mated length of certain forage species of fish a spotted bass can swallow were computed. These estimates are summarized in Table 1.

TABLE 1.

ESTIMATED LENGTH OF VARIOUS FORAGE FISH SPOTTED BASS CAN SWALLOW.

Spotted bass		*Total length of forage fish in inches*				
Total length inches	*Mouth width mm*	*Bluegill*	*Green sunfish*	*Golden shiner*	*Gizzard shad*	*Threadfin shad*
4.5	11.84	1.87	1.71	2.53	2.20	2.09
5.5	14.98	2.16	2.04	3.01	2.62	2.54
6.5	17.99	2.44	2.36	3.47	3.03	2.97
7.5	21.01	2.73	2.68	3.94	3.43	3.40
8.5	22.15	2.84	2.80	4.11	3.59	3.56
9.5	24.26	3.04	3.03	4.43	3.87	3.87
10.5	26.46	3.25	3.26	4.77	4.16	4.18
11.5	28.58	3.44	3.48	5.09	4.44	4.48
12.5	34.30	3.98	4.09	5.97	5.21	5.30
13.5	39.45	4.47	4.63	6.76	5.91	6.03

RESULTS OF A SIX YEAR INVESTIGATION OF CHEMICAL SOIL AND WATER ANALYSIS AND LIME TREATMENT IN GEORGIA FISH PONDS

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ABSTRACT

In some Georgia farm ponds a satisfactory phytoplankton growth is not produced following the application of normal amounts of fertilizer. Chemical investigations indicated a slightly acid condition and a low total hardness in these problem ponds. This condition was corrected by the addition of one ton per acre of agricultural lime or with varying amounts of hydrated lime added periodically.

Phytoplankton production was definitely improved in over 100 Georgia farm ponds after the addition of lime. The average total hardness increase in these ponds, using agricultural lime at the rate of one ton per acre, was 15 ppm. Results lasted from 2-4 years. Hydrogen ion alone is not a satisfactory measure of the need for lime. Total hardness of the water was found to be the best and most reliable measure for lime supplements.

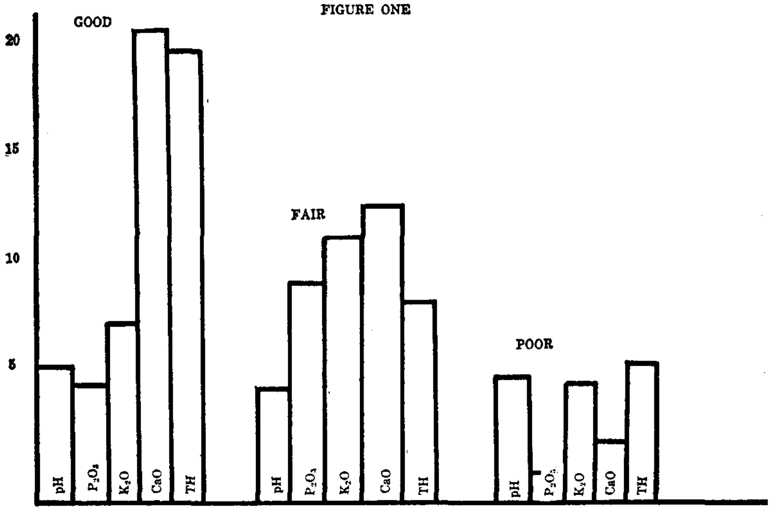
For optimum fertilization results, the total hardness range should be 20 ppm or above. From 10-20 ppm results were varied, and below 10 ppm fertilization results were unsatisfactory.

Ponds with a calcium oxide content in the bottom soils of 1500 lbs. per acre or above produced good fertilization results. With calcium oxide in the range of 1000-1500 lbs. per acre, results were varied, and below 1000 lbs. per acre of calcium oxide, fertilization results were invariably poor.

