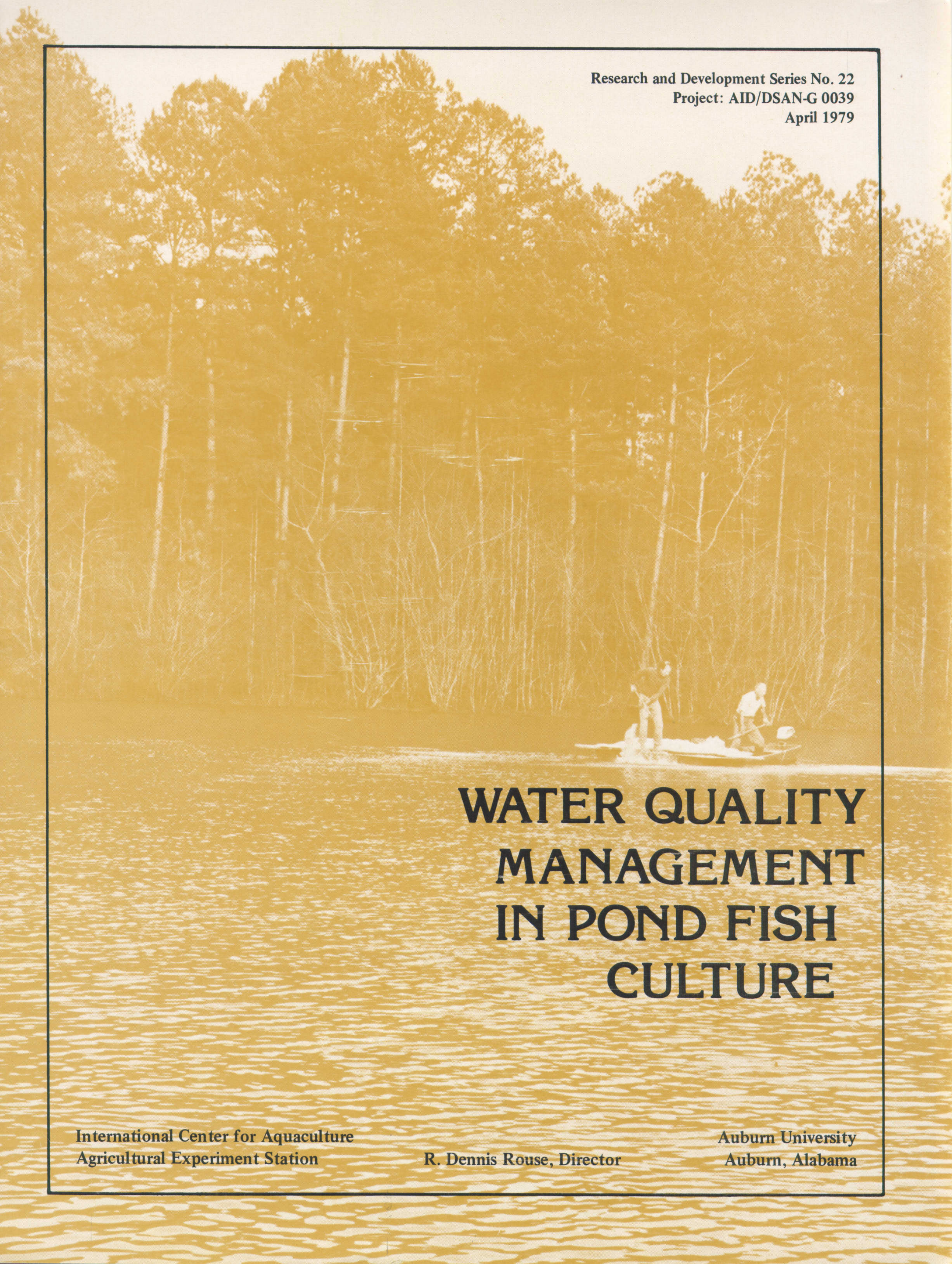

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WATER QUALITY MANAGEMENT IN POND FISH CULTURE

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Water Quality Management in Pond Fish Culture

Claude E. Boyd and Frank Lichtkoppler*

WATER QUALITY includes all physical, chemical, and biological factors that influence the beneficial use of water. Where fish culture is concerned, any characteristic of water that affects the survival, reproduction, growth, production, or management of fish in any way is a water quality variable. Obviously, there are many water quality variables in pond fish culture. Fortunately, only a few of these normally play an important role. These are the variables that fish culturists should concentrate on, and attempt to control to some extent by management techniques.

All other things being equal, a pond with "good" water quality will produce more and healthier fish than a pond with "poor" water quality. In this report an attempt is made to define "good" water quality for fish culture. Information is also presented which will help in determining the potential of a body of water for producing fish, improving water quality, avoiding stress-related fish disease and parasite problems, maintaining fish for research purposes, and ultimately producing more fish per unit of surface area. The following discussion of water quality is brief, but an attempt has been made to cover the most important points. The first part is concerned with general aspects of water quality which influence fish production. Next, several important water quality management techniques are outlined in simple form. Finally, some suggestions are made regarding water analysis in fish culture. Also included is a glossary which contains definitions of the technical terms. The information in this report is essentially a summary of the book, *Water Quality in Warmwater Fish Ponds,* by Boyd (*17*). This book may be consulted for more details and for additional references to the literature on water quality in ponds.

RELATIONSHIPS BETWEEN WATER QUALITY AND FISH PRODUCTION

The material in this report explains the usual relationships between water quality variables and fish production, setting forth, where possible, ranges of desirable levels of the variables. In addition, the management procedures recommended herein will usually be effective in improving water quality. However, because of unexplained reasons, effects of water quality on fish and the effectiveness of management procedures may be quite different from those reported here. Therefore, fish culturists should not consider the information in this report as the final answers to water quality problems, but merely as suggestions on how to solve these problems. Coldwater fish will not be considered, but coldwater fish generally demand water of much better quality than do warmwater fish.

Temperature

Warmwater fish grow best at temperatures between 25° and 32°C (Celsius). Water temperatures are in this range the year around at low altitudes in the tropics, but in temperate regions water temperatures are too low in winter for rapid growth of fish and fish food organisms. For this reason, management procedures such as feeding and fertilizing are halted or reduced in winter. Temperature has a pronounced effect on chemical and biological processes. In general, rates of chemical and biological reactions double for every 10°C increase in temperature. This means that aquatic organisms will use twice as much dissolved oxygen at 30°C as at 20°C, and chemical reactions will progress twice as fast at 30°C as at 20°C. Therefore, dissolved oxygen requirements of fish are more critical in warm water than in cooler water. Chemical treatments of ponds also are affected by temperature. In warm water, fertilizers dissolve faster, herbicides act quicker, rotenone degrades faster, and the rate of oxygen consumption by decaying manure is greater.

In ponds, heat enters at the surface so surface waters heat faster than lower waters. Since the density of water (weight per unit volume) decreases with increasing temperature above 4°C, the surface waters may become so warm and light that they do not mix with the cooler, heavier waters in lower layers. The separation of pond waters into distinct warm and cool layers is called thermal stratification. The upper warm layer is called the epilimnion and the lower, cooler layer is known as the hypolimnion. The layer of rapidly changing temperature between the epilimnion and the hypolimnion is termed the thermocline. The temperature profile for a thermally stratified pond is shown in figure 1. In temperate regions large ponds may stratify in the spring and remain stratified until fall. In small, shallow ponds in temperate regions and in tropical ponds, stratification often exhibits a daily pattern. During the day, the surface waters warm and form a distinct layer. At night the surface waters cool to the same temperature as the lower waters and the two layers mix. An extensive discussion on thermal stratification may be found in any standard text on limnology.

In some ponds, the surface waters may reach temperatures of 35°C or more. This is above the optimum temperature for most warmwater fish, but the fish may seek haven from the high temperature in subsurface waters. Fish have poor tolerance to sudden changes in temperature. Therefore, one should not remove fish from water of one temperature and suddenly thrust them into a water of appreciably higher or lower temperature. Often, a sudden change in temperature of as little as 5°C will stress or even kill fish. The effect is usually worse when moving fish from cooler to warmer water. Since temperatures increase with decreasing altitude, one must allow for temperature

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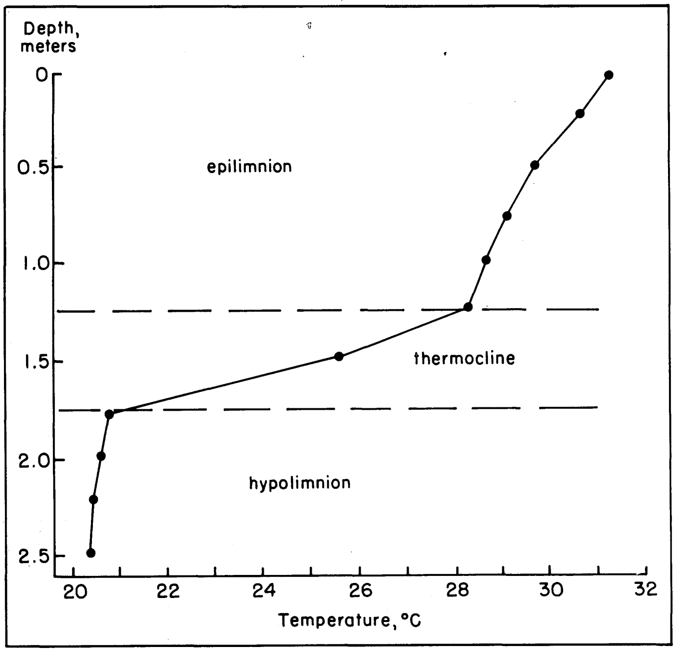

FIG. 1. A well developed pattern of thermal stratification in a fish pond. The epilimnion, thermocline, and hypolimnion are indicated.

adjustment when moving fish from high altitude to low altitude waters. Fish readily tolerate gradual changes in temperature. For example, one could raise the temperature from 25°C to 32°C over several hours without harming fish, but fish suddenly removed from 25°C water and placed in water of 32°C might die.

Salinity

The term salinity refers to the total concentration of all dissolved ions in a natural water expressed in milligrams per liter or parts per million[1]. The osmotic pressure of water increases with increasing salinity. Fish species differ in their osmotic pressure requirements, so the optimum salinity for fish culture differs to some extent with species. Salinity information on some cultured species of pond fish is presented in table 1.

Fish are highly sensitive to sudden changes in salinity. Fish living in water at one concentration of salinity should not suddenly be placed in water with a much higher or lower salinity. Small fish and fry of most species are more susceptible than adult fish to sudden changes in salinity. Sodium chloride may be used to increase the salinity in fish holding facilities and even in small experimental ponds. Conversely, salinity may be lowered in small scale systems by the addition of water with low salinity. Unfortunately, it is usually not practical to adjust the salinity of larger fish culture systems, except in brackishwater ponds where seawater may be introduced by gravity flow or tidal movement.

TABLE 1. HIGHEST CONCENTRATIONS OF SALINITY WHICH PERMIT NORMAL SURVIVAL AND GROWTH OF SOME CULTURED FOOD FISH

Species	Salinity, mg/liter	Reference
Catla catla (catla)	slightly brackish water	*(37)*
Labeo rohita (roha)	slightly brackish water	*(37)*
Ctenopharyngodon idella (grass carp)	12,000	*(39)*
Cyprinus carpio (common carp)	9,000	*(21)*
Hypophthalmichthys molitrix (silver carp)	8,000	*(39)*
Ictalurus punctatus (channel catfish)	11,000	*(48)*
Tilapia aurea	18,900	*(21)*
T. nilotica	24,000	*(21)*
T. mossambica	30,000	*(21)*
Mugil cephalus (grey mullet)	14,500	*(21, 26)*
Chanos chanos (milkfish)	32,000	*(6)*

In practice, one is seldom able to measure concentrations of all ions in water. However, the ability of water to conduct an electrical current (conductivity) increases as salinity rises. A conductivity meter may be used to measure conductivity and the conductivity value allows an approximation of salinity. Many conductivity meters have a scale for reading salinity directly. Another method for obtaining the approximate salinity of a water is to measure the total dissolved solids concentration. A sample is filtered through a fine paper, a known volume is evaporated, and the residue remaining is weighed. The weight of the residue in milligrams per liter is the total dissolved solids concentration, and this closely approximates the salinity. In brackishwater, salinity may be estimated from the chloride concentration by the following equation from Swingle *(65)*:

$$\text{Salinity in mg/liter} = 30 + (1.805)\ (\text{chloride in mg/liter})$$

In practice, chloride concentration (chlorinity) can be measured by refractometers or temperature corrected hydrometers.

The degree of salinity in water reflects geological and hydrological conditions. Surface waters in areas of high rainfall where soils are continually leached usually have low salinity (10 to 250 milligrams per liter). In arid regions, evaporation exceeds precipitation and salinity increases as a result of evaporation. Salinity values in ponds of arid regions often range between 500 and 2,500 milligrams per liter, and much higher values are often encountered. Even in areas of high rainfall, ground water from wells may sometimes have salinity values as high as those encountered in surface waters of arid regions. Seawater has a high salinity (35,000 milligrams per liter), so the salinity of brackishwater ponds reflects the degree of dilution of seawater with freshwater. High rates of evaporation in brackishwater ponds during periods of low rainfall may cause them to become excessively saline. Salinities in excess of 45,000 milligrams per liter are difficult for even marine species to tolerate.

Turbidity and Color

The term turbid indicates that a water contains suspended material which interferes with the passage of light. In fish ponds, turbidity which results from planktonic organisms is a desirable trait, whereas that caused by suspended clay particles is undesirable. Even with the latter condition, the clay particles are seldom abundant enough in water to directly harm fish. If the pond receives runoff which carries heavy loads of silt and clay, the silt settles over the pond bottom and smothers fish eggs and fish food organisms. The clay particles which remain in suspension restrict light penetration and limit the growth of plants. A persistent clay turbidity which restricts visibility into the water to 30 centimeters or less may prevent development of plankton blooms. Methods for controlling clay turbidity will be discussed later.

Some ponds receive large inputs of vegetative matter from their watersheds. Extracts from this plant material (humates) often impart color to the water. Color from vegetative extracts often appears as a dark stain giving the water the appearance of tea or weak coffee. Pond waters with high concentrations of humates are typically quite acid and have a low total alkalinity.

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[1] One part per million (p.p.m.) indicates that there is 1 part by weight of a substance in 1 million parts of the solution. A water sample with 1 p.p.m. salinity would contain 1 milligram of ions and 999,999 milligrams of water. For all practical purposes, 1 p.p.m. equals 1 milligram per liter.

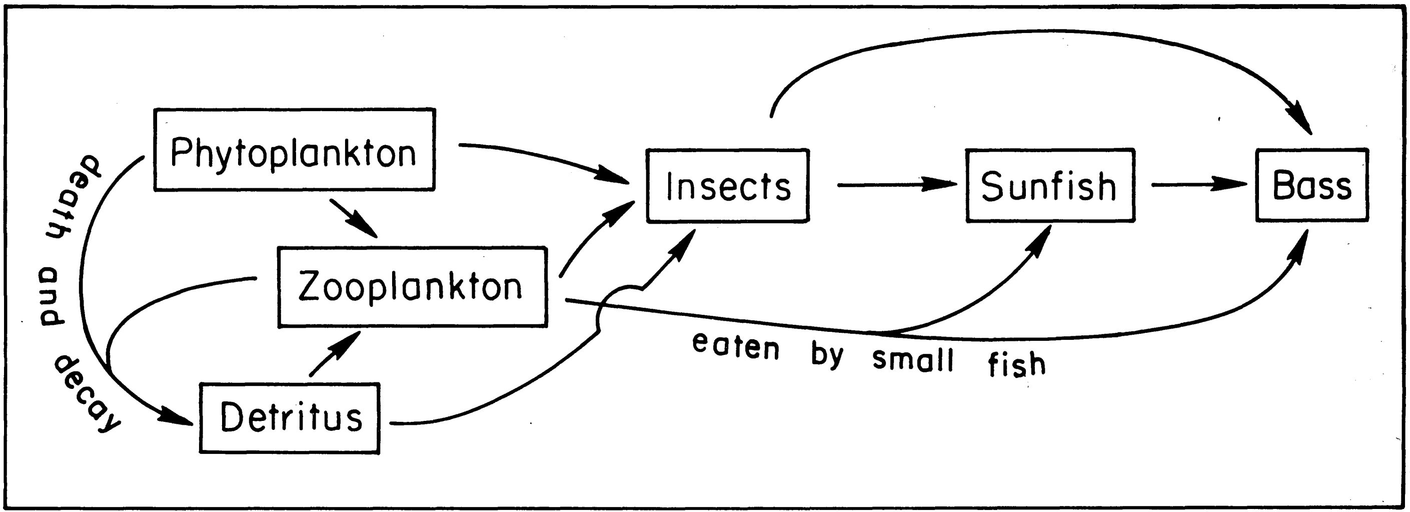

FIG. 2. A representative food web in a sunfish-bass pond.

Although color does not affect fish directly, it restricts light penetration and reduces plant growth. Agricultural limestone applications have been used to successfully remove humates from natural waters *(74)*.

Plankton

Plankton is comprised of all the microscopic organisms which are suspended in water and includes small plants (phytoplankton), small animals (zooplankton), and bacteria. When there is enough plankton in the water to discolor it and make it appear turbid, the water is said to contain a plankton "bloom." The phytoplankton uses inorganic salts, carbon dioxide, water, and sunlight to produce its own food. The zooplankton feeds on living or dead plankton and other tiny particles of organic matter in the water. Bacteria utilize any type of dead organic matter in the water for food. In fish culture systems where fish are not provided supplemental feed, plankton forms the most abundant base of the food web. Examples of food webs in fish culture systems are given in figures 2 and 3. Both food webs begin with phytoplankton growth. In figure 2 there are several steps before ending with largemouth bass, while in figure 3 the food web is simpler because the tilapia feed directly on plankton. Since each step in the food web is rather inefficient, a fish culture system with a more direct food web will produce a greater weight of fish per unit area. For example, during a 6-month period, the sunfish-bass culture might produce 200 kilograms of fish per hectare while the tilapia culture could easily produce 1,000 kilograms.

Because plankton is at the base of the food web, there is a close relationship between plankton abundance and fish production *(58, 66)*, figure 4. In addition to encouraging fish growth, plankton makes water turbid and prevents the growth of undesirable aquatic weeds through shading *(59)*. Despite the benefits of plankton blooms in fish ponds, more plankton can sometimes be produced than can be utilized by the fish for growth. Heavy plankton blooms usually contain large numbers of blue-green algae which can form scums at the surface. These scums absorb heat during the day and cause shallow thermal stratification *(8, 64)*. During the night, heavy plankton blooms consume large amounts of dissolved oxygen and may cause oxygen depletion before the next morning. Scums of plankton may suddenly die, decompose, and cause oxygen depletion. Relationships between plankton and dissolved oxygen will be treated more thoroughly later. In addition to causing dissolved oxygen problems, organisms in heavy plankton blooms often produce substances which impart a strong off-flavor to fish flesh *(44)*.

