocculant aluminum hydroxide precipitate. The 22-acre, 55-ft deep lake was treated in 1970 by application of approximately 11 short tons of slurried alum distributed in its upper two feet of water. Alum concentrations in the treated volume were about 200 mg/l which resulted in maximum phosphorus removal with minimal ecologic risk. The treatment results were a decrease in total phosphorus, no increase in total phosphorus in the anoxic hypolimnion during the following summer's stratification, some increase in water transparency, a short-term decrease in color, absence of nuisance planktonic blooms, improvement in dissolved oxygen, especially during the following two winters, and no observable adverse ecological consequences. Application methods, description of equipment, and costs are given. (Auen-Wisconsin)

83. Porcella, D.B. Cowan, P.A. Middlebrooks, E.J. 1973. Biological Response to Detergent and Nondetergent Phosphorus in Sewage - Part I. Water and Sewage Works. Vol 120. No 11. p 50-67.

Sewage effluent from a suburban community of the city of Logan, Utah, was collected during times when detergents were and were not used to ascertain whether the elimination of phosphate detergents would affect algal growth. Algal bioassays were conducted with Selenastrum capricornutum and Anabaena flos-aquae using nutrient spikes to determine which nutrients were limiting. Bioassays were also performed using secondary treated, detergent-free sewage sample spiked with detergent to observe whether any increase in biostimulation resulted. The nutrient spikes were NH4Cl, KH2PO4, Fe and trace elements, and NAAM solution for control. Chemical analysis of the sewage samples showed that restricted use of detergent resulted in a 57 percent decrease in phosphorus content; alum treatment also reduced phosphorus content. However, calculated phosphorus concentrations in the bioassay flasks for different dilutions of the secondary and tertiary effluents of the two sewage samples indicated the P content was high as a result of the high level of P in the reservoir water used for dilution. It is concluded that if the P content of the water is naturally high, the addition of more P will not affect algal growth. The results of the algal bioassays are not included. (Little-Battelle)

84. Sams, Barry L. Silvey, J.K.G. Stanford, Jack A. 1978. Comparative Chemistry of a Cooling Reservoir and its Water Source. WPCF J Vol 50. No 2. p 193.

Research report the effects of a 700 mw generating station in Texas on the chemical dynamics of the plant's cooling reservoir were studied. The dynamics of the chemical constituents in water and sediments from the reservoir, North Lake, were compared with those of the river that supplies the reservoir. Limited drainage and a high evaporation rate of North Lake has caused the concentration of dissolved solids to increase during the past 19 yr. Phosphorus concentrations have decreased, however, and are limiting biotic production in the lake. The river supported 23 times more algal cells than North Lake supported. The shift in chemical equilibria has resulted in phosphorus precipitation from the water column with calcium and iron. Compared with other Texas reservoirs, North Lake is a less suitable nutrient environment for autotrophic production.

85. Schepers, J.S. Vavricka, E.J. Andersen, D.R. Wittmuss, H.D. Schuman, G.E. 1980. Agricultural Runoff During a Drought Period. Journal of the Water Pollution Control Federation. Vol 52. No 4. p 711-719.

Runoff from the Dee Creek watershed over a 3 year period with less than normal precipitation amounted to less than 2% of the incoming moisture, and sediment losses were less than 0.7 metric ton/ha per year because of the drought conditions. Nutrient losses associated with the sediment averaged 74-76% of the total N and P losses, respectively. Fertilizer application was not consistently related to nutrient losses. These data agree with those from other studies and suggest that nutrient discharge is highly dependent on sediment loss. Over 90% of runoff water samples exceed recommended water quality standards for recreation for total coliforms and fecal coliforms, while base flows exceeded the same standards 90% of the time for total coliforms and 45% of the time for fecal coliforms. (Sims-ISWS)

86. Schlesinger, W.H. Marks, P.L. 1977. Mineral Cycling and the Niche of Spanish Moss Tillandsia-usneoides. Am J Bot Vol 64. No 10. p 1254-1262.