INTRODUCTION

In Georgia a satisfactory phytoplankton growth cannot be produced in some farm ponds with the amount of fertilizer as recommended by Swingle and Smith (1947). The normal pond fertilizer requirement is 6-12 applications per year of 8-8-2 or its equivalent. This varies with the section of the state, soil series, construction of the pond, and other related factors. In some ponds 4 to 6 applications of fertilizer at one bag per acre, produces a good phytoplankton growth. In others, amounts up to one ton per acre would not produce a significant amount of plankton. Figure one graphically shows nutrient concentrations in regard to fertilization results. Upon investigation it was immediately determined that ponds with reduced phytoplankton growth were slightly acid and

FIGURE ONE



Total hardness and pH absolute units
K_20 and P_20_5 Units of 10
Ca0 units of 100

Total hardness expressed as parts per million water. All oth er measurements are ponds per acre of bottom soil.

low in total hardness. This condition was corrected by the addition of various types of lime.

Although this report deals only with phytoplankton production and its correlation with water hardness and calcium oxide concentrations in bottom soils; the relationship between phytoplankton density and fish production is generally acknowledged by fishery workers.

METHODS

The Diehl, Goetz and Hatch Ethylenediamine tetra-acetic acid method was used for measuring the total water hardness. A 200 ml. water sample is desirable using this method since amounts of hardness detected were low. Most of the total hardness found was in the form of calcium carbonate. The Taylor slide comparator and standard indicators were used for measurement of Hydrogen ion.

In some ponds a pH as low as 4 has been measured and is considered a significant measure when it is this low. When the pH is in the range of approximately 6.5 to 9.5 it cannot be considered a significant measure of actual conditions in farm ponds in Georgia. The correlation between the pH and lime content has too wide a variation to be practical in liming and fertilization investigations.

Swingle reported, "The pH of a soft water may be 6.5 at daybreak and 9.5 in the later afternoon if the sun is shining and a heavy growth of plankton or underwater weeds has removed most of the available CO_2. Thus a pH of 9.5 may indicate alkali water soft water depending upon conditions which it is measured." During the winter a pond may show a hydrogen ion range of 6-7 which when fertilized in the spring, a good phytoplankton growth develops. This growth, however, may last for only two or three days if sufficient lime is not present.

Approximately 1000 soil samples were collected with an Eckman dredge and analyzed by the Department of Agriculture. At least five samples were usually collected from each pond. These samples were not mixed, but the results were averaged. Bags designed specifically for soil samples were used, since others had an alkaline base glue which would change the results, especially the pH.

Agricultural limestones, both $CaCO_3$ and $CaCO_3/MgCO_3$, were used extensively at rates of 1000-2000 pounds per acre. A limited number of ponds were treated with hydrated or slaked lime (calcium hydroxide). This form is much more water soluable than the agricultural limes and becomes available almost immediately. Preliminary observations indicate amounts as low as 100 pounds per acre of hydrated lime will supply sufficient calcium for one fertilization season.

A good phytoplankton growth referred to in this report is when a white object cannot be seen 18" under the water. Fair is when an object can be seen at this depth but some phytoplankton is apparent. Poor is when no significant amount of phytoplankton is produced after fertilization. All ponds used in this investigation were fertilized.

APPLICATION AND RESULTS

Lime can be added to a pond at any time after its need is determined. Winter applications are desirable, since some reaction will occur prior to fertilization in the spring. Good distribution of lime in the pond results in a faster and more complete reaction. Usually in about two weeks after an application of agricultural lime in the warm seasons of the year, an increase in plankton growth is apparent. It is generally two to three months and often one year before full benefits from lime treatment are realized. During this time, an increase in total hardness is noted. The time lapse for full results with agricultural limestones is attributed to its low soluability in water. If agricultural limestone is added after stratification, the full benefit may not be realized until after overturn of the water following application. Overturn often occurs in midsummer due to heavy winds and rains in some ponds in Georgia. When using hydrated limestone, a significant change in phytoplankton growth and chemical composition is noted within one week or less. The reaction is probably the same as any other fertilizer element added to water.

Ponds that produced poor phytoplankton growth with fertilization, often respond with good plankton blooms after lime treatment, without subsequent fertilization. This indicates nutrients previously added were chemically bound and rendered unusable due to acid conditions. Neutralization with lime makes these elements available to algae production.

In some ponds the results from the addition of lime was in evidence for only 2-3 months. The short duration of results in these ponds is attributed to the limestone being leeched out or becoming insoluable in the pond bottom.