There are many techniques for measuring plankton abundance, but most are too tedious for use in practical fish culture. The most practical technique for use in ponds which do not contain appreciable clay turbidity is to measure the Secchi disk visibility *(2)*. Details for making Secchi disk measurements will be given later, but for now it will suffice to state that the Secchi disk visibility is the depth at which a disk 20 centimeters in diameter with alternate black and white quadrants disappears from view. There is a high correlation between Secchi disk visibility and plankton abundance, as illustrated in figure 5 with data from Almazan and Boyd *(2)*. It is impossible to establish an ideal plankton turbidity for fish culture. However, a Secchi disk visibility in the 30- to 60-centimeter range is generally adequate for good fish production and for shading underwater weeds. As Secchi disk visibilities decrease below 30 centimeters, there is an increase in the frequency of dissolved oxygen problems. At values above 60 centimeters, light penetrates to greater depths encouraging underwater macrophyte growth, and there is less plankton to serve as food for fish or fish food organisms.

Plankton communities are constantly changing in species composition and in total abundance. This results in corresponding fluctuations in Secchi disk visibility and in the appearance of pond water. These changes in plankton communities may be disconcerting to the fish culturist. However, unless plankton becomes so dense that dissolved oxygen problems occur or so thin as to encourage underwater weeds, the changes do not affect fish production appreciably.

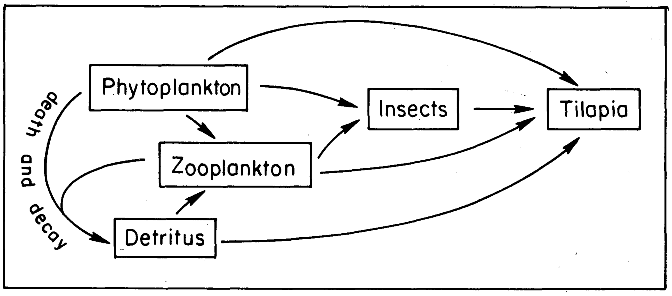

FIG. 3. A representative food web in a pond used for tilapia culture.

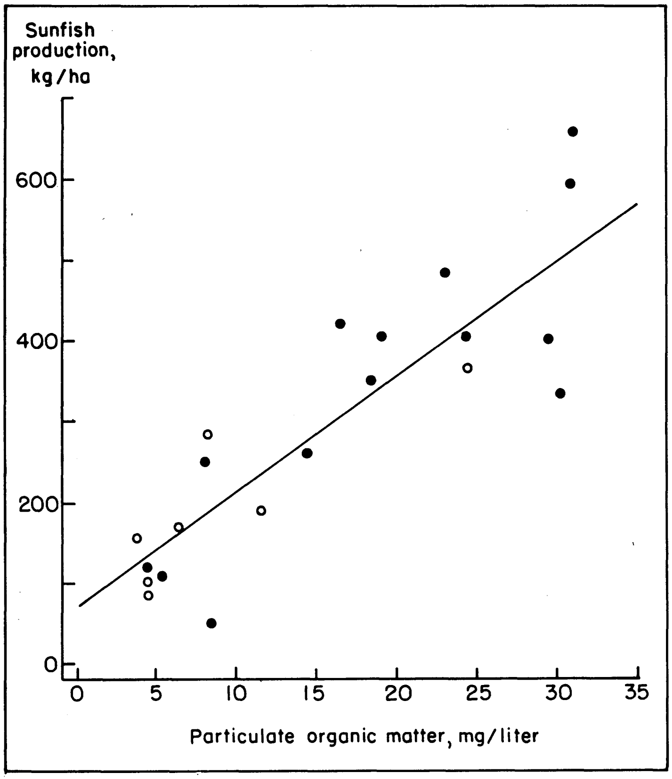

FIG. 4. Plankton production (particulate organic matter) and sunfish production in ponds. Data from Smith and Swingle (58) and Swingle and Smith (66).

By monitoring Secchi disk visibility on a regular schedule (once or twice weekly) and observing the appearance of the water, the fish culturist can obtain information on the continuing condition of the plankton community in a pond and on the supply of fish food organisms.

The ability of water to produce plankton depends on many factors, but the most important is usually the availability of inorganic nutrients for phytoplankton growth. Essential elements for phytoplankton growth include carbon, oxygen, hydrogen, phosphorus, nitrogen, sulfur, potassium, sodium, calcium, magnesium, iron, manganese, copper, zinc, boron, cobalt, chloride, and possibly others. Phosphorus is most often the element regulating phytoplankton growth in ponds *(36, 47)*. The addition of phosphate fertilizer will cause an increase in plankton production and an increase in fish production in most ponds. Inadequate supplies of nitrogen, potassium, and carbon also limit phytoplankton in some ponds.

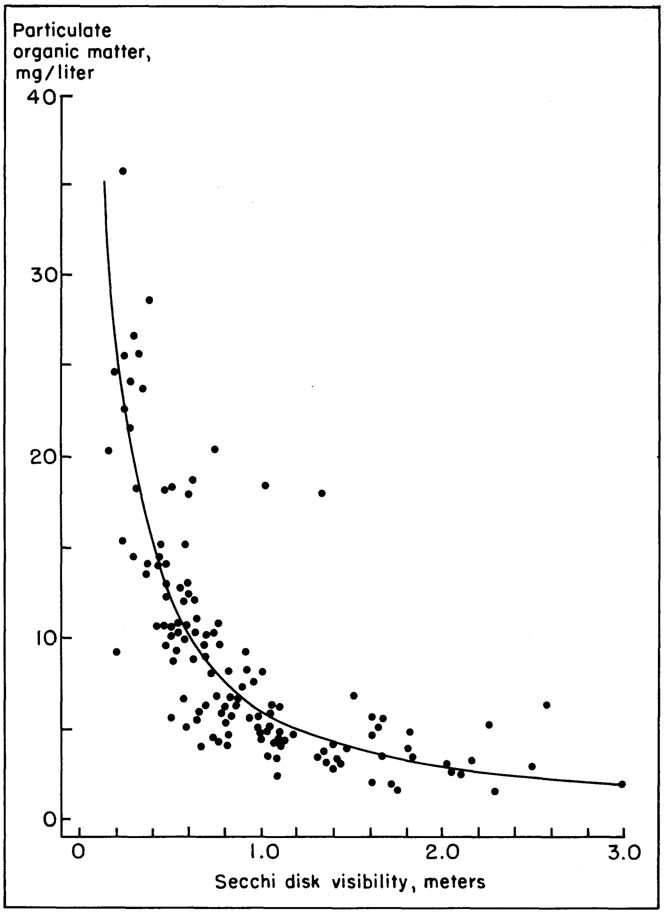

FIG. 5. Relationship between plankton abundance (particulate organic matter) and Secchi disk visibility in fish ponds. After Almazan and Boyd (2).

In general, the level of plankton production in unmanaged ponds is related to the basic soil fertility of the surrounding watersheds. Therefore, the basic levels of plankton and fish production are greater in ponds located on watersheds with fertile soils than in ponds located on watersheds with poor soils. The management practices on watersheds also influence plankton production in ponds. According to a study by Boyd *(13)*, unfertilized ponds in pastures had higher concentrations of nutrients, harder water, higher plankton production, and less transparent water than unfertilized ponds in woods, table 2. In fact, the average plankton production in unfertilized pasture ponds almost equalled plankton production in fertilized ponds, table 2. Although little of the nitrogen and phosphorus applied to pastures is lost in runoff, high concentrations of nutrients in unfertilized pasture ponds were related to agricultural activities on the watersheds. For example, cattle grazing on pastures deposited considerable urine and manure in or near ponds, which served as a source of nutrients.

TABLE 2. WATER QUALITY IN 26 FERTILIZED PONDS, 34 UNFERTILIZED PONDS ON WOODED WATERSHEDS, AND 53 UNFERTILIZED PONDS IN PASTURES — DATA MODIFIED AFTER BOYD (*13*)

Measurement	Unfertilized ponds		Fertilized ponds
	Wooded watershed	Pasture watershed	
Total hardness (mg/liter)	18.9	29.0	20.0
Soluble inorganic phosphorus (mg/liter)	.01	.02	.02
Nitrate (mg/liter)	.33	.43	.32
Ammonia (mg/liter)..........	.06	.13	.12
Potassium (mg/liter)	1.5	2.9	1.7
Secchi disk visibility (cm).....	124	66	76
Plankton (mg/liter)...........	5.3	11.9	12.1

Even though the basic fertility of ponds differs greatly depending on the management and soils of their watersheds, the level of plankton production in most ponds can be raised within the range of plankton production needed for good fish production. Inorganic fertilizers may be added to ponds with low basic fertility to increase plankton production. In some ponds, both lime and fertilizer application may be required to increase plankton production. Manures also increase plankton production.

Dissolved Oxygen

Dissolved oxygen is probably the most critical water quality variable in fish culture, so the fish culturist should be familar with the dynamics of dissolved oxygen concentrations in ponds. The atmosphere is a vast reservoir of oxygen, but atmospheric oxygen is only slightly soluble in water. The solubility of oxygen in water at different temperatures and at standard sea level atmospheric pressure is given in table 3. From this table, it is readily apparent that the solubility of oxygen in water decreases as the temperature increases. When water contains a dissolved oxygen concentration equal to the solubility of oxygen in water at the existing temperature, the water is said to be saturated with dissolved oxygen. If water contains more dissolved oxygen than it should for the particular temperature, it is supersaturated. Water may also contain less dissolved oxygen than the saturation value. The solubility of dissolved oxygen decreases with decreasing atmospheric pressure (barometric pressure). For example, the solubility of oxygen in water at 25°C differs as follows with altitude (given in milligrams per liter at specified altitudes): 0 meters, 8.4 milligrams per liter; 500 meters, 7.9 milligrams per liter; 1,000 meters, 7.4 milligrams per liter; 1,500 meters, 7.0 milligrams per liter; 2,000 meters, 6.6 milligrams per liter; 2,500 meters, 6.2 milligrams per liter; and 3,000 meters, 5.8 milligrams per liter. The solubility of oxygen in water also decreases as salinity increases. At temperatures of 20 to 35°C, the solubility of dissolved oxygen decreases by about 0.008 milligram per liter for each 210 milligrams per liter increase in salinity *(3)*.

TABLE 3. SOLUBILITY OF DISSOLVED OXYGEN IN PURE WATER AT STANDARD SEA LEVEL ATMOSPHERIC PRESSURE (1 ATMOSPHERE)

°C	mg/liter	°C	mg/liter	°C	mg/liter
0.......	14.16	12.......	10.43	24.......	8.25
1.......	13.77	13.......	10.20	25.......	8.11
2.......	13.40	14.......	9.98	26.......	7.99
3.......	13.05	15.......	9.76	27.......	7.86
4.......	12.70	16.......	9.56	28.......	7.75
5.......	12.37	17.......	9.37	29.......	7.64
6.......	12.06	18.......	9.18	30.......	7.53
7.......	11.76	19.......	9.01	31.......	7.42
8.......	11.47	20.......	8.84	32.......	7.32
9.......	11.19	21.......	8.68	33.......	7.22
10.......	10.92	22.......	8.53	34.......	7.13
11.......	10.67	23.......	8.38	35.......	7.04

Even though dissolved oxygen will diffuse into water, its rate of diffusion is quite slow. Therefore, photosynthesis by phytoplankton is the primary source of dissolved oxygen in a fish culture system. Fish culturists are often concerned with the rate at which dissolved oxygen is removed from the water. The primary losses of dissolved oxygen from a pond include respiration by the plankton (phytoplankton included), respiration by fishes, respiration by benthic organisms (organisms living in or attached to the mud), and diffusion of oxygen into the air *(20, 57)*. The gains and losses of dissolved oxygen in a pond are summarized in table 4 along with some values representing the usual magnitudes of daily gains and losses. It is readily apparent that plankton and fish respiration cause the major losses of dissolved oxygen and that photosynthesis is the largest source. Diffusion of oxygen into ponds only occurs when waters are below saturation and diffusion of oxygen out of ponds only occurs when waters are supersaturated. The larger the difference between the dissolved oxygen concentration in the pond water and the concentration of dissolved oxygen at saturation, the greater is the rate of diffusion. Wind and wave action also favor diffusion.

TABLE 4. RANGES OF EXPECTED GAINS AND LOSSES OF DISSOLVED OXYGEN CAUSED BY DIFFERENT PROCESSES IN FISH PONDS, FOR PONDS OF 1.0 TO 1.5 METERS AVERAGE DEPTH

Process	Range, mg/liter
Gains	
Photosynthesis by phytoplankton	5 to 20
Diffusion..	1 to 5
Losses	
Plankton respiration	5 to 15
Fish respiration	2 to 6
Respiration by organisms in mud	1 to 3
Diffusion..	1 to 5

In a fish culture system, more oxygen must enter or be produced in the water by plankton than is used by the organisms or dissolved oxygen depletion will occur. Since nutrients are normally abundant in well-managed fish ponds, light is often the primary factor regulating photosynthesis by phytoplankton. Light rapidly decreases in intensity as it passes through water. This is true even in pure water, but the decrease is even faster in fish ponds because the planktonic organisms and other suspended and dissolved substances reflect and absorb light. Therefore, the rate of oxygen production by phytoplankton decreases with depth, and below a certain depth, no more oxygen is produced. Since oxygen is continually used by the pond biota and only produced during daylight hours by the phytoplankton, there is a depth at which dissolved oxygen production by the phytoplankton and that entering by diffusion just equal the combined utilization of dissolved oxygen by pond life *(32)*. Below this depth in stratified ponds the water will contain no dissolved oxygen. The stratification of dissolved oxygen in ponds usually corresponds closely to thermal stratification *(8)*. The epilimnion contains dissolved oxygen and the hypolimnion is depleted of dissolved oxygen. As with thermal stratification, daily dissolved oxygen stratification may occur in small, shallow ponds.

Obviously, the depth to which light intensity is great enough

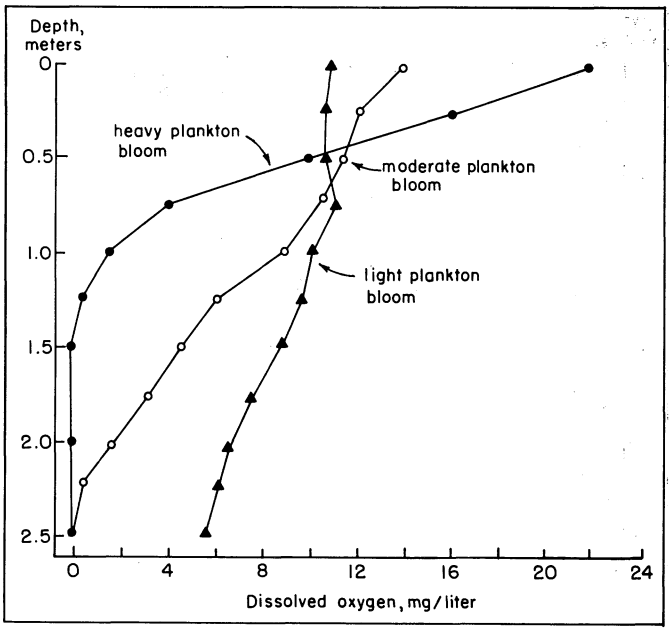

FIG. 6. Dissolved oxygen concentrations in the afternoon at different depths in ponds with different densities of plankton.

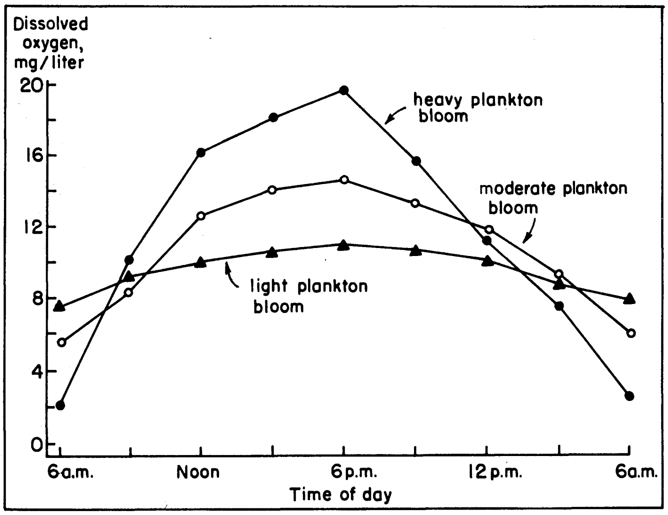

FIG. 7. Daily fluctuations in dissolved oxygen concentrations of surface water in ponds with different densities of plankton.

for adequate photosynthesis to provide surplus dissolved oxygen is related to plankton density. Photosynthesis decreases with decreasing light intensity, and as plankton becomes more abundant, the rate of oxygen consumption by the plankton community increases. When plankton abundance is great, dissolved oxygen production is extremely high near the surface. Because of shading, the rate of oxygen production will decrease rapidly with depth and only a thin layer of surface water, often less than 1 meter, will contain appreciable dissolved oxygen *(32)*. In ponds where plankton is less abundant, rates of dissolved oxygen production are not as high within the illuminated layer of water, but there will be appreciable oxygen production and surplus dissolved oxygen at greater depths than in ponds with greater plankton turbidity. The influence of plankton turbidity on the depth distribution of dissolved oxygen in ponds is illustrated in figure 6. As a general rule, most ponds will contain enough dissolved oxygen to support fish to a depth of at least two or three times the Secchi disk visibility.

There is also a marked fluctuation in dissolved oxygen concentration during a 24-hour period in ponds. Concentrations of dissolved oxygen are lowest in the early morning just after sunrise, increase during daylight hours to a maximum in late afternoon, and decrease again during the night. The magnitude of fluctuation is greatest in ponds with heavy plankton blooms and least in ponds with low plankton abundance. Daily fluctuations of dissolved oxygen concentrations in ponds with different plankton densities are depicted in figure 7. In ponds with extremely dense plankton blooms, dissolved oxygen concentrations will often be below 2 milligrams per liter in early morning. Concentrations are particularly low during periods of cloudy weather *(64)*. The production of oxygen on a cloudy day is less than on a clear or partly cloudy day, so dissolved oxygen concentrations do not increase to usual afternoon levels. This results in lower than usual dissolved oxygen concentrations the following morning. Extended periods of cloudy weather may result in dangerously low dissolved oxygen concentrations even in ponds with moderately heavy plankton blooms. The influence of cloudy weather on dissolved oxygen concentrations is illustrated in figure 8.