On the southeastern coastal plain (USA) the occurrence and abundance of the epiphyte Spanish moss (T. usneoides L.; Bromeliaceae) are linked to the availability of minerals in the canopy of potential host trees. Trees with high rates of foliar leaching (e.g. cypress and oaks) provide an abundant supply of minerals (Ca, Mg, K and P) in precipitation collected beneath the canopy. In forests of these species Spanish moss is more abundant and has higher mineral concentrations than in pine forests (e.g. P 0.04-0.06% dry wt vs 0.03-0.04%). In growth-chamber experiments the concentrations observed in field precipitation collections (0-200 .mu.g/l). In addition to the availability of minerals, the rate of bark sloughing from host trees and allelopathic effects may also control the local distribution of Spanish moss. Light and moisture appear to be less important factors. Thus, within a favorable climatic range, mineral and bark characteristics of host trees may be used to illustrate a niche hydrovolume for this species.

87. Servdori, M. Dal Monte, C. Zini, Q. 1983. Double Crystal X-Ray Analysis of Phosphorus Precipitation in Supersaturated SI-P Solid Solutions. Phys. Status Solidi A. Vol 80. No 1. p 277-285.

The physical nature of the electrically inactive phosphorus in Silicon is investigated by double crystal X-ray diffraction measurements. This analysis is performed on laser annealed supersaturated samples. Doped by ion implantation up to 5*10/SUP 21/CM/SUP -3/. After isothermal heat treatments, these solid solutions show marked reductions in the electrically active phosphorus concentration. In particular, 850 degree heating give rise to a carrier concentration which corresponds to the phosphorus solubility in equilibrium with the inactive dopant. This dopant is characterized by means of lattice strain measurements. They are found consistent with the presence of perfectly coherent cubic SIP precipitates. This result is in agreement with the one obtained in preceding works by electrical measurements and transmission electron microscopy observations and contradicts the hypothesis that the excess dopant atoms are, at least in part, charged point defects. (E-Centres).

88. Shannon, E.E. 1973. Phosphorus Removal on Secondary Effluents. Phosphorus Removal Design Seminar, Conference Proceedings No. 1 (1973). 16 p.

Phosphorus precipitation by chemical addition to the secondary effluent requires the addition of separate equipment onto the existing facility and reduces the effluent total phosphorus levels in the order of .1 to .5 mg/liter and reduces the BOD to less than 10. Some alternatives for post-precipitation are depicted, with the individual components being flash mixing, flocculation, and clarification, or the three combined in a reactor clarifier, pH adjustment, and filtration. Design aspects of the various stages in post precipitation are discussed. (Sandoski-FIRL)

89. Shannon, E.E. Verghese, K.I. 1976. Utilization of Alumized Red Mud Solids for Phosphorus Removal. Journal Water Pollution Control Federation. Vol 48. No 8. p 194801954.

The feasibility of using alumized red mud solids to precipitate phosphorus from water was investigated. Alumized red mud solids are the product obtained when red mud (a waste material formed during the production of alumina) is slurried with sulfuric acid followed by heat drying and crushing of the resulting solid product. Preliminary pilot plant studies revealed that the use of alumized red mud solids as a coagulant in full scale phosphorus removal facilities is technically feasible. Practical dosage levels required to achieve a 1-milligram/liter total phosphorus level were around 200 milligrams/liter. Full-scale demonstration studies are planned to confirm the pilot plant results. Chemical cost savings on the order of 35% over traditional phosphorus removal systems are anticipated. Raw waste water biochemical oxygen demand and suspended solids removals obtained by the use of the alumized red mud solids at a dose of 200 milligrams/liter were comparable with removals obtained by alum at 200 milligram/liter and superior to those obtained by lime at 250 milligrams/liter. (Kreager-FIRL)

90. Shimek, Roming. Jacobs and Finklea. 1976. Process Design Manual for Phosphorus Removal. EPA-625/1-76-001a. 290 p.

Chemical precipitation techniques were reviewed for the removal of phosphorus and its precipitate from waste water to prevent eutrophication of over-fertilization in receiving waters. The kinetics of phosphorus precipitation by chemical additions were described for the various forms of phosphorus found in waste water. Chemical precipitation of phosphorus before primary settlement was tested with alum, iron, and lime as precipitants. The addition of mineral coagulants to trickling filters, activated sludge plants, and secondary effluents was also studied. Lime was used to precipitate phosphorus removal by chemical precipitation in pilot and full-scale plants were performance, equipment, designs, and costs. Recommendations on the storage techniques and dosing rates and amounts were presented. Methods were evaluated for sludge handling and dewatering. (Lisk-FIRL)

91. Sholkovitz, E.R. Copeland, D. 1982. The Chemistry of Suspended Matter in Esthwaite Water, A Biologically Production Lake with Seasonally Anoxic Hypolimnion. Geochimica et Cosmochimica Acta. Vol 46. No 3. p 393-410.