In other situations results from lime treatment have been in evidence for as long as four years after initial application through maintenance of satisfactory phytoplankton growth following fertilization and increases in the amount of calcium in pond water and bottom soils. These ponds maintained a total hardness of 15 ppm or above, whereas prior to the lime application the total water hardness was significantly below 15 ppm.

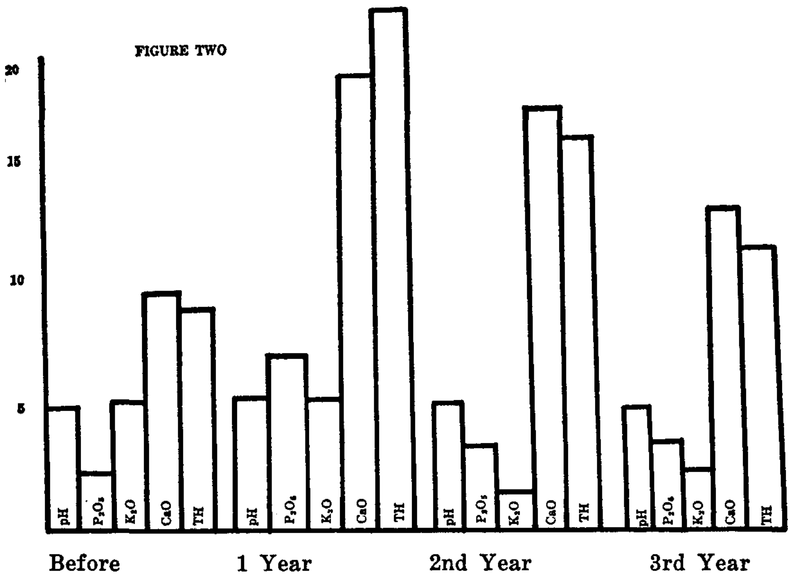
BOTTOM SOILS

It is generally acknowledged that pond bottom soils and the watershed definitely contribute to the success or failure of fertilization of ponds. Swingle states, "Production in acid waters, from pH 3.0 to 6.5 may be improved by liming the water, high production, however, can only be achieved by also liming acid bottom soils". Use of hydrated lime in bottom soil treatment is generally prohibitive, since amounts necessary to correct bottom soils would kill fish by raising the ph of pond water past alkaline death point.

The pH of bottom soils has been raised and the CaO content increased using 1000-2000 pounds per acre of agricultural limestone, see figure two.

A heavy loss of nutrients through seepage undoubtedly takes place. Parsons, reporting on seepage losses from ponds in the Piedmont area near Auburn, Alabama, reports a loss of 95.5 inches annually. The central Georgia area where most of these data were collected is geologically similar and comparable losses are expected. This is probably the main source of calcium depletion, since acids do not accumulate in field soils as the results of cultivation, (Hellige, Mannual, 1959) but rather the bases are depleted through leeching which brings on an acid condition. Field soils in Georgia require periodic liming depending upon

FIGURE 2.
AVERAGE RESULTS FROM THE ADDITION OF APPROXIMATELY ONE TON PER ACRE OF AGRICULTURAL LIMESTONE TO GEORGIA FARMS PONDS.



Total hardness in ppm in water, other measurement of the bottom soil and in lbs/A
TH and pH absolute units
K_2O and P_2O_5 in units of 10
CaO in units of 100

compactness, porosity, and run off. More lime is required for clay soils than sandy soils but the amount required for clay soil will last longer than the amount required for sandy soils.

This appears to be also true with regards to lime treatment in ponds. Soil scientists have stated that muck, the composition of most pond bottoms would require as much as three tons per acre of lime applied periodically to keep nutrient conditions at an optimum. Generally the optimum pH or a field crop of 6.5 to 7, since at this pH more nutrients are available than at any other time. Until more information is available it is assumed that the soils of pond bottoms react principally the same as field soils. Limited data is available to substantiate this assumption, since our analysis of pond bottom soils shows that if the pH is below 5, phytoplankton production is poor. Some newly constructed ponds will not produce a phytoplankton growth until lime is added. Other ponds will produce a satisfactory plankton growth after construction, but later require lime. This situation has been noted to occur as long as ten years after construction. Ponds located on the watershed of a pasture or farmland receiving periodic lime application generally have an adequate lime content in the water and soil, since the lime is apparently washed in the pond from the watershed. Ponds most likely to need lime are located on woodland watershed where no agricultural practices are carried out.