In ponds with heavy plankton blooms, scums of algae often form at the surface. Occasionally, the algae in these scums will suddenly die, and their decomposition will result in depletion of dissolved oxygen *(7, 19, 64)*. For example, figure 9 illustrates the

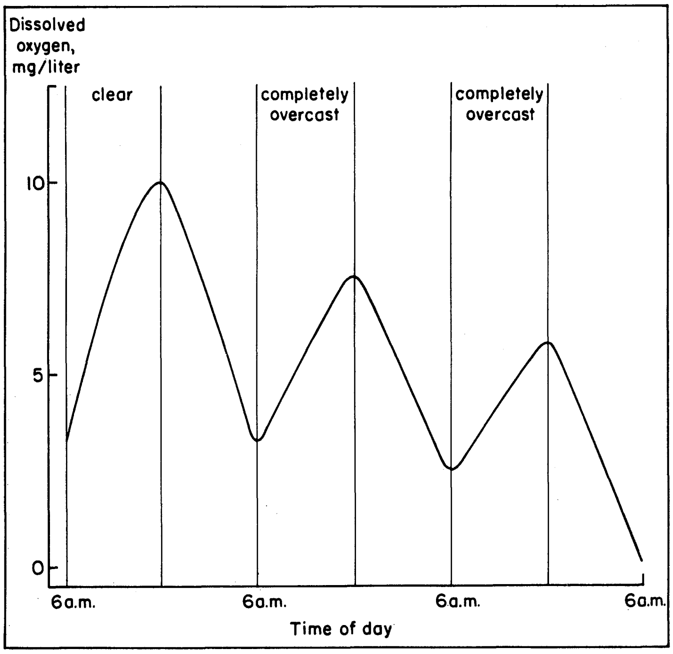

FIG. 8. Influence of cloudy weather on dissolved oxygen concentrations in fish ponds.

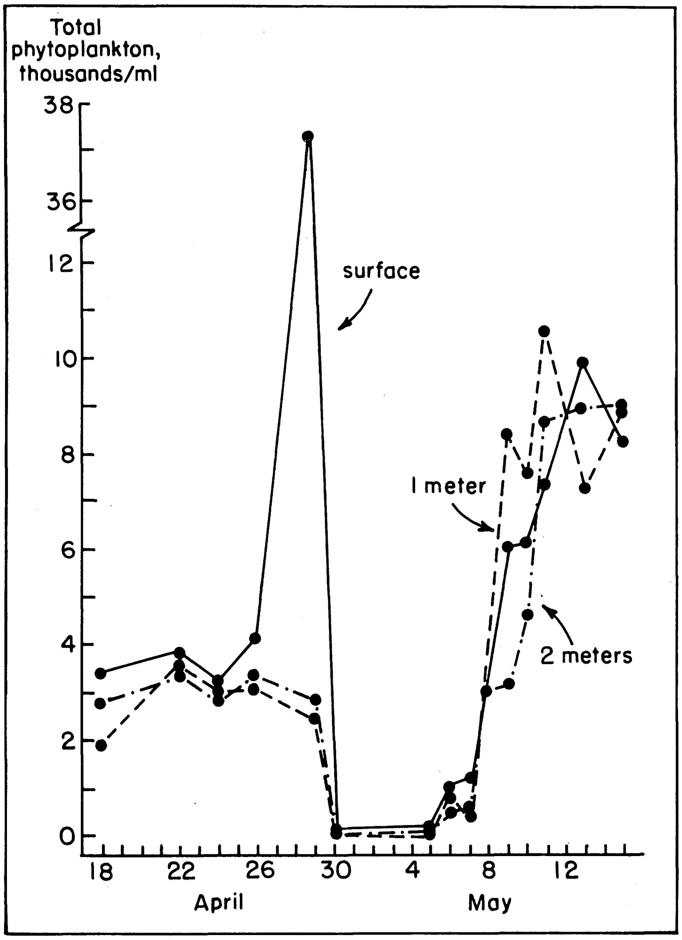

FIG. 9. Decline in phytoplankton following a phytoplankton die-off in a fish pond. The die-off began on April 29. After Boyd et al. (19).

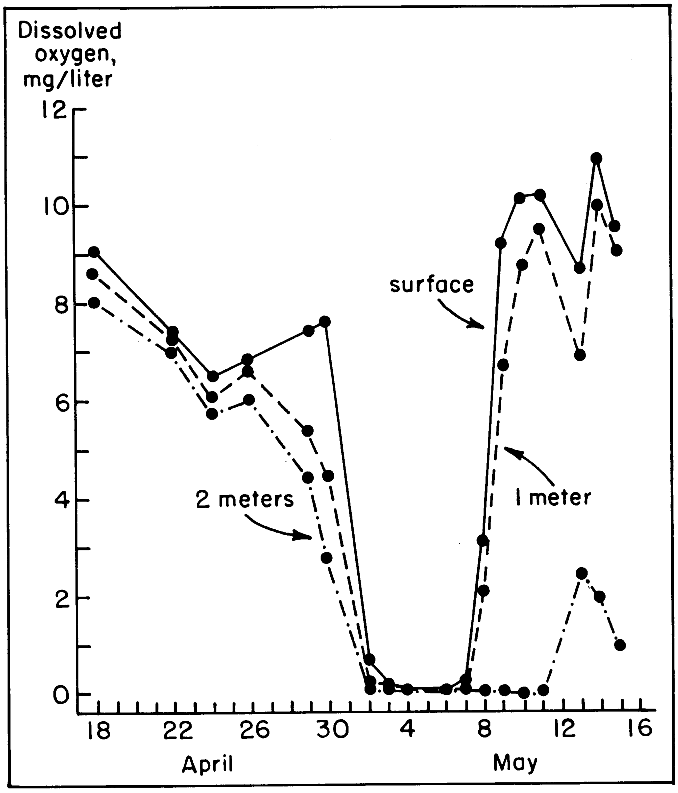

FIG. 10. Concentrations of dissolved oxygen before and after a phytoplankton die-off in a fish pond. The phytoplankton began dying on April 29. After Boyd et al. (19).

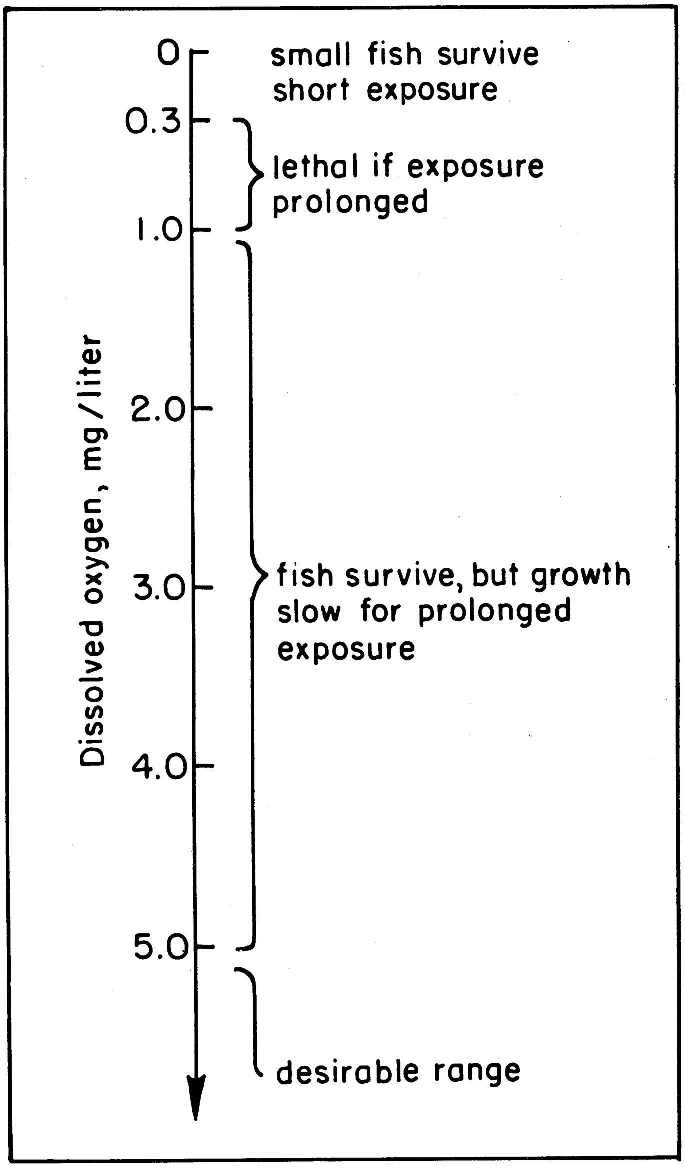

FIG. 11. Effects of dissolved oxygen concentrations on pond fish.

sudden death of phytoplankton in a fish pond. The dissolved oxygen concentration quickly dropped below a detectable level, figure 10. Dissolved oxygen concentrations did not return to normal levels until a new phytoplankton community was established (examine figures 9 and 10). Phytoplankton die-offs usually occur during calm, clear, warm weather. One can recognize a die-off because the algal scum deteriorates and the water takes on a brown or gray appearance.

Winds or heavy, cold rains may break up thermal stratification in ponds *(64)*, causing complete mixing ("overturn") of the oxygenless waters of the hypolimnion and the oxygenated water of the epilimnion. If the pond contains a large volume of oxygenless water, oxygen depletion may result.

Fish require adequate concentrations of dissolved oxygen for survival and growth. The minimum concentration for fish survival varies with time of exposure. A fish may tolerate a particularly low concentration of dissolved oxygen for a few hours without ill effect, but will die if exposed to this same concentration for several days. The concentration of dissolved oxygen tolerated by pond fishes is illustrated in figure 11, with additional data on oxygen requirements presented in table 5. Low dissolved oxygen concentrations adversely affect fish even at levels which do not cause mortality, making them more susceptible to parasites and diseases *(49)*. In addition, fish do not feed or grow as well when dissolved oxygen concentrations remain continuously below 4 or 5 milligrams per liter *(4)*. Daily fluctuations of dissolved oxygen in fish ponds apparently have little effect on feeding and growth as long as the minimum dissolved oxygen concentration for the day does not drop below 1 or 2 milligrams per liter in the early morning and then rises near saturation within a few hours after sunrise. If dissolved oxygen concentrations remain at less than 3 or 4 milligrams per liter for prolonged periods, fish cease to feed or grow well.

TABLE 5. REPORTED LETHAL CONCENTRATIONS OF DISSOLVED OXYGEN FOR SELECTED SPECIES OF POND FISH—DATA FROM DOUDOROFF AND SHUMWAY (*24*)

Species	Lethal level, mg/liter
Carassius auratus (goldfish)	0.1 to 2.0
Catla catla (catla)	0.7
Cirrhina mrigala (mrigal)	0.7
Ctenopharyngodon idella (grass carp)	0.2 to 0.6
Cyprinus carpio (common carp)	0.2 to 0.8
Hypophthalmichthys molitrix (silver carp)	0.3 to 1.1
Labeo rohita (rohu)	0.7
Ictalurus punctatus (channel catfish)	0.8 to 2.0
Lepomis macrochirus (bluegill)	0.5 to 3.1
Micropterus salmoides (largemouth bass)	0.9 to 3.1

pH

The pH is a measure of the hydrogen ion concentration and indicates whether the water is acidic or basic in reaction. The pH

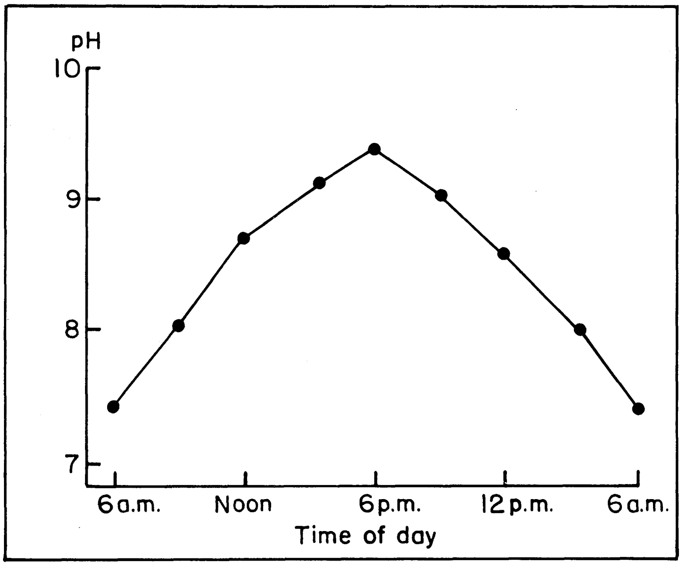

FIG. 12. Daily fluctuations in pH in a fish culture pond.

scale ranges from 0 to 14, with pH 7 being the neutral point. Thus, a water of pH 7 is neither acidic nor basic, while a water with pH below 7 is acidic and one with a pH above 7 is basic. The greater the departure from pH 7, the more acidic or basic a water. The pH of natural waters is greatly influenced by the concentration of carbon dioxide, an acidic substance. Phytoplankton and other aquatic vegetation remove carbon dioxide from the water during photosynthesis, so the pH of a body of water rises during the day and decreases during the night, figure 12. Waters with low total alkalinity often have pH values of 6 to 7.5 before daybreak, but when phytoplankton growth is heavy, afternoon pH values may rise to 10 or even higher *(63)*. Fluctuations in pH are not as great in water with higher total alkalinity where pH values normally range from 7.5 or 8 at daybreak or 9 or 10 during the afternoon. In some water with extremely high total alkalinity, and particularly in waters with high total alkalinity and low total hardness, pH values may rise above 11 during periods of rapid photosynthesis *(63)*. Obviously, pH measurements should be made in the early morning and again in the afternoon to assess the typical pH pattern for a pond. Waters with pH values of about 6.5 to 9 at daybreak are considered best for fish production. Some ponds which receive drainage from acid soils or swamps may be too acid for fish production. Waters with extremely high total alkalinity may have pH values too high for fish culture. Methods for increasing or decreasing the pH of pond water will be given later.

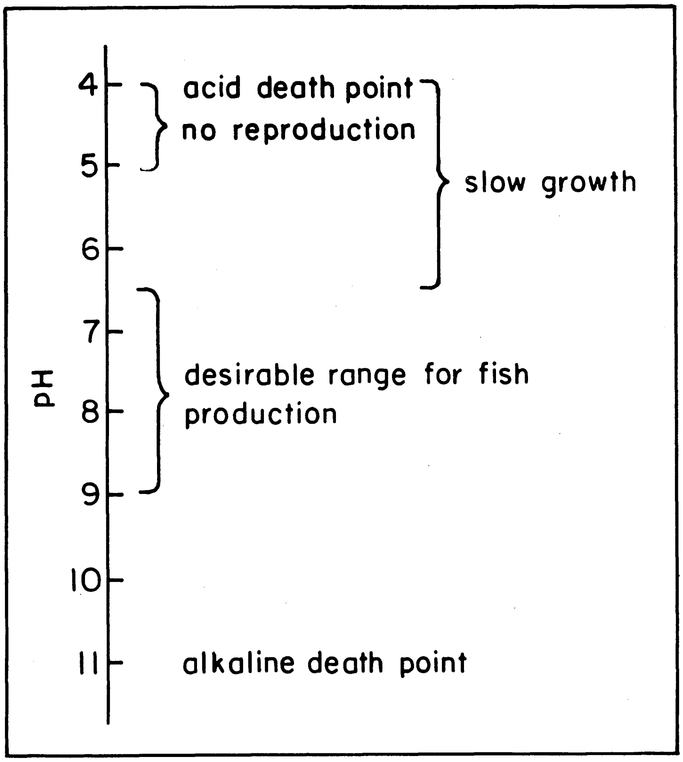

FIG. 13. Effect of pH on pond fish.

The acid and alkaline death points for pond fish are approximately pH 4 and pH 11, respectively *(63)*. Even though fish may survive, production will be poor in ponds with early morning pH values between 4 and 6 and between 9 and 10, figure 13. The afternoon pH in many fish culture systems rises to 9 or 10 for short periods without adverse effect on fish.

Carbon Dioxide

High concentrations of carbon dioxide can be tolerated by fish, although fish avoid levels as low as 5 milligrams per liter. Most species will survive in waters containing up to 60 milligrams per liter carbon dioxide, provided dissolved oxygen concentrations are high *(30)*. When dissolved oxygen concentrations are low, the presence of appreciable carbon dioxide hinders the uptake of oxygen by the fish. Unfortunately, carbon dioxide concentrations are normally quite high when dissolved oxygen concentrations are low. This results because carbon dioxide is released in respiration and utilized in photosynthesis. When dissolved oxygen is low, photosynthesis is not proceeding rapidly. Therefore, carbon dioxide concentrations rise because carbon dioxide released by respiration is not absorbed by phytoplankton for use in photosynthesis. Because of the relationship of carbon dioxide to respiration and photosynthesis, carbon dioxide concentrations usually increase during the night and decrease during the day. Particularly high concentrations of carbon dioxide occur in ponds after phytoplankton die-offs, after destruction of thermal stratification, and during cloudy weather.

Ammonia

Ammonia reaches pond water as a product of fish metabolism and decomposition of organic matter by bacteria. In water, ammonia nitrogen occurs in two forms, un-ionized ammonia and ammonium ion. Un-ionized ammonia is toxic to fish, but the ammonium ion is harmless except at extremely high concentrations. The toxic levels for un-ionized ammonia for short-term exposure usually lie between 0.6 and 2.0 milligrams per liter for pond fish, and sublethal effects may occur at 0.1 to 0.3 milligram per liter *(25, 52)*. The pH and temperature of the water regulate the proportion of total ammonia which occurs in un-ionized form. A pH increase of 1 unit causes roughly a tenfold increase in the proportion of un-ionized ammonia *(71)*. At 28°C, the percentages of total ammonia in un-ionized form are: pH 7, 0.70; pH 8, 6.55; pH 9, 41.23; and pH 10, 87.52. Fortunately, ammonia concentrations are seldom high enough in fish ponds to affect fish growth. The greatest concentrations of total ammonia nitrogen usually occur after phytoplankton die-offs, at which time pH is low because of high concentrations of carbon dioxide.

Hydrogen Sulfide

Un-ionized hydrogen sulfide at concentrations less than 1 milligram per liter may be rapidly fatal to fish *(61)*. Low pH favors the presence of un-ionized hydrogen sulfide, and acid bodies of water which contain high concentrations of hydrogen sulfide may be improved for fish culture by liming *(9)*. Fortunately, hydrogen sulfide is seldom a factor in pond fish culture.

Soils in some areas contain sulfide deposits. Such soils are usually found where coal is mined or along coastal plains. When exposed to the air, the sulfide is oxidized to sulfuric acid and runoff from these soils may have an extremely low pH *(27)*. Construction of fish ponds should not be encouraged on watersheds where sulfide bearing materials occur at or near the surface unless adequate lime is applied to neutralize the acidity.