A study of ten water column profiles is Esthwaite Water (England's Lake District) between April and November 1979 revealed that particle chemistry in this highly productive lake is controlled by three bigeochemical cycles. A large excess of particulate P,S, Mg, Ca, Ba, and K is generated in situ in the epilimnion by growth of phytoplankton in spring and summer. Concentration variations follow that of particulate organic carbon. This particulate buildup is a result of oxidative precipitation of ferric oxide, which causes adsorption and/or coprecipitation with the Mg, Ca, and other elements. The formation of ferric oxide is, in turn, a result of the dissolved ferrous iron released as the hypolimnion becomes anoxic. The onset of anoxic conditions in the hypolimnion also induces an increase in bacterial populations in the bottom water. As reducing conditions become more intense after July, the iron oxide particles with the associated particulate Mg, Ca, etc., solubilize. Just before the lake overturns, large populations of bacteria and the formation of FeS particles concentration of excess particulate carbon, S, P, Mg, K, and Ca. The results of this study point out the importance of understanding the biogeochemical cycles in designing sampling schedules for monitoring a lake's natural or man-modified chemistry. (Cassar-FRC)

92. Shulka, V.S. Rowe, DM. 1981. Precipitation of Boron from Silicon-Germanium Alloy and its Effects in the Thermoelectric Transport Properties. Phys. Status Solidi A. Vol 66. No 1. p 243-248.

The time dependences of the carrier concentration, electrical resistivity and Seebeck coefficient of boron doped SI/Sub 63.5/GE/Sub 36.5/ alloy are investigated at heat treatment temperatures of 1000,1110, and 1200K for periods of up to 2000 h. The carrier concentration decreases with time of heat treatment due to the precipitation of dopant and this is reflected in an increase in the electrical resistivity and Seebeck coefficient. Good agreement is obtained between the Lifshitz-Slyozov precipitation model and

The experimental data. The activation energies of phosphorus and boron in the alloy are estimated to be =30 KCAL/MOL and =56 KCAL/MOL, respectively. It is concluded that although the diffusion coefficient of boron in silicon-germanium alloys over the temperature range of device operation is substantially lower than that of phosphorus, precipitation of boron does occur as a function of time. The rate of precipitation maximises in the temperature range 1000 to 1200K and is sufficiently fast to significantly affect the transport properties of the material and hense the thermo-electric conversion efficiency of a device, based upon silicon-germanium technology during its period of operation.

93. Smeltzer, E. Swain, E.B. 1984. Answering Lake Management Questions with Paleolimnology. Proc Annu Conf Int Symp N Am Lake Manage Soc 4 (0). 1985. p 268-274/

94. Sonzogni, W.C. Uttormark, P.C. Lee, G.F. 1976. A Phosphorus Residence Time Model Theory and Application. Water Res. Vol 10. No 5. p 429-435.

The theoretical basis for the chemical residence time model as it applies to P is considered. The limits, capabilities and applications of the model are discussed. The P residence time model is potentially useful for assessing a variety of lake rehabilitation procedures. Effects of improved waste water treatment may be simulated by reducing the influx concentrations, ci; the impact of diversion projects can be estimated by altering ci and Q (volumetric rate); in-lake schemes such as alum treatment, artificial destratification or hypolimnetic aeration may be assessed by modifying K (internal loss rate constant). As attempts at lake renewal increase and more is learned about the P balance in lakes, the model will become more refined. The P residence time model described, although crude, provides a simple, easily used and generally realistic basis for predicting the results and rate of many lake renewal endeavors.