The removal of loam soil from the pond bottom to get clay for the core of the dam has been the usual practice in pond construction in the past. We believe this is undesirable because soils in some intermediate range between clay and sand produce most fish food organisms. Topsoil areas should, whenever possible, be left undisturbed in the pond area.

When a soil is limed to raise the pH, enough lime must be added to react not only with the free Hydrogen ion or cations but with those held in an inactive form. As soils are neutralized, ionization of the less active Hydrogen ions or cations is in progress and must also be neutralized before the pH is substantially raised. The active acidity or free ions is the pH that is normally measured. The potential acidity or H-ion held on the soil particles is not normally measured with colorimeter or electrode. Coleman and Mehlich (1957) reported the measure of soil pH is effected by the soil-water ratio, the electrolytic content, and the carbon dioxide level. The difference in carbon dioxide of the water and the air, seasonal fluctuation in salt content due to fertilization, mineralization of organic matter also effect the pH. The dependence of the pH of these factors may cause it to be different when measured in the pond bottom. Soil samples collected usually are kept several weeks before being analyzed because of the necessity of a dry sample for analysis. Chemical changes could occur and probably do at this time. The amount of oxidation, reduction, or fixation is not known due to drying of soil samples, but some changes probably do occur. This is somewhat apparent in the samples analyzed up to date. Although ponds with a measured pH of 4-5 in bottom soils will not generally produce a phytoplankton bloom after fertilization: there has been no consistency in improved results if the pH is somewhat higher. The pH of a soil or water cannot be lower than 3.9 under normal conditions unless there is contamination. The soil pH is probably a very significant measurement if accurate and dependable methods can be worked out.

The high and fast fixation of P_2O_5 makes its use unreliable as a measurement. Potassium oxide levels are not significant in soil samples. Although its need as a plant food is recognized, the quantity needed is probably always available. Potassium in some instances will substitute for bases, but this has not occurred in this investigation. Calcium oxide, the actual lime content of the pond bottom soil, is the most stable nutrient for measurement of the need for corrective treatment. Ponds with CaO in bottom soils at a level of 1500 pounds per acre consistently produce good results. Those with a CaO content of 1000-1500 pounds per acre show varied results, and levels below 1000 pounds per acre CaO give poor fertilization results, see figure four. Too much lime could tie up the P_2O_5 as $Ca_3(PO_4)_2$ but this has not been detected in this investigation, and will not likely occur in any area of Georgia.

LIME TREATMENT RESULTS

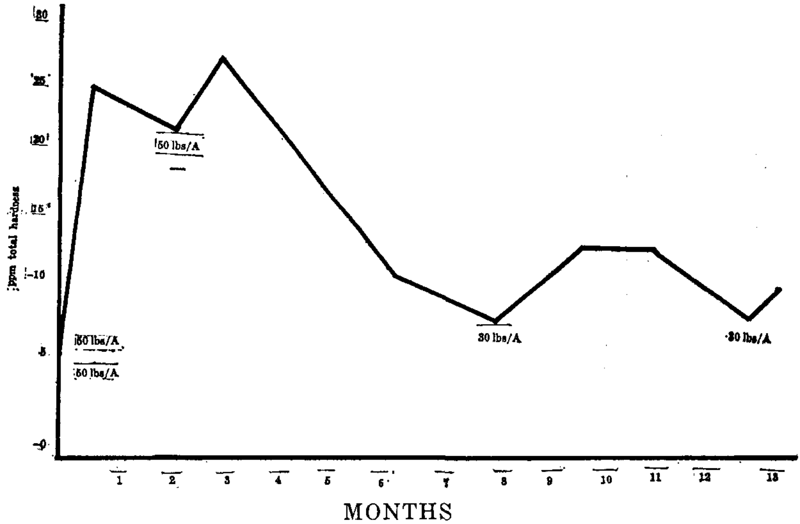
Although many variables are encountered in lime treatment results, certain factors are consistent in all ponds. As a management guideline, we have found that ponds with a total hardness below 15 ppm will respond to lime treatment with more effective utilization of fertilizer and increased production. Full benefits from lime treatment are not immediately realized in water chemistry measurements, nor can amounts needed be fully standardized. Again as a management guideline, we have adopted one ton per acre of agricultural limestone as a standard treatment. Amounts can be increased up to 2-3 ton per acre without danger, however, duration of results is not consistant with increased amounts of lime applied.