Total Alkalinity and Total Hardness

The term total alkalinity refers to the total concentration of bases in water expressed as milligrams per liter of equivalent calcium carbonate. In natural waters, these bases are primarily carbonate and bicarbonate ions. Another way to think of alkalinity is in terms of basicity and resistance to pH change. The amount of acid required to cause a specified change in pH in a given volume of water increases as a function of the total alkalinity levels of the waters. In general, early morning pH is greater in waters with moderate or high total alkalinity than in waters with low total alkalinity. The availability of carbon dioxide for phytoplankton growth is related to alkalinity. Waters with total alkalinities less than 15 or 20 milligrams per liter usually contain relatively little available carbon dioxide. Waters with total alkalinities of 20 to 150 milligrams per liter contain suitable quantities of carbon dioxide to permit plankton production for fish culture. Carbon dioxide is often in low supply in waters with more than 200 to 250 milligrams per liter of total alkalinity. The afternoon pH in waters with low total alkalinity may often be as great as in waters with moderate or high total alkalinity. Waters of low alkalinity are poorly buffered against pH change, and the removal of carbon dioxide results in rapidly rising pH.

The total concentration of divalent metal ions (primarily calcium and magnesium), expressed in milligrams per liter of equivalent calcium carbonate, is termed the total hardness of water. Total alkalinity and total hardness values are normally similar in magnitude because calcium, magnesium, bicarbonate, and carbonate ions in water are derived in equivalent quantities from the solution of limestone in geological deposits. However, in some waters total alkalinity may exceed total hardness and *vice versa*. If total alkalinity is high and total hardness low, pH may rise to extremely high levels during periods of rapid photosynthesis.

Desirable levels of total hardness and total alkalinity for fish culture generally fall within the range of 20 to 300 milligrams per liter. If total alkalinity and total hardness are too low, they may be raised by liming. However, there is generally no practical way of decreasing total alkalinity and total hardness when they are above the desirable level. As a general rule, the most productive waters for fish culture have total hardness and total alkalinity values of approximately the same magnitude. For example, a water with a total alkalinity of 150 milligrams per liter and a total hardness of 25 milligrams per liter is not as good for fish culture as a water in which the total alkalinity is 150 milligrams per liter and the total hardness is 135 milligrams per liter.

Aquatic Weeds

Large aquatic plants (aquatic macrophytes) which may grow in fish ponds are usually undesirable. They interfere with fish management operations such as seining, feeding, and fish harvest, compete with phytoplankton for nutrients, provide havens for prey fish to escape predatory fish and thus encourage unbalanced fish populations, favor mosquito production, and contribute to water loss through evapotranspiration. Aquatic macrophytes include filamentous algae and submersed, floating-leafed, floating, and emergent macrophytes. Aquatic macrophytes which begin their growth at the pond bottom are limited to relatively transparent waters. Therefore, management procedures which favor plankton turbidity will often eliminate macrophytes *(59)*. Obviously, floating or floating-leafed macrophytes must be controlled by other methods.

Pollutants

Fish ponds are usually constructed in areas where industrial pollution is not a factor. However, agricultural pollutants, and especially pesticides, may reach ponds in runoff or drift. Many pesticides, insecticides in particular, are extremely toxic to fish. Acute toxicity values for many commonly used insecticides range from 5 to 10 micrograms per liter and much lower concentrations may be toxic upon longer exposure. Even if adult fish are not killed outright, long-term damage to fish populations may occur in environments contaminated with pesticides. The abundance of food organisms may decrease, fry and eggs may suffer mortality, and growth rates of fish may decline.

Pesticides sprayed onto fields may drift over considerable areas and reach ponds. Therefore, ponds in agricultural areas are often contaminated to some degree with pesticides. Key factors in protecting fish ponds from pesticide contamination are: distance from pesticide treated fields, tree and other vegetative cover between ponds and fields, topographic barriers to drift or runoff from treated fields, and proper methods of application of pesticides to fields. If watersheds receive heavy applications of persistent pesticides, ponds are not suitable for fish production. Cotton and other non-food crops are often treated with especially toxic and persistent pesticides. In some regions, pesticides which contain heavy metals, such as arsenic and lead, are still used. Heavy metals may reach ponds and kill fish or adversely affect production.

WATER QUALITY MANAGEMENT

Inorganic Fertilizers

Inorganic fertilizers used in ponds are the same ones used for agricultural crops. Nitrogen, phosphorus, and potassium are termed the primary nutrients in fertilizers. The grade of a fertilizer refers to percentages by weight of nitrogen (as N), phosphorus (as P_2O_5), and potassium (as K_2O, also called potash). For example, a 20-20-5 grade fertilizer contains 20 percent N, 20 percent P_2O_5, and 5 percent K_2O. This method of expressing nitrogen, phosphorus, and potassium content is traditional rather than descriptive. Fertilizer does not contain elemental nitrogen (N), phosphorus pentoxide (P_2O_5), or potash (K_2O). The use of N, P_2O_5, and K_2O to indicate fertilizer grades originated long ago and has been accepted for practical purposes. Primary nutrients in fertilizers are usually present as relatively simple compounds which dissolve to give nitrate, ammonium, phosphate, or potassium ions. The compositions of

Table 6. Composition of Some Common Inorganic Fertilizer Materials

Material	Content, percent		
	N	P_2O_5	K_2O
Ammonium nitrate	33-35	-	-
Ammonium sulfate	20-21	-	-
Calcium metaphosphate	-	62-64	-
Calcium nitrate	15.5	-	-
Ammonium phosphate	11-16	20-48	-
Muriate of potash	-	-	50-62
Potassium nitrate	13	-	44
Potassium sulfate	-	-	50
Sodium nitrate	16	-	-
Superphosphate (ordinary)	-	18-20	-
Superphosphate (double or triple)	-	32-54	-

some common fertilizer materials are given in table 6. Calcium, magnesium, and sulfur, which occur incidentally or are intentionally added, are called secondary nutrients in fertilizers. Trace nutrients, copper, zinc, boron, manganese, iron, and molybdenum, may also be present in minute amounts in some fertilizers.

Fertilizers with specific grades are made by mixing appropriate quantities of nitrogen, phosphorus, and potassium fertilizers. If all the primary nutrients are included, the mixed fertilizer is said to be a complete fertilizer. Ingredients needed to supply the primary nutrients for 100 kilograms of a particular grade seldom weigh 100 kilograms. A filler is added to make up the difference in weight. The filler may be an inert material, or it may be a neutralizing agent, such as limestone, to reduce acidity. Preparation of 100 kilograms of 8-8-8 from ammonium nitrate (33.5 percent N), triple superphosphate (46 percent P_2O_5), muriate of potash (60 percent K_2O), and filler is illustrated below:

(1) Calculate the amount of ammonium nitrate (35 percent N) needed to give 8 kilograms of N

$$8 \text{ kg N} \div 0.335 = 23.9 \text{ kg ammonium nitrate}$$

(2) Calculate the amount of triple superphosphate (46 percent P_2O_5) needed to give 8 kilograms of P_2O_5

$$8 \text{ kg } P_2O_5 \div 0.46 = 17.4 \text{ kg triple superphosphate}$$

(3) Calculate the amount of muriate of potash (60 percent K_2O) needed to give 8 kilograms of K_2O

$$8 \text{ kg } K_2O \div 0.60 = 13.3 \text{ kg muriate of potash}$$

(4) Combined, the three fertilizer materials only weigh 54.6 kilograms, so 45.4 kilograms of filler must be added to give 100 kilograms.

The calculations for preparing mixed fertilizers from basic source materials are slightly more difficult if one of the source materials contains two primary nutrients. The appropriate calculations for preparation of 100 kilograms of 20-20-5 fertilizer from diammonium phosphate (21 percent N and 54 percent P_2O_5), urea (45 percent N), and muriate of potash (60 percent K_2O) are given below:

(1) Calculate the amount of diammonium phosphate (54 percent P_2O_5) needed to give 20 kilograms of P_2O_5

$$20 \text{ kg} \div 0.54 = 37.0 \text{ kg diammonium phosphate}$$

(2) Calculate the amount of N contained in 37.0 kilograms of diammonium phosphate (21 percent N)

$$37.0 \text{ kg} \times 0.21 = 7.8 \text{ kg N}$$

(3) Since the diammonium phosphate supplies 7.8 kilograms N, only 12.2 kilograms N are needed from urea. Calculate the amount of urea (45 percent N)

$$12.2 \text{ kg} \div 0.45 = 27.1 \text{ kg urea}$$

(4) Calculate the amount of muriate of potash (60 percent K_2O) required for 5 kilograms of K_2O

$$5 \text{ kg} \div 0.60 = 8.3 \text{ kg muriate of potash}$$

(5) The three ingredients weigh a total of 72.5 kilograms, so 27.5 kilograms of filler must be added for 100 kilograms of 20-20-5 fertilizer.

In fish culture, it is usually not necessary to mix ingredients and add filler as illustrated above. The appropriate quantities of fertilizer source materials may be calculated, weighed, and applied to the pond. For example, suppose that a 1-hectare pond must be treated with 20 kilograms per hectare of 10-20-0 fertilizer, and ammonium sulfate (20 percent N) and triple superphosphate (46 percent P_2O_5) are available for use. First, calculate the amounts of ammonium sulfate and triple superphosphate as follows:

(1) Since a 10-20-0 fertilizer contains 10 percent N, 20 percent P_2O_5, and 0 percent K_2O, the amounts of N and P_2O_5 in 20 kilograms of 10-20-0 are

$$20 \text{ kg} \times 0.10 = 2 \text{ kg N}$$

$$20 \text{ kg} \times 0.20 = 4 \text{ kg } P_2O_5$$

(2) Calculate the amount of ammonium sulfate (20 percent N) which contains 2 kilograms N

$$2 \text{ kg} \div 0.20 = 10 \text{ kg ammonium sulfate}$$

(3) Calculate the quantity of triple superphosphate (46 percent P_2O_5) needed to give 4 kilograms of P_2O_5

$$4 \text{ kg} \div 0.46 = 8.7 \text{ kg triple superphosphate}$$

Next, weigh out 10 kilograms of ammonium sulfate and 8.7 kilograms of triple superphosphate and apply these quantities to the pond.

Inorganic Fertilization and Fish Production

The use of fertilizers to increase fish yields has an agricultural analogy in the use of fertilizers to favor greater growth of pasture grasses which, in turn, allows increased production of livestock. Therefore, the fish culturist should understand some of the basic principles regulating the beneficial use of fertilizers in agriculture *(69)*. When a single growth factor is limiting the growth of a plant, the increase in growth with each equal successive addition of the growth factor is progressively smaller. Although slightly more complex, this idea may be extended to more than one growth factor. In crop production, the fertilization rate which results in maximum yield is not

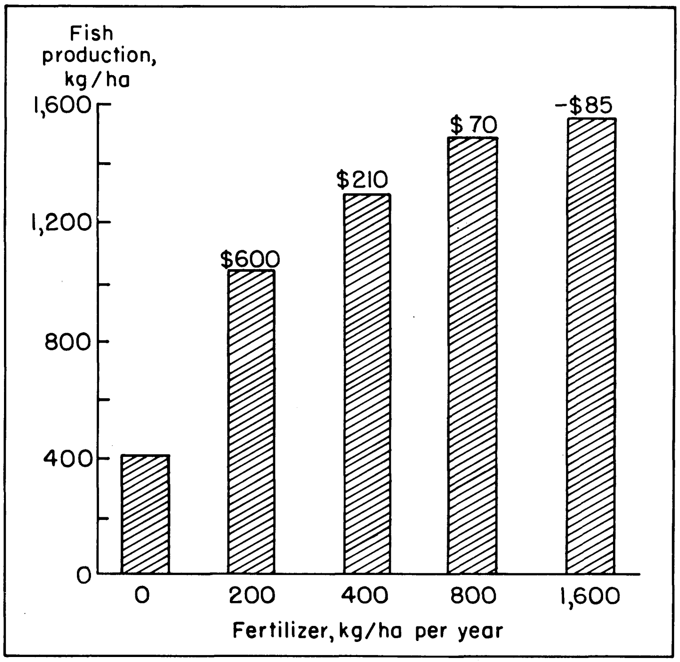

FIG. 14. An example of the increase in fish production with increasing fertilizer application rates. The value in dollars per hectare of the increase in fish production above the added cost of the fertilizer is given above the bars representing fish production at progressively increasing fertilizer rates. For calculations, fertilizer was given a value of $0.20 per kilogram and fish a value of $1.00 per kilogram.

necessarily the most economical. After the addition of a few units of fertilizer, the economic value of the increase in crop resulting from another unit of fertilizer may be less than the value of a unit of fertilizer. These same principles apply to fish production *(35, 36)*. The relationships between fertilizer rate, fish yield, and economic value of fish and fertilizer are illustrated in figure 14.

Since plankton production is most often limited by inadequate phosphorus, phosphate fertilizers are widely used in fish culture *(36, 47)*. In some ponds, it has been beneficial to include nitrogen fertilizers along with phosphate fertilizers. There has also been limited use of potassium fertilizers in fish production. Increases in fish production resulting from inorganic fertilization differ greatly, but fish production is normally increased two to five times through proper use of fertilizers *(29, 36, 62)*. Some typical increases in fish production through inorganic fertilization are summarized in table 7.

Experience with fertilization of tilapia ponds in Indonesia *(36)* indicated that the most efficient fertilization program was the application of 45 kilograms per hectare annually of P_2O_5 as superphosphate. In Europe, the annual application of 25 to 30 kilograms per hectare of P_2O_5, usually as superphosphate, has given adequate production of common carp *(47)*. In Israel, common carp and tilapia ponds are fertilized with 60 kilograms per hectare of ammonium sulfate and 60 kilograms per hectare of superphosphate at 2-week intervals *(33, 34)*. In Alabama, the most efficient fertilizer schedule for tilapia ponds consisted of biweekly applications of 22.5 kilograms per hectare of 5-20-5 fertilizer *(14)*. A popular fertilization schedule which is widely used in the Southeastern United States is outlined below.

TABLE 7. TYPICAL INCREASES IN FISH PRODUCTION FOLLOWING FERTILIZATION, THE FACTOR OF INCREASE OBTAINED BY DIVIDING PRODUCTION IN FERTILIZED PONDS BY PRODUCTION IN UNFERTILIZED PONDS

Culture species	Factor of increase attributable to fertilizer	Source
Tilapia sp.	3.70	*(36)*
Tilapia sp., *Puntius javanicus*, and *Ctenopharyngodon idella*	4.38	*(36)*
Lepomis macrochirus	3.37	*(17)*
Cyprinus carpio	1.72 to 8.32	*(33)*

(1) In mid-February or early March apply 45 kilograms per hectare of 20-20-5 fertilizer. Follow with two additional applications at 2-week intervals.
(2) Make three more applications of 45 kilograms per hectare of 20-20-5 at 3-week intervals.
(3) Continue applications of 45 kilograms per hectare of 20-20-5 at monthly intervals or whenever the water clears so that the Secchi disk visibility exceeds 45 to 60 centimeters.
(4) Discontinue applications by last week in October.

This fertilization program has been widely used and will produce moderate to dense plankton blooms in most ponds. However, recent research at Auburn University has demonstrated that ponds in well-managed pastures often need no fertilization, while woodland ponds almost invariably need to be fertilized for good fish production *(13)*; nitrogen and potassium fertilization is not required in many ponds *(18, 23)*; and periodic applications of 4.5 kilograms per hectare of P_2O_5 (10 to 12 applications per year) will give good plankton and fish production in woodland ponds *(23, 43)*.

It is unreasonable to assume that a single fertilizer application rate would be the most effective one under all conditions. Ponds vary greatly in morphometry, hydrology, bottom muds, water quality, and type of fish culture, so their responses to a given fertilization program vary greatly. To use an agricultural analogy, it is common knowledge that fertilizer requirements of different fields and crops differ greatly. Fertilization recommendations based on soil analyses have been calibrated against crop response and the results of soil analyses are used to establish fertilizer rates. Calibration must be conducted for individual crops and for specific soil associations *(55)*. The nature of different pond muds and waters no doubt varies as greatly as do the characteristics of soils, so a fertilizer rate which works perfectly well in ponds at Auburn, Alabama, may be entirely unsuitable for ponds in another locality. Unfortunately, methods for determining the fertilizer requirements of individual ponds are not available. The results reported above may serve as guidelines to establish a suitable fertilization program for a given pond. The abundance of plankton as measured by Secchi disk visibility may be used to determine if a particular fertilizer application rate is suitable. This allows for adjustments in the rate without having to wait until fish are harvested to determine if the initial application rate was successful.

Methods of Application

Large applications of fertilizers at long intervals are wasteful because much of the phosphorus is adsorbed by the mud *(31)* and nitrogen is lost through denitrification *(10)*. In the United States, fertilizers have traditionally been applied at 2- to 4-week intervals. Fertilizers may be broadcast over shallow water areas of the pond, but application is more efficient if the fertilizers are placed on underwater platforms *(41)* such as the one pictured in figure 15. This method of application prevents phosphorus fertilizer from settling to the pond bottom where the phosphorus is rapidly adsorbed by mud. Platforms should be about 30 centimeters underwater and one platform is adequate for 2 to 4 hectares of pond area. Fertilizer is simply poured on the platform and water currents distribute nutrients as they dissolve.

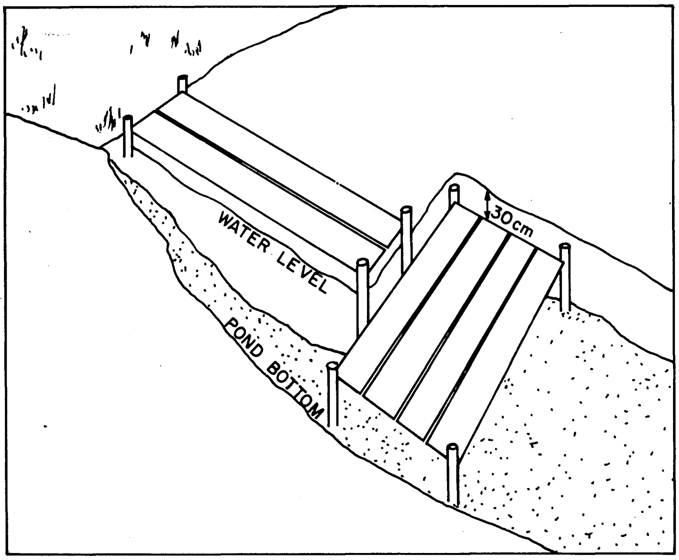

FIG. 15. A fertilizer platform.

Ponds with muddy water or water stained with humic substances in which the Secchi disk visibility is less than 30 centimeters will not respond to fertilizer nutrients because of inadequate light for plankton growth. Weed control must be effected in ponds that are choked with macrophytes, otherwise fertilizers will stimulate macrophytes instead of plankton. If the retention time of water in a pond does not exceed 3 or 4 weeks, fertilizer nutrients will be flushed out of the ponds before they produce plankton. Finally, ponds with acid muds and total alkalinities below 15 or 20 milligrams per liter may not respond to inorganic fertilization unless lime is first applied.

Some other factors must also be considered when using fertilizers. New ponds which have never been fertilized may require more fertilizer than older ponds that have a history of fertilization. Obviously, fertilization is not effective in flowing waters. In ponds where fish obtain their food almost entirely from feeds, little or no fertilizer should be applied. Some fertilizers are acid forming (urea, ammonium sulfate, ammonium nitrate) and their continued use may result in decreased alkalinity and pH. The acidity of nitrogen fertilizers can be counteracted by liming.