95. Soon, Y.K. Bates, T.N. Moyer, J.R. 1978. Land Application of Chemically treated Sewage Sludge - 2. Effects on Plant and Soil Phosphorus, Potassium, Calcium, and Magnesium and Soil pH. Journal of Environmental Quality. Vol 7. No 2. p 269-273.

Anaerobically digested sewage sludge resulting from treatment of sewage with Ca(OH)//2, Al//2(SO//4)//3, or FeCl//3 for phosphorus precipitation were applied at rates supplying up to 1,600 kg N/ha each eary to corn and bromegrass. Treatments with NH//4NO//3 supplying up to 400 kg N/ha were included. Soil pH was increased by Ca-sludge and reduced slightly by Fe-sludge application. Phosphorus and magnesium concentrations in corn grain and stover were unaffected by treatment. Phosphorus concentration in bromegrass, and NaHCO//3-soluble soil P, were increased by Ca-sludge and, to a lesser extent, by Fe-sludge additions. The Ca-sludge treatments resulted in a lower K concentration in corn stover and seedlings than either Al-or Fe-sludge treatments. Increasing sludge or NH//4NO//3 application reduced K concentration in bromegrass. Sludge application has no effect on Ca concentration in corn grain or stover from Conestoga loam and Caledon loamy sand, but increased it in corn seedlings and stover from Oneida clay loam. Calcium in bromegrass was increased by sludge treatment with the Ca-sludge having the greatest effect.

96. Stalzer, W. 1981. Phosphorus Removal in the Drainage Area of the Neusiedler Lake. Europaeisches Abwasser- und Abfallsymposium EAS 5th. Publ by Gesellschaft zur Foerderung Der Abwassertechnik, St. Augustine, Ger p 503-520. 1981.

97. Steniberg, C. Niesslbeck, P. 1981. Bacterioplankton Affected by Phosphorus Precipitation Treatment in a Polytrophic Lake. Zeitschrift fur Wasser und Abwasser Forshung. Vol 14. No 2. p 43-46.

The bacterioplankton population of the Fischkaltersee, a lake in Upper Bavaria (Federal Republic of Germany) was monitored to assess the effects of artificial phosphorus precipitation using aluminum chloride. Direct counts of the bacterioplankton, selected plate counts, bacterichlorophyll a readings, and CO2-dark uptake measurements were taken. After precipitation treatment, bacterial densities (direct count) decreased from 9.5 x 109 to 5.5 x 109 bacteria per sq cm. This partial breakdown of population did not exceed levels measured after a natural breakdown 4 months previously. One week after aluminum input, bacterial density and returned to its former level, and this was accompanied by a recovery of phytoplankton. Biological transport of phosphorus by the predominant alga, Oscillatoria redekei, was assumed to be the cause of rapid phosphorus replenishment in the productive layers. Changes found in saprophytic bacteria supported these results. Plotting direct counts against the sum of plate counts (Razumov quotient) resulted in great variations, and the slight shift toward plate count bacteria after aluminum treatment did not exceed the natural range. Biocenosis structure proved to be stable. Aluminum treatment decreased the bacterial biomass from 13 to 10 micrograms per liter. Microbial activity represented by CO2-dark fixation exhibited damage after treatment, declining greatly. The reduction may have been due partly to coprecipitation of microbial substrates with aluminum, though the reduction did not parallel readings for dissolved organics. Low winter temperatures at the time of treatment may also have played a role. (Gish-FRC)

98. Sutton, P.M. Murphy, K.L. Jank, B.E. Managhan, B.A. 1977. Reliability of Nitrification Systems with Integrated Phosphorus Precipitation. Canada-Ontario Agreement on Great Lakes Water Quality, Research Report. No 64. 115p.