Slaked lime ($Ca(OH)_2$) will also effectively increase calcium concentrations and fertilization results will improve, see figure three. Small amounts, and frequent application is necessary however. The advantage with slaked lime lies in much improved solubility.

The following problem ponds have been treated for low phytoplankton production and results followed closely for several years:

Barnes pond: This pond was constructed during 1954 and immediate results were obtained through the fertilization seasons with the average addition of 10 applications of 8-8-2. The total hardness when checked was found to be approximately 10 ppm. During the fall of 1958, 2000 lbs/A of agricultural limestone was added to the pond. Within one month the total hardness was raised from 10 ppm to 30 ppm and has remained at this level up to July 1, 1961. An excellent plankton growth was produced during 1959 with eight applications of fertilizer. The plankton growth remained good from August of 1959 until December 1960, a period of 16 months, without further addition of fertilizer. Only four applications of fertilizer were required during 1961. Apparently the previously added fertilizer was tied up in the bottom soil, and subsequently released with addition of lime. The full benefit from lime treatment was not realized for almost one year. Soil samples were taken

Figure 3. The results of the addition of Limestone, $Ca(OH)_2$, to Jones' Pond



before and after the lime was added. The only significant change was in the CaO content which was raised from 200 pounds per acre to 2000 pounds per acre.

McKenney pond: This pond has been treated with lime and results observed for six years. Previous treatment with one ton per acre of agricultural lime would give satisfactory results for approximately two years. During 1960, 1000 pounds per acre of Calcium hydroxide was applied at scattered intervals along with 20 applications of fertilizer. A good phytoplankton growth was maintained throughout the 1960 fertilization season. This high amount of fertilizer had been added previously to the pond and fertilization results were unsatisfactory when the total hardness was significantly below 15 ppm. When the total hardness was 15 ppm or above, a satisfactory plankton growth was produced with fertilization.

Theus Pond: This pond did not support a good plankton growth from fertilization until treated with lime. Five hundred pounds per acre of hydrated lime was added periodically with approximately 20 applications of fertilizer. This produced good plankton growth as long as lime was added each time with the fertilizer. The owner failed to add lime with the fertilizer for three applications and a phytoplankton growth did not develop. Upon resuming addition of lime, a satisfactory phytoplankton growth was maintained. During this period, total hardness did not reach 15 ppm but, apparently calcium was always available for plant growth. The treatment with hydrated lime produced an increase in total hardness in some instances within two days and an increase in phytoplankton growth in less than one week.

Klepenski pond: On August 12, 1959 this pond had a total hardness of 10 ppm and the water was turbid. At this time 200 pounds per acre of hydrated lime was added. Two days later the total hardness had increased to 28 ppm. The highest total hardness measured was 34 ppm five days later. The pond cleared up immediately after the addition of hydrated lime and without further addition of fertilizer, developed a good phytoplankton growth. The pond had received seven applications of fertilizer prior to the addition of lime without any appreciable phytoplankton growth. On July 15, 1960, approximately one year later, the total hardness had decreased to 11 ppm and poor results were produced with fertilization. The addition of 50 pounds per acre of hydrated lime at this time stimulated a good phytoplankton growth and the total hardness increased to 20 ppm in five days.

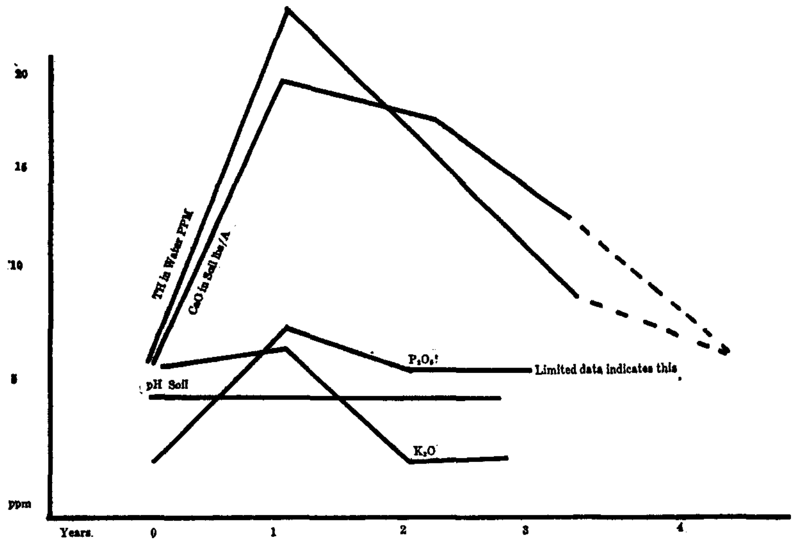
FIGURE 4.