Organic Fertilizers

Organic fertilizers consist of various animal manures or plant wastes and are usually called manures. Organic materials may serve as direct sources of food for fish food organisms and fish, or they may decompose and the inorganic nutrients released may cause plankton blooms. Organic fertilizers have low N, P_2O_5, and K_2O contents, table 8, and tremendous quantities are required to supply the same amounts of fertilizer nutrients found in small quantities of chemical fertilizers. When added to ponds, manures decay and exert an oxygen demand. Thus, excessive applications may result in depletion of dissolved oxygen *(56)*. The rate of oxygen consumption by manure varies with the type of manure and water quality, so the fish culturist must work out safe application rates for a particular manure through trial and error or experimentation.

TABLE 8. FERTILIZER CONSTITUENTS IN FRESH MANURE OF SELECTED FARM ANIMALS — AFTER MORRISON *(46)*

Type of manure	Average composition, percent			
	Moisture	N	P_2O_5	K_2O
Dairy cattle	85	0.5	0.2	0.5
Beef cattle	85	.7	.5	.5
Poultry	72	1.2	1.3	.6
Swine	82	.5	.3	.4
Sheep	77	1.4	.5	1.2

TABLE 9. PRODUCTION OF BLUEGILL *(LEPOMIS MACROCHIRUS)* IN PONDS FERTILIZED WITH ORGANIC FERTILIZERS AND INORGANIC FERTILIZER — AFTER SMITH AND SWINGLE *(60, 62)*

Type of fertilization	Bluegill, kg/ha
Cottonseed meal, 1,160 kg/ha	423
Cow manure, 9,000 kg/ha	272
Kudzu hay, 9,000 kg/ha	176
Inorganic fertilization, 8-8-8, 1,100 kg/ha	341

Organic fertilizers are not widely used in the United States, but they receive extensive use in many other countries *(47, 50)*. Manures frequently represent waste products and may be beneficially used in fish culture. However, because of labor and transport costs they are usually more expensive per unit of N, P_2O_5, and K_2O than chemical fertilizers. Fish production may be similar or even greater in ponds treated with manures than in ponds treated with chemical fertilizers, table 9. This is especially true with species such as the tilapia that will feed directly on the manure.

Liming

Total Alkalinity and the Need for Lime

Phytoplankton growth in waters with low alkalinity is often limited by inadequate carbon dioxide and bicarbonate ion. Some waters of low alkalinity are so acid that fish do not survive or grow well. Muds in ponds with low total alkalinity are acid and strongly adsorb the phosphorus added in fertilizer. The addition of a liming material increases the pH of bottom muds and makes phosphorus more available. Liming also increases the availability of carbon for photosynthesis by raising the total alkalinity of the water. The greater total alkalinity after liming results in a higher concentration of bicarbonate ion which is in equilibrium with carbon dioxide. Liming also increases the pH and total hardness of pond waters. Ponds with total alkalinity values less than 10 milligrams per liter seldom produce adequate plankton for good fish production unless they are limed. Responses to fertilization are variable in unlimed ponds with waters containing 10 to 20 milligrams per liter total alkalinity, but unlimed ponds with waters above 20 milligrams per liter total alkalinity consistently produce adequate plankton after fertilization to allow good fish production provided all other factors are favorable *(68)*.

The decision to lime a pond should always be based on total alkalinity measurements rather than guesswork. Ponds in the same general area may differ greatly in total alkalinity. For example, most ponds near Auburn will benefit from liming, but among these are a few which have total alkalinity values well above 20 milligrams per liter. The "rule of thumb" recommendation that all ponds in the vicinity need lime would result in unnecessary and wasteful application of lime to some ponds. In determining whether to lime a pond, it should be remembered that there is no single total alkalinity value below which lime is undoubtedly needed. Experience has shown that liming is of little or no benefit if total alkalinity is above 20 milligrams per liter. At total alkalinity values below 20 milligrams per liter, judgment must be used to decide whether to lime because the need for lime increases with decreasing total alkalinity. In ponds with total alkalinity values between 15 and

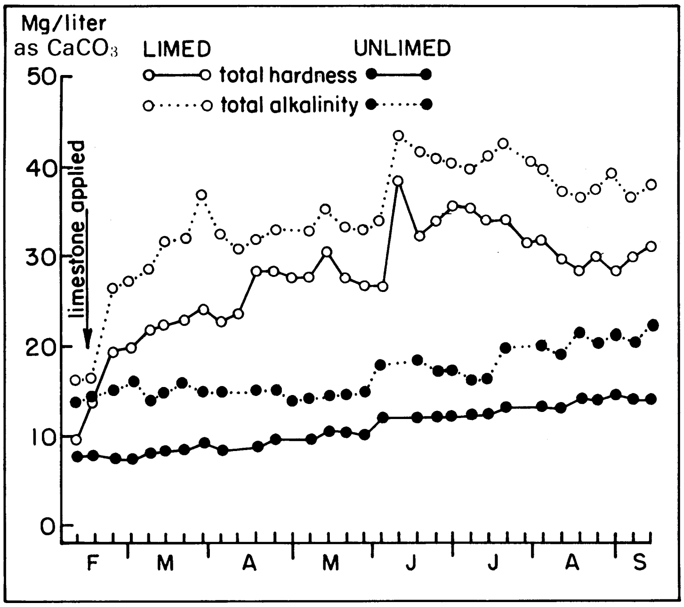

FIG. 16. Effect of application of agricultural limestone on total hardness and total alkalinity in fish ponds. After Arce and Boyd (5).

20 milligrams per liter, the response to liming may be too slight to justify the effort and expense. Lime should not be used in a pond that is not to be fertilized because liming alone will not appreciably increase fish production, except in waters that are so acid that fish will not survive or grow at normal rates. Furthermore, lime is seldom needed in ponds where fish are supplied feed and do not depend on naturally occurring organisms for food.

When lime is applied to a pond, it reacts with the mud. Until enough lime is added to satisfy the lime requirement of the mud, little if any of the added lime will be available to increase the pH, total alkalinity, and total hardness. A lime requirement procedure is available for determining the amount of lime needed to raise the total alkalinity above 20 milligrams per liter in ponds *(12)*. This procedure is based on a chemical analysis of a mud sample. Since many fish culturists and biologists will be unable to use the chemical analysis to obtain a lime requirement value for their ponds, it is suggested that liming material equivalent to about 2,000 kilograms per hectare of calcium carbonate be applied and the total alkalinity determined after 1 or 2 months. If the total alkalinity is still too low, another application equal in amount to the first should be made and the total alkalinity measured again. This procedure should be repeated until enough lime has been applied to maintain the total alkalinity above 20 milligrams per liter. The addition of liming material equal to about 2,000 to 6,000 kilograms per hectare of calcium carbonate should suffice for most ponds. However, some ponds having high concentrations of organic matter in bottom muds or sulfide deposits in bottom muds or on their watersheds may require much greater amounts of lime. Occasionally the lime application rate may be so high that the cost of the lime will be prohibitive and the water will be unsuited for fish culture.

TABLE 10. AVERAGE MUD pH VALUES FOR FIVE LIMED AND FIVE UNLIMED PONDS — LIME APPLIED BETWEEN FEBRUARY 17 AND MARCH 17, 1973

Type pond	November 1972	August 1973	January 1974
Limed	5.2	6.7	6.8
Unlimed	5.4	5.5	5.5

Typical effects of liming may be illustrated by results of experiments conducted at Auburn University *(5)*. Agricultural limestone (finely crushed $CaMg(CO_3)_2$) was applied to five ponds at the rate of 4,000 kilograms per hectare and five ponds served as the unlimed controls. All 10 ponds were fertilized. Liming caused a marked increase in total hardness and total alkalinity, figure 16, and an increase in the pH of bottom muds, table 10.

Tilapia production was 25 percent greater in the limed ponds than in the control ponds. The total alkalinity of these ponds before liming averaged 13.5 milligrams per liter. Even greater responses to liming have been reported in waters which had lower total alkalinity before liming *(17)*.

Applying Lime to Ponds

Agricultural limestone is the best liming material to use in ponds. The material should be finely ground (particles should pass through a sieve with 0.025-centimeter openings) and have a high neutralizing value. Small particle size is necessary so that the agricultural limestone will react quickly with water and mud. The neutralizing values of liming materials refer to the amounts of acid they will neutralize, expressed as a percentage of the amount of acid neutralized by an equal amount of pure calcium carbonate *(1)*. Thus, pure calcium carbonate, with a neutralizing value of 100 percent, is used as a standard in referring to liming rates. For example, if using a liming material having a neutralizing value of 80 percent, to apply at a rate equal to 2,000 kilograms per hectare of calcium carbonate would require an application of 2,500 kilograms per hectare (2,000 kg ÷ 0.80) of the liming material.

Hydrated lime (calcium hydroxide, $Ca(OH)_2$) and burnt lime (calcium oxide, CaO) have higher neutralizing values than agricultural limestone. If applied in large quantities, however, these materials cause excessively high pH and fish mortality. Hydrated lime and burnt lime are sometimes applied to waters which contain no fish or to muds of ponds which have been drained to raise the pH and kill fish disease organisms. Basic slag has been used as a liming material in fish culture, but since its neutralizing value is lower than that of most agricultural limestones, extremely large applications are required *(75)*. Agricultural gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$) is not a liming material, although it has incorrectly been used as one by some fish culturists.

Liming materials can be easily broadcast over the bottoms of empty ponds, but application is more difficult when ponds are full of water. Best results may be achieved by broadcasting the liming material over the entire pond surface. Bags of liming material may be emptied from a moving boat. Bulk liming material is cheaper and may be applied from a plywood platform attached between two boats, figure 17. Liming material should be applied during late fall or early winter in temperate regions so that it will react with waters and muds before fertilizers are applied in the spring. In tropical regions, lime should be applied at least 1 month before fertilizer applications are initiated. This is important because liming materials will precipitate phosphorus if applied at or near the same time as fertilizers. However, reaction of liming material with the mud increases availability of phosphorus fertilizer. The residual effect of liming is governed by the rate of water loss to seepage and pond overflow. In ponds with normal rates of water loss, liming will usually last 3 to 5 years. Once a pond has been limed, small annual applications (20-25 percent of the initial application rate) may be used to avoid having to make large applications of lime every few years.

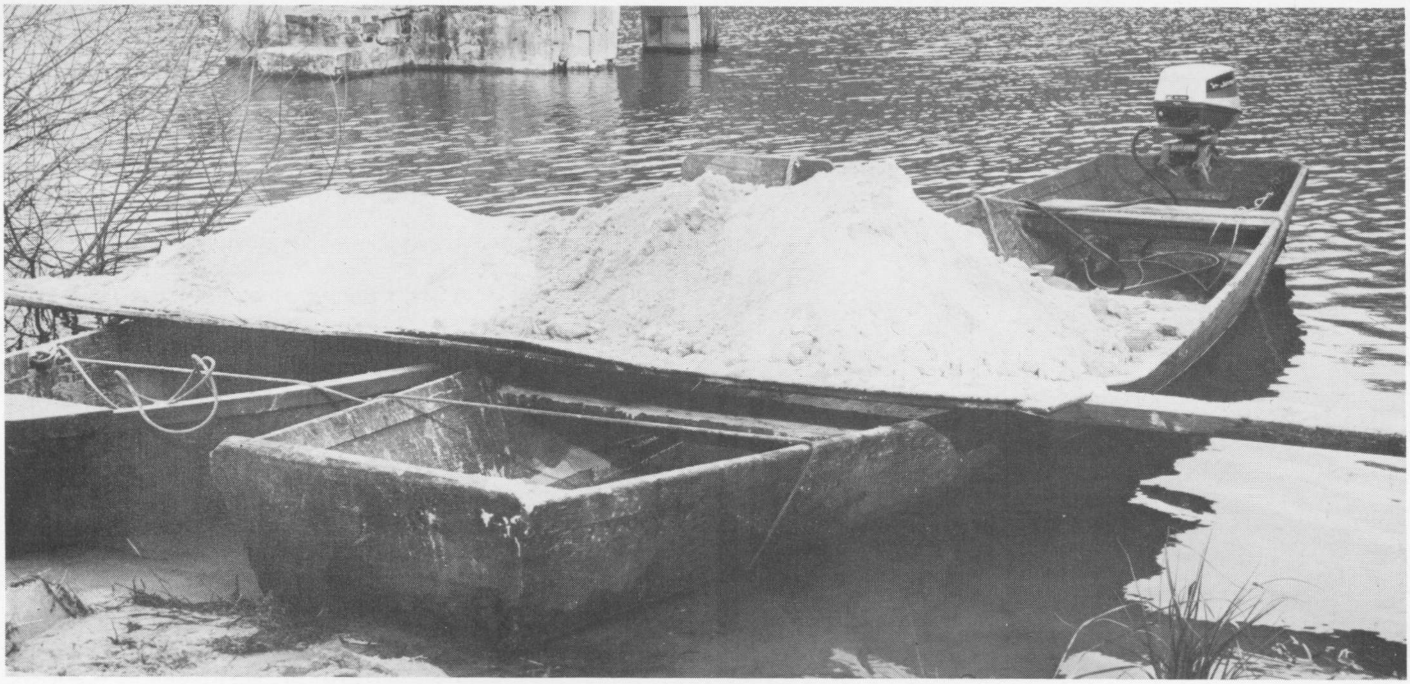

FIG. 17. A simple method for applying agricultural limestone to a pond which is full of water.

Removal of Clay Turbidity

In some ponds, it is necessary to remove the turbidity caused by suspended clay particles so that light will penetrate deep enough into the pond for phytoplankton growth. The oldest technique for removing clay turbidity involves the application of organic matter *(38, 67)*. Recommendations vary, but the most popular include: two or three applications of 2,000 kilograms per hectare of barnyard manure; one or more applications of 2,000 to 4,000 kilograms per hectare of hay; and 75 kilograms of cottonseed meal plus 25 kilograms of superphosphate per hectare at 2- to 3-week intervals. The effectiveness of organic matter applications in removing clay turbidity varies, and several weeks must usually pass before success of a particular treatment can be determined.

A better method for removal of clay turbidity is treatment with filter alum (aluminum sulfate, $Al_2(SO_4)_3 \cdot 14H_2O$). Alum will cause suspended clay particles to coagulate and precipitate from the water within a few hours *(51)*. The exact application rate for alum may be determined by treating samples of pond water in beakers with concentrations of alum ranging from 10 to 40 milligrams per liter at 5 milligrams per liter concentration intervals. The lowest concentration of alum which causes a floc of clay particles to form within 1 hour is taken as the desired treatment rate. Many fish culturists will be unable to conduct this test, but an application of 25 to 30 milligrams per liter will apparently precipitate the clay turbidity from most ponds. When applying alum, it should be dissolved in water and quickly distributed, preferably by spraying, over the entire pond surface. Application should be made during calm, dry weather because mixing by wind and rain will break up the floc and prevent it from settling out. The results of alum treatment in four ponds are illustrated in table 11. Alum has an acid reaction in water, so it destroys total alkalinity and reduces pH. Each milligram per liter of alum will decrease the total alkalinity by 0.5 milligram per liter. If the total alkalinity of water is below 20 milligrams per liter, alum treatment may depress the pH to the point that fish are adversely affected. Hydrated lime (calcium hydroxide, $Ca(OH)_2$) applied simultaneously at the rate of 0.40 milligram per liter for each 1.0 milligram per liter increment of alum will prevent unfavorable changes in alkalinity and pH. Another alternative is to lime ponds with waters of low alkalinity before treating with alum. Liming materials will often precipitate clay turbidity, but if turbidity persists after liming, alum treatment may be conducted without danger of pH depression.

Although alum treatment will clear pond water of clay turbidity, it does nothing to correct the cause of turbidity. Unless the source of the turbidity is eliminated, ponds will again become turbid with clay particles. Clay turbidity usually results because ponds receive large volumes of turbid runoff after each rain. Erosion of the watershed may be prevented by revegetation. If this is impossible, it is sometimes possible to divert the turbid runoff from the pond by use of a diversion ditch.

Reduction of pH

Waters with high total alkalinities and low total hardnesses may have dangerously high pH values during periods of rapid phytoplankton growth. Although waters of this type do not occur often, an analysis should be made to determine if the potential for high pH exists.

Liming to increase total hardness is of no value in preventing high pH because lime application increases total alkalinity and total hardness by roughly the same amount. Applications of ammonium fertilizers have been recommended to lower the pH of pond water. The ammonium ion in fertilizer is nitrified to

TABLE 11. EFFECTS OF ALUM (ALUMINUM SULFATE) TREATMENT ON CLAY TURBIDITY IN FISH PONDS

Pond	Alum applied, mg/liter	Turbidity units		Reduction in turbidity, percent
		Before treatment	After treatment	
E-67	15	40	2	95
E-68	20	28	3	89
E-73	20	19	3	84
S-27.....	20	830	24	97

nitrate with the release of hydrogen ion which lowers the pH. However, at high pH a large percentage of the ammonium ion applied to a pond will immediately be transformed to un-ionized ammonia, which is highly toxic to fish. Filter alum (aluminum sulfate) may be added to ponds to decrease pH. An alum treatment equal in milligrams per liter to the phenolphthalein alkalinity will reduce the pH to approximately 8.3. Although alum treatment may be used to prevent a fish kill when the pH is too high, it does nothing to change the conditions responsible for high pH.

Agricultural gypsum (calcium sulfate) may be applied to water to increase the total hardness without affecting the total alkalinity. Experience indicates that gypsum will alleviate the conditions responsible for high pH, but confirmatory research is needed. The best treatment rate for agricultural gypsum appears to be the amount which will increase the total hardness to a level where it equals the total alkalinity. The treatment rate may be determined from the following equation:

$$\begin{array}{l}\text{agricultural}\\ \text{gypsum (mg/liter)}\end{array} = (\text{total alkalinity} - \text{total hardness}) \times 2.2$$

The agricultural gypsum should be applied in the same manner as liming materials. The residual effect of gypsum treatment is not known.

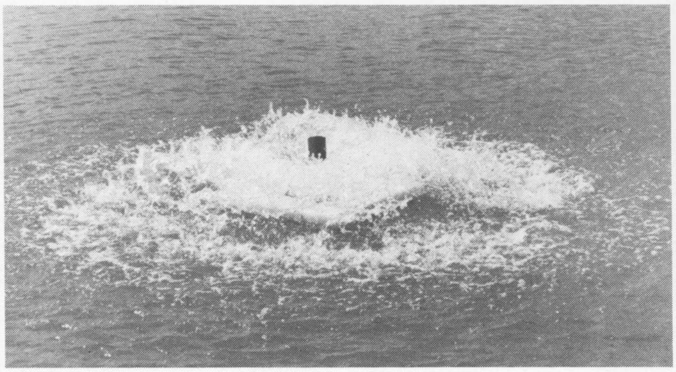

FIG. 18. A small spray-type surface aerator.