The desire to produce high quality effluents for municipal wastewater treatment plants has led to increasingly strigent limitations on the discharge of phosphorus and ammonia-nitrogen. The addition of iron or aluminum salts to a nitrifying activated sludge plant represents an economical method for phosphorus and nitrogen control. In this study, the effects of metal ion addition on nitrification were assessed by parallel operation of combined and separate sludge carbon removal nitrification systems with and without chemical addition for phosphorus removal. Paired data analyses indicated little or no effect on filterable total Kjeldahl nitrogen (TKN) removal and nitrate production. Significant increases in alkalinity consumption and sludge production due to addition of Ae (+3) and Al (+3) were observed, and the results were compared to theoretical values. The capacity of nitrifying activated sludge system to meet effluent variability criteria was determined by parallel operation of combined sludge systems under various flow conditions at temperatures down to 5 degrees C with and without chemical addition for P removal. The solids retention time required to produce a consistently low effluent filterable

TKN concentration will be affected by the magnitude and variability of the influent filterable TKN loading under steady or variable flow conditions. The results indicate that combined sludge systems designed to operate at high solids retention times can produce an effluent filterable TKN concentration of less than 2.5 mg per l 90 percent of the time at wastewater temperatures as low as 5 degrees C. (WATDOC)

99. Sutton, P.M. Murphy, K.L. Jank, B.E. 1978. Nitrification Systems with Integrated Phosphorus Precipitation. Water and Pollution Control. Vol 116. No 4. p 27-33.

Design criteria for nitrifying activated sludge systems with integrated phosphorus precipitation were developed in pilot studies with combined and separate systems. The pilot plants included a two-stage separate sludge system with two 480 Imperial gal aeration tanks and a two-stage combined sludge system having by-passable intermediate clarification and two aeration tanks. The latter unit operated as a separate sludge system when the clarifier returned sludge to the initial aeration tank. Alum or ferric chloride were added to the separate and combined systems in a precipitant:influent phosphorus ratio of 1.0-2.0 with a dissolved oxygen concentration maintained at or above 2.0 mg/liter. Biological equilibrium was maintained with a solids retention time of 8-10 days. The effect of chemical addition at 15 mg/liter on nitrification was insignificant as measured by the amount of filterable total Kjeldahl nitrogen (TKN) in both systems. Both systems generated comparable quantities on nitrate. The geometric mean value of total filterable phosphorus in the precipitant-treated effluent from both plants was 0.35 mg/liter compared to 2.1 mg/liter in the untreated system. Alkalinity consumption as CaCO3 was 8.0 g/g filterable TKN in the chemically-treated system and 6.0 g/g filterable TKN in the system without chemical precipitation. An additional 1.23 kg of solids was generated in the chemically treated systems. The nitrification rate in the combined and separate sludge systems was determined to be a function of temperature. (Lisk-FIRL)

100. Tsai, K.C. 1977. Aerobic Digestion of Sewage Lime Sludge. University Microfilms International, Ann Arbor, Michigan 48106; Order No 77-23,686. PhD Thesis, 1977. 263 p.

Laboratory studies were conducted to establish design and operational criteria for aerobic digestion of lime sewage sludge generated during phosphorus precipitation in a primary clarifier. Batch and semi-continuous flow reactors were operated at temperatures of 10, 20, and 30C. Parameters used in the evaluation of optimal process design and control included: detention time, oxygen uptake rate, volatile suspended solids destruction, liquid sludge COD reduction, supernatant COD and phosphorus contents, sludge settleability and dewaterability, and potential phosphorus release. The studies indicated that lime sludges having an initial pH as high as 11.0 are aerobically digestible in the presence of appropriate micro-organisms. An optimal sludge retention time of 10 days and an air flow of 60 scfm/1000 cu ft of digester volume were suggested for a semi continuous flow unit operating at 20C. A dissolved oxygen concentration of 1-2 mg/liter and a pH above 7.0 are recommended to minimize potential phosphorus release from the sludge to the liquid phase. The sludge was easily settled and dewaterability was improved significantly by digestion. (Schulz-FIRL)

101. Uttormark, P.D. Chapin, J.D. Green, K.M. 1974. Estimating Nutrient Loadings of Lakes from Non-Point Sources. EPA-660/3-74-020. 112 p.