THE RELATIONSHIP OF PHYTOPLANKTON PRODUCTION, PH, TOTAL HARDNESS, AND CALCIUM OXIDE IN GEORGIA PONDS.

0 CAO-Lbs/A[1] 1000		1500
POOR: Production low. No growth from fertilizer. PH usually below 6.5. Often no reproduction. Treat with 100 lbs/A of hydrated lime or one ton per acre of agricultural limestone.	Fair: Production ranges from poor to good. Results from fertilization do not last. PH ranges from 6-10. Treat with 100 lbs/A of hydrated lime or one ton per acre of agricultural limestone.	Good: Production good, generally less than average amount of fertilizer required. PH ranges 6 to 10. Limestone not needed.
O TH-ppm[2] 10		20

[1] CaO—lbs/A is pounds per acre of calcium oxide in bottom soil.
[2] TH—ppm is total hardness of water.

Figure 5. The average results of adding one ton per acre of Calcium Carbonate to Georgia farm ponds.



Total Hardness and pH
Absolute units
K_2O and P_2O_5 in units of 10
CaO in units of 100

The danger exists of killing fish using excess quantities of hydrated lime. The alkaline death point is generally accepted as being approximately at pH of 11 or less for pond fishes. Since hydrated lime is highly soluable, the alkaline extreme could be reached rapidly. Agricultural lime was found to raise the pH to approximately 8.4. The potential acidity or the H-ion exchange capacity of the water and soil would determine the amount of lime and type of lime that is necessary or could be used to best advantage without detrimental effects.

DISCUSSION

Treatment with lime is essential in ponds with minimum calcium levels for full fertilizer utilization. Results will not be apparent above these minimum levels. Frequency of application depends upon construction, watershed, overflow, leeching through the pond bottom, and soil type of the pond in question.

Ponds with a timber watershed required lime most often in this investigation. When lime was regularly applied to the water-shed as an agricultural practice, pond treatment was rarely needed. When the total hardness and pH of the water is low the bottom soil pH and available minerals are also low. Ponds maintaining a total hardness of 20 ppm or above have consistently produced a satisfactory plankton growth, while those with a total hardness of 10-20 ppm will usually vary in fertilization results from good to poor. A pond with a total hardness of 10 ppm or less will invariably fail to produce satisfactory phytoplankton growth.

When fertilizer has been added without satisfactory results, the addition of lime will often stimulate a phytoplankton growth without further addition of fertilizer. Neutralization releases bound nutrients and they become available for plant growth.

The frequency of application of lime varies from pond to pond. Experimental treatments indicate that agricultural limestone is needed every 2-4 years or hydrated lime at least annually, see figure five. There are no indications that total hardness in excess of 20 ppm is beneficial for plankton growth. The maximum or optimum total hardness level is not known and no difference in results have been noted with the various forms of agricultural limestone available to the pond owner. Hydrated lime treatment does not last as long as agricultural lime treatment in the quantities tested in Georgia.

Agricultural limestone when applied to ponds is apparently not completely utilized. Ponds have been drained after lime treatment with agricultural limestone and piles of it could be seen partly covered with mud and very hard. This material is probably very slow to go into solution if soluable at all. It may be necessary to use agricultural limestone if bottom soil neutralization is required. Hydrated lime is extremely soluable, and when in solution, 1500 pounds of hydrated lime has the calcium equivalent of approximately 2200 pounds of agricultural lime.

The CaO of the pond bottom soil and the total hardness of the water have been the most reliable indicators of the need for lime. An estimated 10 soil samples should probably be collected and the results averaged to get a reliable sample of the chemical conditions in the bottom soils. Figures show the expected range of chemical conditions and recommendations for treatment of problem ponds determined in this investigation.