Dissolved Oxygen

Almost all problems with dissolved oxygen in fish culture are the consequences of heavy plankton blooms. In fertilized ponds, fertilization should be halted when plankton blooms get too dense (i.e., Secchi disk readings of 25 centimeters or less). In ponds where fish are supplied feeds, heavy plankton blooms are the natural consequences of high feeding rates. Lower feeding rates will result in less plankton growth, but only at the expense of decreased fish production. Suitable plankton densities result in Secchi disk visibilities of 30 to 60 centimeters. The probability of problems with low dissolved oxygen concentration increases as the magnitude of the Secchi disk visibility decreases below 30 centimeters. In ponds with Secchi disk visibility values of 10 to 20 centimeters, dissolved oxygen concentrations may fall so low at night that fish are stressed, and a cloudy day may lead to dissolved oxygen depletion the following morning *(53)*.

A number of procedures are used to prevent fish kills when dissolved oxygen concentrations are dangerously low. Application of up to 6 or 8 milligrams per liter of potassium permanganate has been frequently recommended in the United States *(42)*. The potassium permanganate is supposed to oxidize organic matter and lower the demand for dissolved oxygen in the pond. Recent research *(72)* has demonstrated that potassium permanganate is entirely worthless for this purpose and that its application actually increases the length of time required for dissolved oxygen concentrations to return to normal levels. Applications of calcium hydroxide have been recommended to destroy organic matter in ponds with low dissolved oxygen concentrations and thereby reduce rates of oxygen consumption by bacteria. There is no reason to believe that applications of calcium hydroxide will lower concentrations of organic matter. However, when dissolved oxygen is low, carbon dioxide is usually quite high. The application of calcium hydroxide will remove carbon dioxide which will allow fish to better utilize the low concentration of dissolved oxygen. Each milligram per liter of carbon dioxide will require 0.84 milligram per liter of calcium hydroxide for its removal. For example, if a pond contains 25 milligrams per liter of carbon dioxide, a calcium hydroxide treatment of 21 milligrams per liter (25 × 0.84) would remove the carbon dioxide. Following phytoplankton die-offs, applications of fertilizers have been employed to encourage phytoplankton growth and encourage dissolved oxygen production. Research to document the effectiveness of this

FIG. 19. A Crisafulli pump and sprayer.

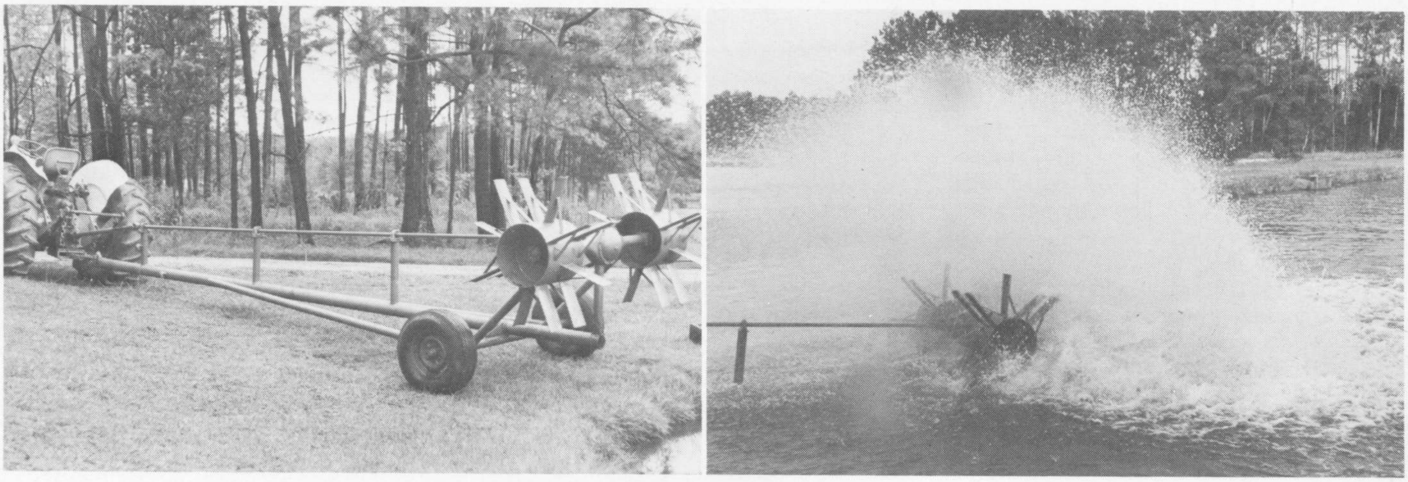

FIG. 20. A paddlewheel aerator.

procedure has not been conducted, but nutrient concentrations are already high in ponds following phytoplankton die-offs and it is doubtful that fertilization is necessary.

The only really effective procedure for preventing fish mortality during periods of extremely low dissolved oxygen involves the use of mechanical devices *(28, 45)*. Large, tractor-powered pumps may be used to pump fresh, oxygenated water from a nearby pond into the pond with low dissolved oxygen concentrations. Alternatively, water from well, spring, or stream may be released into the oxygen depleted pond. Well water should be discharged across a baffle for aeration because well water is often high in carbon dioxide and deficient in dissolved oxygen. When oxygenated water is released into a pond with oxygen depletion, bottom water which contains less dissolved oxygen and more carbon dioxide than surface water should simultaneously be released from the pond if possible. Pumps may also be used to remove water from the pond with low dissolved oxygen and release it with force back onto the surface of the same pond. The agitation and circulation of the water increases its dissolved oxygen content. However, this method is not as effective as pumping fresh, oxygenated water from another pond or well into the pond with low dissolved oxygen.

Various types of aeration devices may be used to introduce oxygen into waters with low dissolved oxygen concentrations. Small spray-type surface aerators are in common use, figure 18. These aerators are most effective in small ponds or when several are operated in a large pond. More powerful aerators, such as the Crisafulli pump and sprayer, figure 19, and the paddlewheel aerator, figure 20, supply considerably more dissolved oxygen to ponds than the spray-type surface aerators. However, Crisafulli pumps and paddlewheel aerators are expensive and must be operated from the power take-off of a farm tractor. Large fish farms and research stations can afford to maintain and operate emergency aeration equipment, but small scale fish culturists have little recourse when faced with dissolved oxygen problems. Fortunately, problems with dissolved oxygen seldom occur except in ponds where fish are fed at high rates.

Fish culturists often monitor dissolved oxygen concentrations during the night in ponds to determine if emergency aeration is needed. Recent research has resulted in procedures for predicting how low dissolved oxygen concentrations will fall during the night *(20, 53, 54)*. Such predictions permit the fish culturist to prepare for emergency aeration in advance. The simplest of these procedures involves the measurement of dissolved oxygen concentrations at dusk and 2 or 3 hours later. These two values are plotted versus time on a graph and a straight line is projected through the two points and used to estimate the dissolved oxygen concentration at later hours during the night. The use of this technique is illustrated in figure 21.

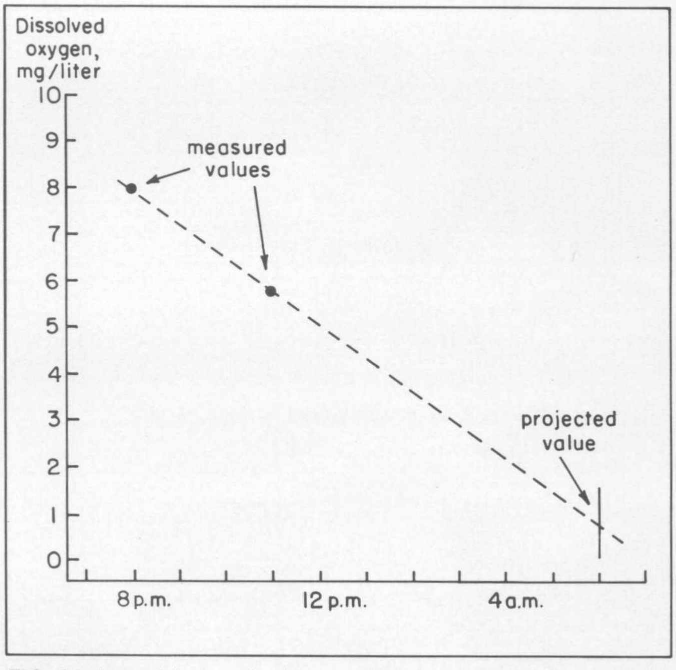

FIG. 21. A graphical method for predicting the nighttime decline in dissolved oxygen concentration in fish ponds. After Boyd et al. (20).

Fish Feeding and Water Quality

Fish eat most of the feed applied to ponds, but on a dry matter basis only about 25 percent of the nutrients in the feed is converted to fish flesh *(11)*. The rest of the nutrients reach the water as metabolic waste. This waste includes carbon dioxide, ammonia, phosphate, and other inorganic and organic substances. These nutrients stimulate plankton production, and the amount of organic matter produced by photosynthesis will exceed by several times the amount of organic matter reaching the water in metabolic waste *(11)*. The density of plankton in a pond is closely related to the feeding rate. For example, during the course of the growing season the feeding rate was gradually increased in catfish ponds resulting in a corresponding decrease

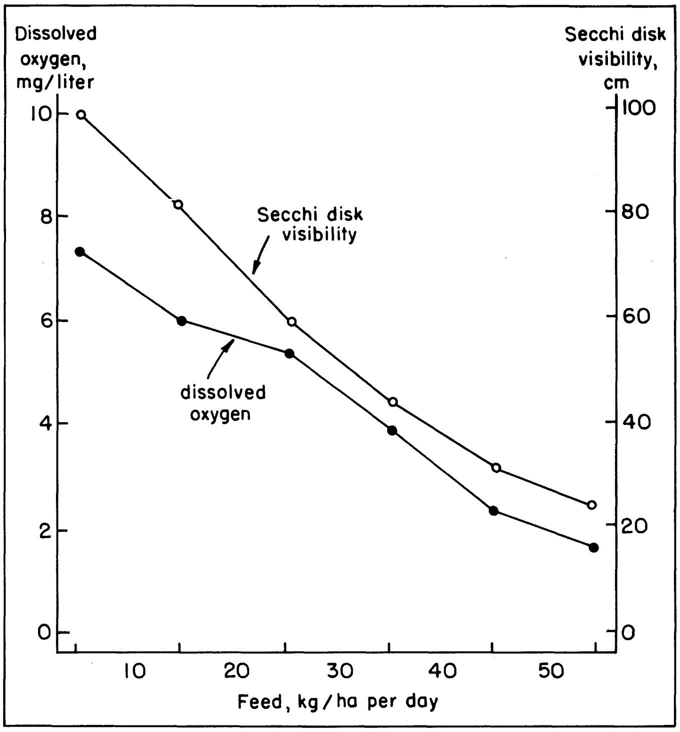

FIG. 22. Secchi disk visibilities and early morning (6:30 a.m.) dissolved oxygen concentrations in a channel catfish pond as the feeding rate was gradually increased from May to September.

in Secchi disk visibilities, figure 22. Along with the decrease in Secchi disk visibilities, there was a decrease in the early morning dissolved oxygen concentrations, figure 22. Similarly, average plankton density increased and average concentrations of dissolved oxygen in the early morning decreased with greater feeding rate in catfish ponds with low, medium, and high feeding rates, table 12.

TABLE 12. AVERAGE EARLY MORNING DISSOLVED OXYGEN CONCENTRATIONS AND SECCHI DISK VISIBILITIES IN CHANNEL CATFISH PONDS WITH DIFFERENT FEEDING RATES

Feeding rate	Early morning dissolved oxygen, mg/liter	Secchi disk visibility, cm
Low (34 kg/ha per day)........	4.71	68
Medium (56 kg/ha per day)	2.95	45
High (78 kg/ha per day)	1.95	21

Obviously, the frequency of dissolved oxygen problems increases with feeding rate. Thus, the ultimate limit on feeding rate and on fish production is set by water quality. As a general rule, fish production increases linearly with feeding rate while water quality deteriorates exponentially with feeding rate.

Aquatic Plant Control

As mentioned earlier, one effective technique of controlling many species of macrophytes is through fertilization to produce plankton turbidity and shade the pond bottom. This technique is especially powerful if ponds are constructed so that no areas are shallower than about 60 centimeters. Grass carp (white amur) eat tremendous quantities of aquatic vegetation and provide a biological method for controlling macrophytes. When stocked at 60 to 80 per hectare, grass carp will control most species of macrophytes that cannot be controlled by plankton turbidity. Grass carp are even effective in controlling macrophytes in ponds that are not turbid with plankton. In small ponds, macrophytes may be controlled by cutting or by dragging them out with a rake or seine.

Herbicides are also used in fish culture to control macrophytes. The manufacturer's label gives the rate and method of application for a herbicide. The label provides information on safety precautions. Usually, the concentrations of aquatic herbicides used to kill macrophytes are safe to fish. Decay of macrophytes killed by herbicides can cause dissolved oxygen depletion. If ponds have extensive areas of macrophytes, one-fourth to one-fifth portions of the pond should be treated at 1- to 2-week intervals to reduce the chance of dissolved oxygen depletion. The major limitation of herbicides for controlling macrophytes is that once the concentration of a herbicide declines to a non-toxic level, macrophytes will regrow. Thus, repeated applications of herbicides are required to control macrophytes, often at considerable expense.

Algicides are sometimes used to control phytoplankton in ponds. Copper sulfate, the most widely used algicide, will kill most species of phytoplankton at concentrations of 0.1 to 0.5 milligram per liter in waters with total alkalinities below 40 or 50 milligrams per liter *(70)*. In waters with higher alkalinities, copper sulfate concentrations of 1.0 milligram per liter or more may be required to kill phytoplankton. Copper sulfate may be applied by dissolving it in water and distributing it over the pond surface. Alternatively, copper sulfate crystals may be placed in a burlap bag and the bag towed behind a boat until the copper sulfate dissolves. Burlap bags of copper sulfate may be positioned in ponds so that the chemical gradually dissolves and mixes with the water *(22)*. Copper sulfate may also be used to treat scums of phytoplankton which drift to the leeward sides of ponds *(40)*.

Phytoplankton killed by copper sulfate decomposes rapidly and may result in low dissolved oxygen concentrations. Copper sulfate has no appreciable residual toxicity and phytoplankton growth will resume soon after treatment. Fish are susceptible to copper sulfate, and in waters with alkalinities less than 20 milligrams per liter, treatment with 0.5 to 1.0 milligram per liter of copper sulfate may kill fish.

Synthetic algicides, such as Diuron (3-(3, 4 dichlorophenyl)-1, 1-dimethyl urea) and Simazine (2-chloro-4, 6-bis (ethylamino)-triazine), are sometimes used to kill phytoplankton. These algicides are extremely toxic to algae, have a long residual action, and are not toxic to fish at concentrations used to kill phytoplankton. As with copper sulfate, extensive mortality of phytoplankton following applications of synthetic algicides may result in depletion of dissolved oxygen. Some fish culturists have attempted to "thin" phytoplankton blooms by small, periodic applications of synthetic algicides to ponds receiving heavy applications of feed. However, recent research *(73)* demonstrated that this practice results in prolonged periods of low dissolved oxygen concentrations and reduced fish yields.

Calculations for Chemical Treatments

Concentrations for chemical treatments of ponds are given in milligrams per liter so fish culturists must calculate how much of a chemical to add to a pond to give the desired concentration. To calculate the amount of a chemical needed, the volume of the pond must be known. Assuming the surface area of a pond is known, the simplest technique for obtaining the average depth to use in computing the volume is to make transects (8 or 10 will usually suffice) across the pond in a boat while making depth soundings at regular intervals with a calibrated rod or sounding line. The average of all soundings is taken as the average depth.

Once the volume of a pond is known, it is a simple matter to calculate treatment rates. For calculations of pond treatments, one must realize that 1 gram per cubic meter is equivalent to 1 milligram per liter. The following examples illustrate how to calculate amounts of chemicals to add to ponds.

Example. A pond has a surface area of 0.26 hectare and an average depth of 1.15 meters. How much filter alum (100 percent pure) must be applied to the pond to give an alum concentration of 25 milligrams per liter?

(1) Since 0.26 hectare = 2,600 square meters, the pond volume is:

$$2{,}600\ m^2 \times 1.15\ m = 2{,}990\ m^3$$

(2) Each cubic meter will require 25 grams of alum for a concentration of 25 milligrams per liter, so the amount of alum needed for the entire pond is:

$$2{,}990\ m^3 \times 25\ \text{grams}/m^3 = 74{,}750\ \text{grams}$$

(3) A treatment of 74,750 grams equals 74.75 kilograms.

Example. The average depth of a pond is 0.57 meter and the surface area is 0.01 hectare. How much agricultural gypsum (80 percent pure) must be applied to produce a gypsum concentration of 50 milligrams per liter?

(1) Since 0.01 hectare = 100 square meters, the pond volume is:

$$100\ m^2 \times 0.57\ m = 57\ m^3$$

(2) Each cubic meter will require 50 grams of gypsum for a concentration of 50 milligrams per liter, but the agricultural gypsum is only 80 percent pure. Therefore, we may calculate the concentration of gypsum as follows:

$$50\ \text{grams} \div 0.80 = 62.5\ \text{grams}$$

The amount of agricultural gypsum needed for the entire pond will be:

$$57\ m^3 \times 62.5\ \text{grams}/m^3 = 3{,}562\ \text{grams or } 3.56\ kg$$

Example. A pond with a volume of 1,000 cubic meters must be treated with a herbicide. The herbicide is a liquid with 75 percent active ingredient and a density of 0.85 gram per milliliter (0.85 kilogram per liter). How much of the liquid herbicide must be applied to the pond to give a concentration of 1 milligram per liter of active ingredient?

(1) The amount of the active ingredient to give a concentration of 1 milligram per liter is:

$$1{,}000\ m^3 \times 1\ \text{gram} = 1{,}000\ \text{grams} = 1.0\ kg$$

(2) The herbicide has an active ingredient content of 75 percent, so the weight of herbicide containing 1.0 kilogram active ingredient is:

$$1.0\ kg \div 0.75 = 1.33\ kg$$

(3) The density of the herbicide is 0.85 kilogram per liter, so the volume of the herbicide weighing 1.33 kilograms is:

$$1.33\ kg \div 0.85\ kg/\text{liter} = 1.56\ \text{liters}$$

Thus, 1.56 liters of the liquid herbicide would give a concentration of 1 milligram per liter of the active ingredient when applied to the pond.

Chemicals which are applied to ponds come in a variety of formulations including crystals, solutions, wettable powders, emulsifiable concentrates, and granules. Fish culture stations and large fish farms can afford rather elaborate equipment for applying chemicals. For example, chemicals may be dissolved in a tank of water or some other solvent and sprayed over the surface with a power sprayer. Liquids may be dispersed uniformly from a boat mounted tank through a boom consisting of a pipe with a series of small diameter holes in its underside. A valve regulates the rate at which the solution is fed by gravity into the water, or a pump may be used to effect more uniform and forceful release. Dispensers for granules or powders may consist of hoppers with adjustable dispensing holes in the bottom. An auger is employed to prevent clogging of holes. Finally, chemicals may be released into the wash of an outboard motor propeller to effect mixing as the boat moves over the pond surface.