Data describing nutrient contributions from non-point sources were compiled from the literature, converted to KG/HA/YR, and tabulated in a format convenient for estimating nutrient loadings of lakes, contributing areas are subdivided according to general use categories, including agricultural, urban, forested, and wetland. Data describing nutrient transport by groundwater seepage and bulk precipitation are given along with data for nutrient contributions from manure handling, septic tanks, and agricultural fertilizers. Nutrient content of urban runoff was the highest; forested areas were lowest. Nutrient export data for agricultural lands were tabulated as seepage through vertical soil profile, overland runoff, and transport by streams draining agricultural watersheds. The latter group was judged to be most applicable for estimating nutrient loading of lakes. Marshes appear to temporarily store phosphorus and nitrogen during the growing season and release them at a later time; net nutrient runoff is estimated to be near zero. Nutrient contributions to lakes from groundwater seepage require site-specific information for assessment. Phosphorus and nitrogen transport by groundwater can be significant. Atmospheric contributions of nitrogen are large in some area. The technique of estimating nutrient loadings of lakes requires considerable judgement in selecting runoff coefficients; however, the approach provides insight into potential management options.

102. Valiela, I. Teal, J.M. Volkmann, S. Shafer, D. Carpenter, E.J. 1978. Nutrient and Particulate Fluxes in a Salt Marsh Ecosystem: Tidal Exchanges and Inputs by Precipitation and Groundwater. Limnology and Oceanography. Vol 23. No 4. p 798-812.

Waterborne nutrients enter Great Sippewissett Marsh in Massachusetts through groundwater, rain, and tidal flooding. The ebb of tidal water removes nutrients. During summer, uptake by marsh biota leads to net import of nutrients. The increased export of ammonium in August may be due to leaching from senescent marsh plants. There is a net annual export of ammonium, nitrate, nitrite, dissolved organic (DON) and particulate (PN) nitrogen, particulate carbon (PC), and phosphate. Ammonium, DON, and PN are the major forms of nitrogen exported. Nutrient concentrations in coastal and marsh water are correlated, and marsh exports could contribute substantially to nutrient supplies of coastal waters. Groundwater entering the marsh provides primarily NO3-N and DON. Nutrient inputs through precipitation consist primarily of DON, NO3-N, and HN4-N. Groundwater carries over 20 times the amount of nutrients brought in by rain; therefore, nitrogen inputs from this source are important to the nitrogen economy of a salt marsh. About half the dissolved inorganic nitrogen brought into the marsh by groundwater is converted to and exported as PN, a form suitable for consumers. PC exported to coastal water is equivalent to 40% of the net annual production of Spartina alterniflora, the dominant marsh plant. (Howard-Mass)

103. Van Riemsdijk, W.H. Van Der Linden, A.M.A. 1984. Phosphate Sorption by Soils 2. Sorpiton Measurement Technique. Soil Sci Soc Am J. Vol 48. No 3. p 541-544.

A computer-controlled apparatus was developed for measurement of P sorption by soils. A solution containing P is constantly pumped from a vessel through a soil column and back to the vessel again. P concentration in the vessel can be assessed and regulated; constant, increasing and decreasing concentration is optional. The method of pumping solution through a column is convenient for relatively slow reactions and for reactions in which a high soil/solution ratio is required. When a high pumping rate is used, the results are comparable with classical batch experiments. The proposed method, however, has many advantages, e.g., avoiding mechanical disturbance of the soil particles and separating solids from solution. Eight soil samples can be examined at 1 time. This makes the apparatus suitable for routine as well as research experiments. The analytical part of the apparatus can easily be replaced; other ions of interest (K+, Mg2+, trace elements) can then be studied in the same way.

104. Viets, F.G. 1975. The Environmental Impact of Fertilizers. CRC Critical Reviews in Environmental Control. Vol 5. No 4. P 423-453.

Fertilizers are one source of nitrogen and phosphorus that can degrade surface water quality and increase nitrate in groundwater, but sewage disposal is probably the most important degrader. Natural forests and grasslands can conserve these nutrients, thus loss in runoffs and percolates is less than the amount received from precipitation and dry fallout. The negative environmental impact of phosphorus and nitrogen began when forests and grasslands were destroyed for agriculture. Agriculture causes soil erosion, sedimentation, and transport of phosphorus and ntirogen to water. Loss of soil organic nitrogen and partial conversion to nitrate due to break up of grassland was a major factor in nitrate accumulation in ground waters. Commercial fertilizers are used due to soil removal, consumption of animal products, and improvement of crop varieties, pest control, and yields. However, fertilizer use has permitted production of crops on a minimum of land, thus reducing erosion hazards, irrigation requirements, energy, pesticides, etc. in the future, emphasis will be placed on the efficient use of fertilizers to make every acre produce to near its potential. The negative and positive uses of fertilizers are discussed in detail. (Buchanan-Davidson-Wisconsin)

105. Water and Sewage Works. 1978. Hot Springs Gets Regional Tertiary Treatment Plant. Water & Sewage Works. Vol 125. No 5. p 92.