Theoretically a solution with any lime present should have a pH of 7 or above, but such is not always the case. This is probably due to the insolubility and slight ionization of the lime in the presence of weak acids found in fish ponds. Soils as acid as pH 4 have been found with a 10-15% saturation of limestone (Hellige Soil Manual). A comparable situation apparently exists in pond water since very often a total hardness of 5-10 ppm is found along with a pH of 5 or below. This water has little or no buffering effect and probably cannot provide calcium for plant growth. It may be that as long as calcium is available for plant growth, fertilization will be satisfactory.

CONCLUSIONS

The efficiency of fertilization programs are definitely improved following lime treatment in ponds with soft water. The amounts of fertilization required for optimum plankton production have also been significantly reduced in lime treated ponds. State wide investigations of fertilization problems has definitely established lime treatment as a necessary supplement to fertilization programs in Georgia.

The data from this investigation have generally established the following conclusions:

1—Ponds with a total water hardness below 15 ppm, and calcium oxide content of bottom soil below 1000 pounds per acre, should be limed for maximum fertilization results and phytoplankton production.

2—Agricultural lime applied at the rate of one ton per acre will increase total water hardness approximately 15 ppm, and calcium oxide of bottom soils approximately 1000 pounds per acre. Results from lime applied at rates listed above will last 2-4 years.

3—Hydrogen ion is not a reliable measure of the need for lime unless extremes of acidity are encountered.

4—Nutrient measurements of phosphorus and potassium do not exhibit significant changes following lime treatment. Such changes are believed to occur, however, measurement techniques are believed inaccurate for pond bottom soils. This is also true for hydrogen ion measurements in bottom soils.

5—Hydrated or slaked lime is effective for correction of low total hardness in pond waters although frequent applications are necessary. This form of lime is completely soluable and apparently supplies a direct source of dissolved calcium in the water for phytoplankton growth.

6—Phytoplankton production was definitely improved in over 100 ponds after the addition of lime.

7—Apparently as much as 1000 lbs/A of agricutural lime added to the pond is necessary before there are any significant results and 2000 lbs/A has corrected situations.

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VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN AND WATER TEMPERATURES IN LAKE HAMILTON WITH SPECIAL REFERENCE TO SUITABLE RAINBOW TROUT HABITAT

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ABSTRACT

Lake Hamilton is the middle of three lakes located in series on the Ouachita River in Southwestern Arkansas. Following the initial release of water through the penstocks from the upper newest lake, a subsurface current was detected in Lake Hamilton. During the summer of 1960, physical-chemical tests were made at nine stations along the channel to determine the extent of the current. Data collected showed the water remained oxygenated from the surface to the bottom. Cold water drawn from below the thermocline of the upper lake becomes oxygenated in the tailrace and slides under the warm upper stratum of water in the Lake Hamilton. Existing temperature ranges and sufficient dissolved oxygen levels, as were found in the channel, should sustain trout throughout the critical summer months.

INTRODUCTION

Lake Hamilton is the middle of three lakes located in series on the Ouachita River in southwestern Arkansas. This 7200 acre lake, lying a few miles southwest of Hot Springs, was created in 1931 by the construction of Carpenter Dam. It extends upstream from Carpenter Dam to Blakely Dam, a distance of nineteen miles. Immediately below Lake Hamilton is Lake Catherine, a 3000 acre lake impounded by Remmel Dam which was constructed in 1923. Above Lake Hamilton is Lake Ouachita, a 40,000 acre lake formed by the Blakely Dam. This dam was completed in 1952 and Lake Ouachita started filling during the winter of 1952 and early spring of 1953.

Dams forming Lakes Hamilton and Catherine were constructed by the Arkansas Power and Light Company to provide hydro-electric power. Blakely Dam was built by the U. S. Army, Corps of Engineers. Two generating units, with a generating capacity of 75,000 kilowatts were installed in Blakely Dam. Two sixteen-foot diameter penstocks and one nineteen-foot diameter flood control conduit permit release of water through the dam into Lake Hamilton.

Periodic water releases and various generator tests were made at Blakely Dam during the fall of 1955. Routine generation was established