In instances where the owner of one or a few ponds must apply chemicals, it is usually not practical to purchase or construct an elaborate dispenser. The chemical can be dissolved or mixed in a large container of water and applied to the pond surface. Application may be accomplished with a pressurized garden sprayer, or the solution or mixture may be splashed with a dipper over the pond surface. Care should be taken to dispense the chemical as uniformly as possible. Granules may be broadcast by hand or with a small "cyclone" seeder. Crystals may be placed in a burlap bag and the bag towed behind a boat until they have dissolved. Only a little ingenuity is needed to develop a method for applying a chemical to a pond once the treatment rate has been established.

WATER ANALYSIS

Water analysis is a highly specialized field and methods for measuring the concentration of almost any possible constituent of water are available. These methods may be found in several standard water analysis manuals. The most widely used of these manuals is the *Standard Method for the Examination of Water and Wastewater (3)*. To make water analyses according to standard procedures, a water analysis laboratory and a well trained analyst are essential. In practical fish culture, however, only a few water quality data are needed in making water quality management decisions. These normally include pH, total alkalinity, total hardness, dissolved oxygen, carbon dioxide, and plankton abundance. Water analysis kits, such as the one illustrated in figure 23, are available at a modest cost. The kits provide sufficiently accurate data on which to base management decisions *(15)*. A Secchi disk, which may be constructed from common items or purchased for a small cost, may be used to estimate plankton abundance.

Sampling Water

Water samples for dissolved oxygen or carbon dioxide analyses must be collected so that they do not come in contact with the atmosphere. If a sample is supersaturated with dissolved gases, the gases are lost to the atmosphere. Samples below saturation will gain gases from the atmosphere. A number of samplers are available for collecting water for dissolved gas analyses, but the least expensive types may be obtained from the

FIG. 23. A small water analysis kit suitable for use in fisheries management.

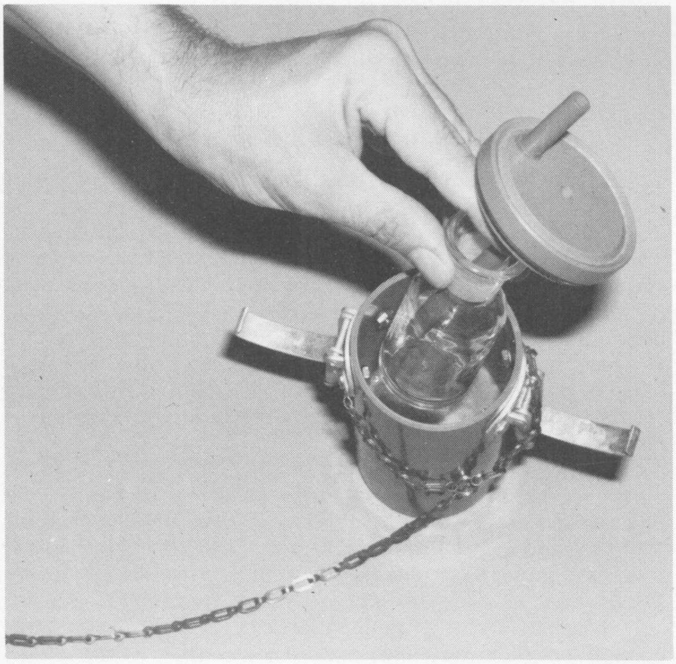

FIG. 24. A small sampler for taking samples for dissolved gas analysis.

manufacturers of water analysis kits. A small sampler for dissolved gases is shown in figure 24. Samples for total alkalinity, total hardness, or pH may come in contact with the air without introduction of appreciable errors in measurement. Samples of surface water may be secured by simply immersing an open-mouthed bottle and allowing it to fill. Samplers may also be constructed for obtaining water from greater depths. For example, a stoppered bottle may be attached to a wooden stick and lowered to the desired depth. The stopper is then jerked out with an attached cord so that the bottle may fill. This sampler is illustrated in figure 25. A slightly more elaborate sampler for taking water from specific depths is shown in figure 26. The bottle is lowered to the desired depth and the stopper is removed by a sharp tug on the line. Once the water sample has been collected it should be analyzed as soon as possible to prevent changes in concentrations of the constituents of interest.

Water Analysis Kits

The largest and best known manufacturer of water analysis kits is probably the Hach Chemical Company of Ames, Iowa, and Loveland, Colorado. However, kits of comparable quality may be obtained from other companies, so the use of the Hach water analysis kits in the illustrations is by no means an endorsement of Hach Chemical Company products. In using kits, the directions should be followed carefully and all operations conducted with as much precision as possible. Slight errors in measuring the volumes of samples or titrating agents

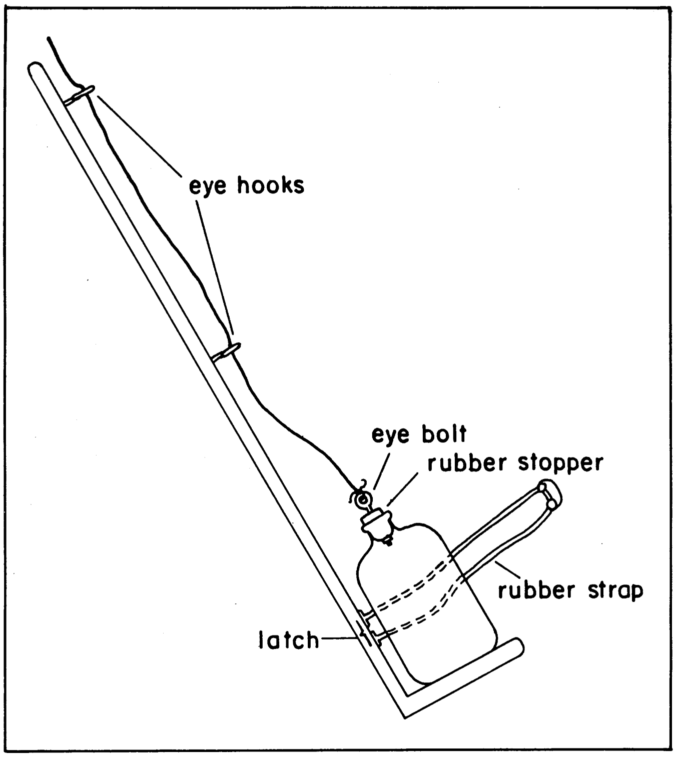

FIG. 25. Water sampler useful for collecting water from depths of up to 2 meters.

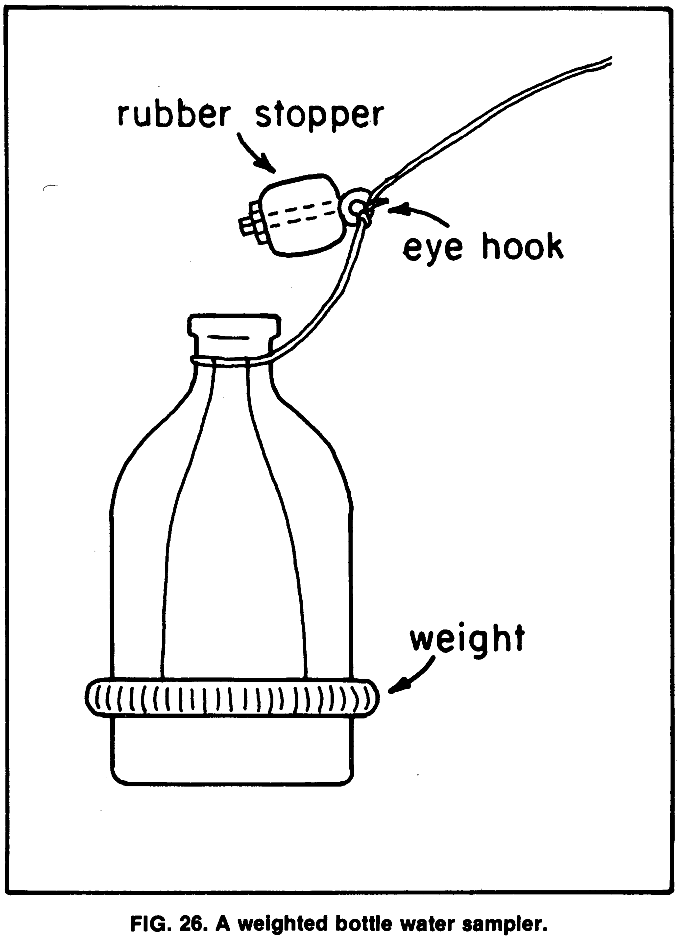

FIG. 26. A weighted bottle water sampler.

will be greatly magnified in the final results. For measuring total hardness or total alkalinity on samples with low concentrations (below 20 or 30 milligrams per liter) of these constituents, the volumes of samples and reagents should be increased by five times to get reliable results. Measurements of pH with water analysis kits are 0.5 to 1.0 pH unit higher than the correct values obtained with a pH meter. The reagents in water analysis kits deteriorate with time and should be replaced every 6 to 12 months. In spite of the limitations of water analysis kits, they are often the only method available for water analysis in fish culture, and with reasonable care the kits will provide useful data. In table 13, comparisons are made between data obtained on the samples by a Hach Model AL-36B water analysis kit, figure 23, and by standard laboratory procedures.

TABLE 13. COMPARISON OF DETERMINATIONS MADE ON WATER SAMPLES BY STANDARD METHODS (*3*) AND A HACH WATER ANALYSIS KIT (MODEL AL-36B) — AFTER BOYD (*15*)

Procedure	Sample			
	A	B	C	D
Total alkalinity (mg/liter)				
Standard method	11.0	31.8	49.6	119.7
Hach kit	15.6	33.7	49.4	116.3
Total hardness (mg/liter)				
Standard method	7.7	27.1	53.4	107.5
Hach kit	11.1	32.7	55.7	110.4
Carbon dioxide (mg/liter)				
Standard method	1.2	4.3	10.9	18.0
Hach kit	5.0	5.0	10.0	15.0
Dissolved oxygen (mg/liter)				
Standard method	1.1	2.7	4.9	8.6
Hach kit	2.0	2.8	4.0	8.0
pH				
Standard method	4.5	5.5	7.8	8.8
Hach kit	5.0	6.1	9.0	9.7

More advanced, and expensive, water analysis kits are available, figure 27. These kits have the capacity for measuring dissolved gases, pH, ammonia, nitrate, nitrite, phosphate, sulfate, chloride, conductivity, and several other water quality variables. The more elaborate kits are suitable for fishery management work and for some types of research in fish culture (*16*).

Secchi Disk Visibility

A Secchi disk is 20 centimeters in diameter, painted with black and white quadrants, and attached to a calibrated line, figure 28. The disk is weighted on the underside with a lead plate so that it will sink readily. Secchi disks may be purchased from scientific supply houses or constructed from sheet metal, plexiglass, or masonite. A flat paint should be used to prevent glare. A suitable alternative to attaching the disk to a calibrated line is to attach it from its center to a vertical meter stick. Secchi disk visibilities seldom exceed 100 centimeters in productive fish culture systems, so measurements will seldom be limited because of the length of the meter stick.

Secchi disk visibility is not a suitable estimate of plankton unless plankton is the primary source of turbidity. An experienced observer can readily distinguish between plankton turbidity and other forms of turbidity. However, the novice must remember that plankton blooms are not always green. Plankton blooms may also impart yellow, red, brown, or black coloration to water. Usually plankton organisms are large enough that their particulate nature is obvious if water and its contents are viewed against a white background.

To obtain the Secchi disk visibility, lower the disk into the

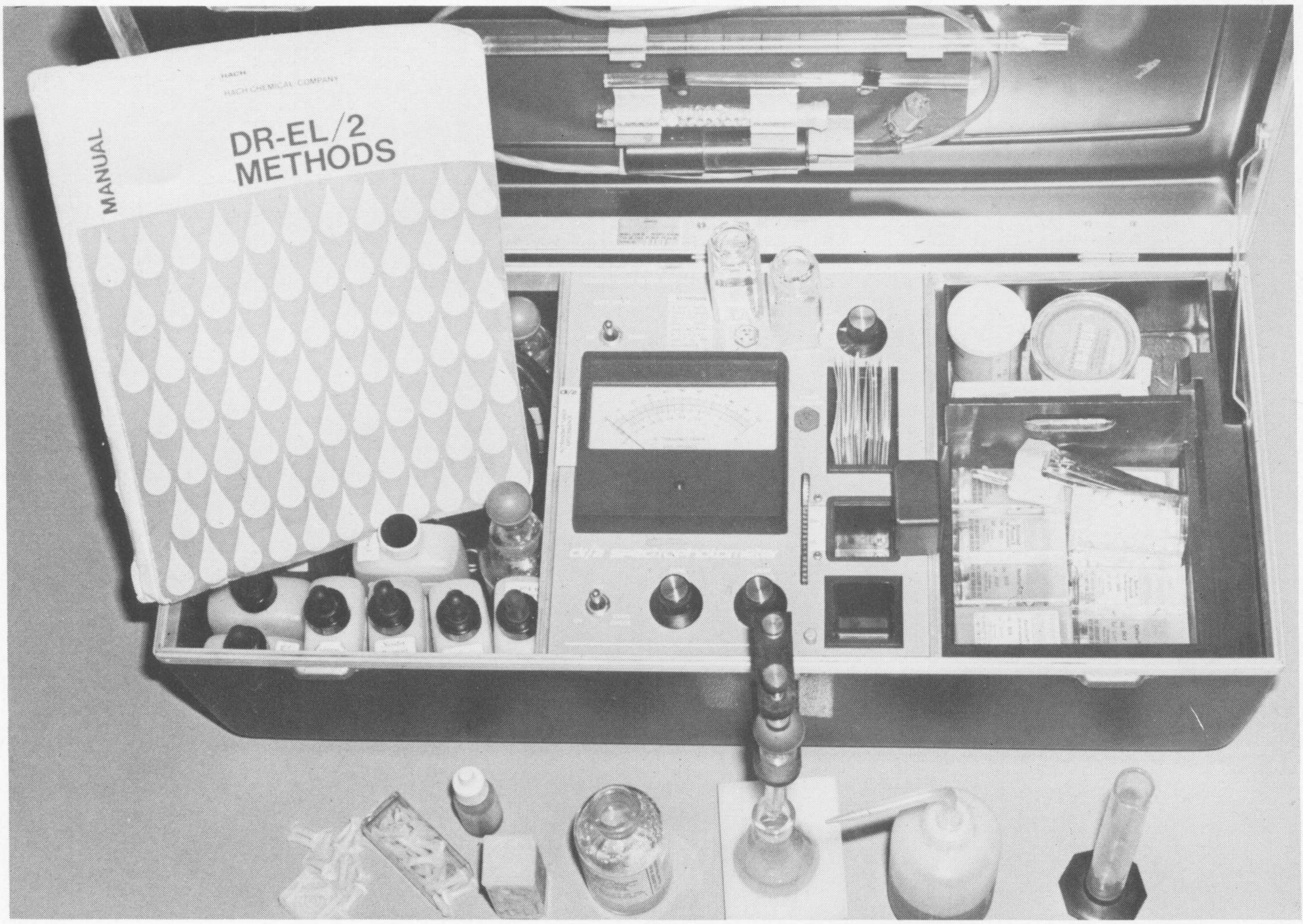

FIG. 27. A large water analysis kit used in fisheries management and occasionally in fisheries research.

water until it just disappears and record the depth. Lower the disk a little more and then raise it until it just reappears and record the depth. In making these measurements, view the disk from directly above. The average of the two depth readings is the Secchi disk visibility. Conditions for taking Secchi disk measurements should be standardized. A good practice is to make measurements on calm days between 9 a.m. and 3 p.m. If possible, make readings when the sun is not behind clouds. Make measurements on the lee (downwind) side of the boat with the sun behind you. Even when conditions are carefully standardized, Secchi disk visibilities obtained at the same time by different observers for the same body of water will vary slightly. Furthermore, the same observer may obtain slightly different readings if the disk is viewed in the same pond at different times of the day. In practice these slight variations are not critical. In the absence of a Secchi disk, any white object or even the palm of your hand can be used to judge turbidity in pond waters.

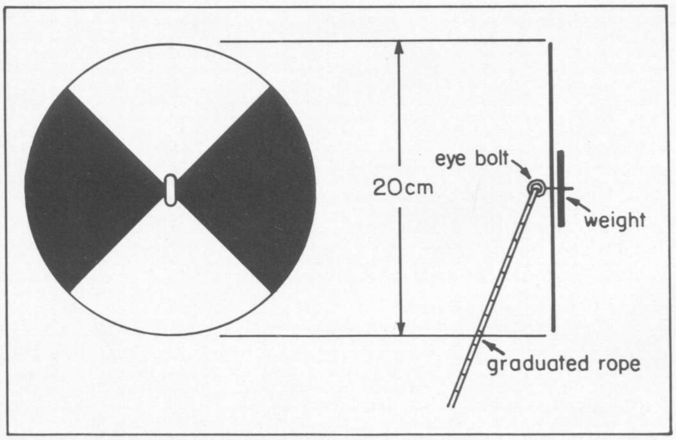

FIG. 28. A Secchi disk.

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GLOSSARY

ACID. A substance characterized by the ability to react with bases or alkali in water to form salts. An acid releases hydrogen ions upon dissociation in water.

ACIDIC. Tending to be acid.

ACID DEATH POINT. A pH so low as to kill fish. A pH of less than 4 will usually kill fish.

ACUTE TOXICITY. The toxicity of a substance after a short exposure time of a few hours or days.

AERATION. To aerate, to supply oxygen to pond water by mechanical or physical means.

AGRICULTURAL GYPSUM. Calcium sulfate, $CaSO_4 \cdot 2H_2O$. This compound may be used as a source of calcium or sulfur, but it is not a liming material for use in fish culture.

AGRICULTURAL LIMESTONE. Calcium carbonate ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) which is finely ground and used to neutralize acidity in soils, muds, and waters.

ALGICIDE. One of a group of plant poisons used to kill filamentous algae and phytoplankton.

ALGAL SCUM. An undesirable visible layer of filamentous algae or phytoplankton floating on the surface of a body of water.

ALKALINE. Relating to the hydroxide (OH^-) or carbonate ($CO_3^{=}$) radical of a highly reactive group of metals that are characteristically basic. Having a pH greater than 7.

ALKALINE DEATH POINT. Having a pH so great as to kill fish. A pH greater than 11 will usually kill fish.

ALKALINITY. The total concentration of alkaline substances in water expressed as milligrams per liter of equivalent calcium carbonate ($CaCO_3$).

AMMONIA. NH_3, a colorless gas used in the manufacture of fertilizers. It is also a form of nitrogen found in fresh water and may be toxic to fish under certain conditions.