Upgrading of the sewerage and trickling filter waste water treatment plant in Hot Springs, Arkansas, included the construction of a $14.7 million tertiary treatment plant, new interceptors and force mains costing a total of $3.8 million, and three pumping plants costing $1.6 million. An additional 15,000 acres will also be sewered. The modular 12 mgd tertiary treatment plant, with a peak capacity of 30 mgd, provides primary aeration and settling, as well as degritting, coarse bar screening, and automatic primary sludge removal. The activated sludge system is aerated with high purity oxygen and mixed with three mechanical mixers; detention time is 1.33 hrs with a recycle rate of 30%. Gravity thickened primary sludge is mixed with wastes activated sludge which has been thickened with polymers in a dissolved air flotation tank. The mixed sludge is heated to 350F in a wet air oxidation tank for 15 min at 500 psi; the sludge is stored and supernatant is decanted. Two coil filters dewatered the sludge to a cake suitable as a soil amendment. The activated sludge liquor is treated with alum and polymer for phosphorus precipitation and filtered through a 49 inch mixed media filter, prior to chlorination and discharge. Filter backwash water, which is also used for chlorination, was down, pump seal, and fire extinguishing, is passed to the clarifiers after use. Screening, degritting, primary sludge removal, phosphate precipitation, and filter backwashing are computer-controlled.(Lisk-FIRL)

106. Welch, E.B. Michaud, J.P. Perkins, M.A. 1982. Alum Control of Internal Phosphorus Loading in a Shallow Lake. Water Resources Bulletin. Vol 18. No 6. p 929-936.

Alum was applied at 5.5 mg per liter in September 1980 to eutrophic Long Lake, Washington (2 m mean depth, 137 ha area) to control internal phosphorus loading. Mean summer total P and chlorophyll a decreased from 76 and 27 micrograms per liter, respectively, in 1978 before treatment to 29 and 14 micrograms per liter. Mean summer Secchi transparencies increased from 1.6 to 2.2 m. After treatment cryptomonads, diatoms, and green algae became relatively more abundant at the expense of blue-green algae. Macrophyte biomass, reduced by 84% after a 4 month drawdown in 1979, returned to the previous levels within a year after alum treatment. It is not known whether decomposition of macrophytes during the winter of 1982 will increase the P loading in the following summer. If this loading does not occur, it can be assumed that the aluminum hydroxide floc was an effective control of P. The increased transparency may encourage proliferation of macrophytes, with negative impacts in recreational use and relapse of P during decomposition. Long-term improvements may be produced by harvesting the macrophytes each season or by removing the top half meter of the sediment layer. (Cassar-FRC)

107. Weyrauch, Wolfram. 1980. Deliberate Modification of the Sedimentation Behavior of Precipitated Sludges Resulting from Phosphorus Precipitation after Biological Treatment. Gas und Wasserfach, Wasser Abwasser. Vol 121. No 7. p 326-330.

Operating parameters, operating results and their relations were examined by observing the functioning of a semicommercial treatment plant with biological phase and subsequent precipitation of phosphates. Characteristic data could then be worked out, with the aid of which it is possible to control by simple means, in the inlet channel leading to the precipitation phase, the operating result not only of the precipitation but also of the degree of sedimentation of precipitation sludge. In addition, an operating monogram for precipitation with aluminum sulfate after biological treatment is presented in such a way that it is then very easy to perfect an elimination-oriented and also sludge-oriented operating process.

108. Willen, E. 1976. Phytoplankton and Environmental Factors in Lake Hjalmaren. NLU Rappört 87, 1976. 89 p.

Phytoplankton species composition and diversity, biomass, and production were studied in Lake Hjalmaren, Sweden's fourth largest lake, during 1966-73. Water chemistry, bacteria, macrophytes, attached algae, phytoplankton (including chlorophyll a) primary production, zooplankton, benthic fauna, and fisheries were investigated in the shallow, eutrophic lake which as a mean depth of 6 m, greatest depth of 20 m, length of 60 km, width of 20 km, and a drainage area of 4,000 sq km. Four main basins comprise the lake - Hemfjarden, Mellanfjarden, Storhjalmaren, and Ostra Hjalmaren - separated by islands and narrow sounds. Oxygen supply is good, due to constant water circulation. Nutrient concentrations decrease from west to east, with highest concentrations near Orebro. Total nitrogen range is 0.62-2.17 mg/l, total phosphorus 0.03-0.26 mg/l, nitrogen loading 4.1-30.0 g/sq m/yr, and phosphorus loading 0.2-3.0 g/sq m/yr. A total of 330 species of phytoplankton were found, dominated by blue-green algae, diatoms, and green algae. Species diversity in Hemfjarden was much higher (4.13) than in Storhjalmaren (2.34), although the former is the more highly polluted; constantly circulating water provides a steady nutrient supply and prevents blue-green algae shading. Phosphorus precipitation begun in 1975 at the Orebro sewage treatment plant is expected to decrease phytoplankton biomass and limit algal blooms in the western basins. (Lynch-Wisconsin)

109. Willen, E. 1981. Water Bloom. Sven Bot Tidskr. Vol 75. No 6. p 345-355.

A variety of problems in connection with algal waterblooms are discussed with emphasis on those caused by dinoflagellates, diatoms and blue-green algae. Extreme mass-development of algae within these groups are mainly caused by pollution. Buoyancy, luxury consumption of nutrients and capability of N fixation are factors making blue-green algae capable of surviving during extraordinary conditions. Different treatments in order to get rid of the blooms in inland waters are discussed. For more durable effects P precipitation in the sewage treatment plants or sewage diversion is recommended. Sometimes combined with removal of the top sediment layer.

110. Willen, E. Ericsson, P. Hajdu, S. 1984. The Water Quality of Goervaeln, a Dynamic Bay of Lake Maelaren. Water Chemistry and Phytoplankton in a Perspective of Forty Years. Vatten Water. Vol 40. No 2. p 193-211.

The Bay of Goervaeln in Lake Maelaren has a complicated hydrodynamic pattern with a mixture of nutrient-rich water coming from north and water of mesotrophic character coming from south. Investigations of the water-chemistry have been performed since 1942 and of phytoplankton since 1955 and more regularly since 1965. The variation between different years is mainly controlled by the water discharge. A phosphorus precipitation measure in the sewage treatment plants in the 1970's reflects in less phosphorus concentrations in the water. The phytoplankton composition has altered although the total biomasses are only slightly diminished.

111. Wuhrmann, K. 1964. Nitrogen Removal in Sewage Treatment Process. Verh Int Ver Limnol. Vol 15. p 580-596.

Nitrogenous compounds derived from sewage probably play a significant role in eutrophication and nitrate-enrichment of groundwaters, although detailed knowledge of their involvement is still forthcoming. Author has reviewed nitrogen removal by conventional treatment processes. Land disposal, pond treatment, and biological oxidation, in trickling filters or with activated sludge, remove not more than 50% of total nitrogen from waste water, percentages ineffective in preventing enrighment of receiving waters. Over 90% removal has been achieved with physico-chemical processes of ion exchange and ammonia stripping at high pH, methods which are presently uneconomical. Microbial denitrification may be a practical technique of nitrogen elimination. Already occurring during conventional biological treatment, denitrification can be optimized to achieve 90% elimination from sewage. Author describes technical scale experiments which easily achieved highly reliable denitrification. In the experiments, final effluents after treatment of domestic sewage (total nitrogen after preliminary sedimentation, 25-30 ppm) contained 2-4 ppm. Attainment of complete anaerobiosis during an extra detention step was essential for such removal. Subsequent phosphorus precipitation yielded effluent with 1-2 ppm total nitrogen. Report contains record of brief floor discussions relative to phosphate removal, characteristics of denitrifying flora, sulfate reduction, and nitrogen fixation by cyanophytes.