AMMONIUM HYDROXIDE. A solution of ammonia in water. It has the formula NH_4OH.

AMMONIUM ION. NH_4^+, the positively charged ion resulting from the reaction of ammonia in water. This ion is not appreciably toxic to fish.

ANALOGY. A relation of likeness between two things, consisting not in the resemblance of the things themselves, but of two or more of their attributes. The statement, "fish culture is agriculture," is an analogy.

AQUATIC ORGANISMS. Those plants and animals that live and grow in the water.

AQUATIC WEEDS. Undesirable water plants growing in a pond. Any plant growing in a body of water that reduces the ability of the water to support fish life, or interferes with fishing or fish harvest.

ARID. Dry, lacking moisture. An area with low rainfall and high evaporation is an arid region.

BACTERIA. Single-celled microorganisms that lack chlorophyll. Bacteria are important agents of decay and some species are responsible for human, animal, and plant diseases.

BAFFLE. Any structure used to impede, regulate, or alter the flow or direction of a liquid. For purposes of aeration, a baffle causes turbulence in water flowing over it.

BASE. A chemical that has the ability to react with acids to form salts.

BASIC. Having a pH greater than 7, tending to form a base.

BASICITY. The degree of strength of a base.

BASIC SLAG. A liming material which is a by-product of the steel-making industry, and is used to neutralize acidity of soils, muds, and waters.

BENTHIC ORGANISMS. Organisms living in and on the mud of the bottom of lakes or ponds.

BICARBONATE. Having HCO_3^- group, such as sodium bicarbonate ($NaHCO_3$).

BIOLOGIST. One who is trained in and studies biology, the science of life.

BIOTA. Plant and animal life of a particular area considered as a total ecological unit. For example, all of the organisms in a pond are collectively termed the biota of the pond.

BIWEEKLY. Happening every 2 weeks.

BLUE-GREEN ALGAE. Any of the microscopic aquatic plants of the division Cyanophyta. Blue-green algae are considered to be among the simplest forms of plants.

BRACKISHWATER. Waters containing considerable salt but not as much salt as the ocean; intermediate between fresh and salt water.

BUFFER. A substance capable of maintaining the relative concentration of hydrogen (H^+) and hydroxide (OH^-) ions in a solution by neutralizing, within limits, added acids or bases.

BURNT LIME. Calcium oxide (CaO). This material is occasionally used as a liming material.

CALCIUM CARBONATE. $CaCO_3$, a white compound occurring naturally as limestone rock. It is crushed and used in fish culture as a liming material.

CALCIUM CARBONATE EQUIVALENT. The amount of calcium carbonate required to be chemically equivalent to a given amount of another substance. For example, 1 milligram per liter of hydrogen ion has the same chemical reacting power as 50 milligrams per liter of calcium carbonate.

CALCIUM HYDROXIDE. $Ca(OH)_2$, also called hydrated lime or slaked lime, a chemical compound which is sometimes used to lime fish ponds.

CALCIUM MAGNESIUM CARBONATE. $CaMg(CO_3)_2$, a liming agent used in fish culture. This is also called dolomite.

CALIBRATED ROPE. A line or rod that is marked at measured intervals so that it may be used to determine distances.

CARBONATE. A substance having the $CO_3^{=}$ group. For example, $CaCO_3$ is a carbonate of calcium.

CARBON DIOXIDE. An atmospheric gas. It is used by plants to produce organic matter during photosynthesis and is released during combustion, respiration, or organic decomposition.

CELSIUS. A temperature scale set up so that 0°C is equal to the freezing point of water and 100°C is equal to the boiling point of water.

CENTIMETER. A unit of measurement equal to 1/100 meter or 0.3937 inch.

CLAY. Very fine soil particles. Grains of earth smaller than 0.002 millimeter are clay.

COAGULATE. To cause the transformation of dispersed particles in a liquid into a semisolid or solid mass.

COLDWATER FISH. A fish which requires relatively cool water for survival. The optimum temperatures of different species vary, but most species are found in water where temperatures are usually 20°C or less. Trout and salmon are coldwater species.

COMPLETE FERTILIZER. A fertilizer containing the primary nutrients nitrogen (N), phosphorus (P), and potassium (K).

CONDUCTIVITY. The ability or power to convey electricity. In water, the conductivity increases as a function of increasing concentrations of ions.

COPPER SULFATE. A poisonous blue crystalline copper salt ($CuSO_4 \cdot 5H_2O$) sometimes used in fish culture as an algicide or in control of parasites and diseases.

CORRELATION. A simultaneous increase or decrease in value of two related variables.

CRYSTAL. A symmetrical granular solid form of a substance.

DENITRIFICATION. To remove nitrogen from a material or chemical compound. As an example, bacterial action in mud often converts nitrate to nitrogen gas which is lost to the atmosphere.

DENSITY. The amount of a substance per unit volume. In physics, it refers to the mass of a substance per unit volume; in limnology, plankton density increases when the amount of plankton per unit volume of water increases.

DETRITUS. Any disintegrated matter, such as organic debris, accumulated in pond water or on mud or soil.

DIFFUSION. The movement of molecules of a substance from an area of greater concentration to an area of lower concentration of the substance. Diffusion will continue until equilibrium exists in the system. For example, there is a net movement of dissolved oxygen molecules from air into water until the pressure of oxygen molecules in the water equals the pressure of oxygen molecules in the air.

DISSOLVED OXYGEN. The elemental oxygen gas contained in a body of water and available for the support of fish life.

DIVALENT METAL ION. A metal atom that has lost electrons so that it has a positive electrical charge of +2. These ions are capable of combining with other ions of equal but opposite electrical charges to form compounds, such as calcium ions combining with carbonate ions to form calcium carbonate.

DRIFT. Carried along by wind or water currents.

EMULSIFIABLE CONCENTRATE. A liquid pesticide that will form a suspension of small globules in water. The concentrated pesticide must be diluted in water before application.

EPILIMNION. The upper layer of water in a pond or lake. Water of the epilimnion is warmer than water in deeper layers.

EQUILIBRIUM. A stable balanced system. In chemistry, it is the state of a reaction in which forward and reverse reactions occur at equal rates so that the concentrations of the materials that are reacting do not change with time.

EQUIVALENT. Equal in substance, degree, or value; having the same ability to combine.

EVAPORATION. To convert or change into a vapor as when water molecules diffuse into the air to become water vapor.

EVAPOTRANSPIRATION. The combined process of evaporation of water and the loss of water from plants.

EXPONENTIALLY. Increasing by multiples of a number. The dependent variable increases or decreases as a multiple (power) of the independent variable.

FERTILE. Rich in nutrients needed to sustain plant growth.

FERTILIZATION. The act of increasing the fertility of the mud or water in order to increase plant growth and, ultimately, fish production.

FERTILIZER. A natural or man-made material that is added to soil or water to increase the production of desirable plants.

FERTILIZER FILLER. An inert material or limestone mixed with fertilizer materials and used to bring the total ingredients of a complete fertilizer up to a specified weight.

FILAMENTOUS ALGAE. Multicellular algae that grow in thin threadlike sections.

FILTER ALUM. Aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$). This substance coagulates particulate matter in water and is used to remove turbidity from water.

FISH CULTURE. The deliberate growing and rearing of economically important numbers of fish or other aquatic animals for recreational, ornamental, scientific, or food purposes.

FLOC. A coagulated mass of particles.

FLOCCULATE. To cause particles to form lumps or masses.

FOOD WEB. A living ecological system in which plants are eaten by small animals, which in turn are eaten by larger animals.

FRESHWATER. Inland waters, waters that contain little or no salt, not salty or saline.

GOOD WATER QUALITY. Water having all the physical, chemical, and biological characteristics necessary for the support and production of an optimum amount of fish life.

GRANULE. A small, grain-like particle of a substance, often about the size of sand grains.

GROUND WATER. Water from beneath the earth's surface that supplies wells, springs, and dry-weather stream flow.

HARDNESS. Refers to the concentration of divalent metalic ions, primarily calcium and magnesium, in the water expressed as calcium carbonate equivalent.

HAVEN. A place of refuge.

HECTARE. A metric unit of area equal to 10,000 square meters or 2.471 acres.

HERBICIDE. A chemical used to control or destroy plants, especially weeds.

HUMATES. Refers to partially decayed vegetable and organic matter.

HYDRATED LIME. Calcium hydroxide ($Ca(OH)_2$), a liming material occasionally used in fish culture.

HYDROGEN ION. The positively charged ion of hydrogen (H^+) formed by the removal of the electron from atomic hydrogen.

HYDROGEN SULFIDE. A gas with the formula H_2S. It is formed by microbial decomposition of organic matter in the absence of oxygen. Hydrogen sulfide is a weak acid in water and strongly dissociates into HS^- and $S^=$ at pH values above 7. Un-ionized H_2S is highly toxic to fish.

HYDROLOGY. The study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

HYDROXIDE. A chemical compound containing the hydroxide ion, OH^-.

HYDROXIDE ION. The negatively charged ion OH^- characteristic of hydroxides.

HYPOLIMNION. The lower layer of water near the pond bottom.

ILLUMINATED. Provided with light.

INERT. Exhibiting no chemical activity, totally unreactive.

IONS. An atom, group of atoms, or molecule that has acquired or is regarded as having acquired a net electrical charge by gaining electrons or by losing electrons from an initial electronically neutral state.

IONIZED. To become converted partially or totally into ions.

INORGANIC. Not composed of organic matter, involving neither organic life nor the products of organic life.

INORGANIC FERTILIZER. Natural or man-made substances lacking carbon composition, used to increase the ability of soil or water to produce plant life.

KILOGRAM. One thousand grams, a metric unit of weight equal to 2.2 pounds.

LEACHED. To be dissolved and washed out by a percolating liquid.

LEEWARD. Located on or moving to the side toward which the wind is blowing.

LIME. Refers specifically to calcium oxide. However, it is more generally used to refer to any material used for raising mud pH and alkalinity in fish culture or raising soil pH in agriculture.

LIMING. Applying neutralizing agents, such as agricultural limestone, basic slag, hydrated lime, or burnt lime, to soil or water for the purpose of increasing its basicity.

LINEARLY. Refers to dependent and independent variables. Each successive unit of increase in the independent variable will cause the same amount of increase or decrease in the dependent variable. When plotted on ordinary graph paper, a relationship between the variable is given as a straight line with a constant slope.

LITER. A metric unit of volume equal to 1,000 milliliters or 1.056 quarts.

MACROPHYTE. Relatively large vascular plants as opposed to the microscopic phytoplankton, and filamentous algae. The basic structure of an aquatic macrophyte is visible to the naked eye.

MANAGEMENT TECHNIQUES. With respect to fish and water quality, it is the means by which a fish culturist can exert control and influence over the water quality and, ultimately, the fish production of a pond.

MANURE. Animal dung, compost, or other organic matter used as fertilizer. The nutrients are released from the manure as it decays. The decay of manure in water is caused by bacterial action and requires dissolved oxygen.

METABOLIC WASTE. By-products of metabolism excreted from the body of an organism.

METABOLISM. The complex and chemical processes involved in the maintenance of life.

MICROGRAM. Metric unit of measure equal to 1/1,000,000 gram.

MICROSCOPIC. Too small to be seen by the unaided eye.

MILLIGRAM. Metric unit of measure equal to 1/1000 gram.

MILLIMETER. A metric unit of measure equal to 1/1000 meter or 0.0394 inch.

MILLIGRAM PER LITER. One milligram of a substance in 1 liter of a second substance. It is a way of expressing concentrations of small amounts of a substance dissolved in another substance.

MORPHOMETRY. The structure, form, or shape of an object, thing, body of water, or place.

NEUTRALIZE. To make a solution chemically neutral as when an acid and a base react to form a salt and water.

NITRATE. The nitrate ion has the formula NO_3^-. Substances containing the NO_3 group are termed nitrates.

NITRITE. The nitrite ion has the formula NO_2^-. Substances containing the NO_2 group are termed nitrites.

NITRIFIED. To oxidize reduced nitrogen forms to nitrate. The action of certain bacteria will convert ammonium (NH_4^+) to nitrate. The ammonium is said to be nitrified.

NUTRIENT. Something that provides life sustaining nourishment, an element necessary for life and growth.

OFF-FLAVOR. Bad tasting, varying from the usual flavor.

OPTIMUM. Most favorable or advantageous. The best conditions or degree or amount for a particular situation.

ORGANIC MATTER. A living substance or its remains. Organic matter contains carbon.

ORGANIC FERTILIZER. Materials derived from animal waste products or dead animals or plants which are used to supply nutrients to soil and water to increase plant growth.

OSMOTIC PRESSURE. The pressure exerted by the tendency of fluids to diffuse through a semi-permeable membrane until there is an equal concentration of fluid on either side of the membrane.

OXIDIZE. To combine with oxygen, to make into an oxide.

OXYGEN DEMAND. The oxygen required by all the biological and chemical processes that occur within a pond.

PARTS PER MILLION. A means of expressing concentration, usually by weight, as one portion of a substance in 999,999 portions of a second substance; e.g. 1 pound of lime in 999,999 pounds of water. 1 part per million = 1 milligram per liter.

PARTICULATE ORGANIC MATTER. Particles of living or dead organic matter which are suspended in water. Plankton is a form of particulate organic matter.

PESTICIDE. Any chemical used to control or kill harmful or unwanted plants or animals.

PHENOLPHTHALEIN ALKALINITY. The equivalent amount of acid required to lower the pH of a water sample of 8.3 (the endpoint of the indicator phenolphthalein), expressed as milligrams per liter of equivalent calcium carbonate.

PHOTOSYNTHESIS. The process by which green plants convert light energy into chemical energy and make organic compounds from inorganic compounds, especially carbohydrates from carbon dioxide and water, with the release of oxygen. Photosynthesis may be thought of as the production of food by a plant.

PHYTOPLANKTON. Microscopic aquatic plants which are suspended in water. They are usually the major oxygen producing organisms in a pond.

PHYTOPLANKTON DIE-OFF. An abrupt, massive mortality of phytoplankton resulting from natural or man-made causes.

PLANKTON. Plant and animal organisms, generally microscopic, that are suspended in natural waters.

PLANKTON BLOOM. A large quantity of plankton giving water a definite color. Pond water usually appears green because the majority of plankton organisms are greenish, but plankton blooms may also appear black, yellow, red, brown, or blue-green.

PLANKTONIC. Of or relating to plankton.

POOR WATER QUALITY. Water having some physical, chemical, or biological characteristic such that the support and production of fish life is less than the optimum.

PRECIPITATE. To chemically cause a solid substance to be separated from a solution.

PRECIPITATION. Any form of rain or snow. Water droplets or ice particles condensed from the atmospheric water vapor and sufficiently massive to fall to the earth's surface.

PRIMARY NUTRIENTS. Referring to the fertilizer elements nitrogen (N), phosphorus (P), and potassium (K). An increase in plant growth most often follows the application of these essential nutrients to the water or soil.

QUADRANT. A circular arc of 90 degrees, one-quarter of the circumference of a circle.

REAGENT. Any substance used in a chemical reaction to detect, measure, examine, or produce other substances.

RESIDUAL EFFECT. The length of time in which the effect of a treatment of an ecological system with a chemical will persist.

RESIDUAL TOXICITY. The continuing toxicity of a substance applied to an ecological system.

RESPIRATION. The metabolic process by which an organism combines oxygen with organic matter and releases energy, carbon dioxide, and other products of oxidation. Respiration can be thought of as the utilization of food by a plant or animal.

ROTENONE. An organic compound extracted from the roots of derris, timbo, and cube' and used as an insecticide and fish poison.

RUNOFF. Rainfall that is not absorbed by the soil and flows over the land surface of the earth.

SALINITY. Relating to the concentration of mineral salts in the water.

SALT. Any chemical compound that is formed by replacing all or part of the hydrogen ions of an acid with one or more positively charged ions of a base. Sodium chloride (NaCl) is a common salt.

SATURATED. To contain all of a substance that can normally be dissolved in a second substance at a given temperature and pressure.

SEA WATER. Salt water of the oceans.

SECCHI DISK. A disk 20 centimeters in diameter painted in alternate quadrants black and white and used in fish culture and limnology to measure the passage of light through the water.

SEINE. A large fish net made to hang vertically in the water with floats at the top and weights on the bottom and a staff attached to each end; to catch fish with such a net.

SILT. A soil material consisting of fine mineral particles intermediate in size between sand and clay. Silt is suspended in runoff, but when runoff enters a pond, the silt settles to the pond bottom.

SMOTHER. To deprive of oxygen, to conceal, suppress, or cover.

SOLUBILITY. The amount of a substance that can be dissolved in another substance.

SOLUTION. A uniformly similar mixture of one or more substances that will not settle out. Sodium chloride added to water dissolves to form a solution of sodium chloride.

SOUNDINGS. To measure the depth of a body of water with a calibrated line or rope.

SOURCE MATERIALS. Original materials from which essential fertilizer nutrients are derived. Phosphate rock is the source material for elemental phosphorus.

STRATIFY. To become layered, as when a warm layer of water overlies a cooler layer of water.

STRESS. To subject an organism to physically disruptive forces that are harmful to that organism's growth and survival.

SUBLETHAL. Not causing death. A sublethal concentration of a substance will not cause death, but may cause stress or injury.

SULFIDE. A chemical compound containing bivalent sulfur.

SUPERSATURATED. To cause a chemical solution to be more highly concentrated than is normally possible under given conditions of temperature and pressure.

SUSPENSION. A relatively coarse dispersion of solid particles in a liquid. For example, silt in water is a suspension.

TEMPERATE REGION. Neither very hot nor very cold in climate.

THERMAL STRATIFICATION. The separation of pond waters into distinct warm and cool layers caused by differential heating or cooling of such waters.

THERMOCLINE. The layer of water between the epilimnion and the hypolimnion; the layer where there is a great change in temperature per unit of depth.

TITRATING AGENT. A chemical substance used to determine the concentration of another chemical substance in a solution.

TOLERATE. To endure or resist, to bear, to survive.

TOPOGRAPHIC. The physical features of a region or place.

TOTAL ALKALINITY. The total measurable bases (OH^- HCO_3^-, $CO_3^=$) in the water. The total alkalinity of a water is a measure of its capacity to neutralize acids.

TOTAL DISSOLVED SOLIDS. The total concentration of all substances in true solution in water.

TOTAL HARDNESS. The total amount of divalent metallic ions in the water, expressed as milligrams per liter of equivalent $CaCO_3$. The principal hardness causing ions are calcium and magnesium.

TOXICITY. The degree of being harmful, destructive, or poisonous to life.

TRACE NUTRIENTS. Nutrient elements essential for the life and growth of an organism, but needed in only very small quantities or amounts.

TRANSECTS. To divide by cutting crosswise. In sampling, a transect is an imaginary or real line along which samples are taken.

TRANSPIRATION. The giving off of water vapor from plant pores as a part of plant metabolism.

TROPICAL REGION. Hot and humid in climate. Near the equator.

TURBIDITY. Having sediment (soil) or foreign particles (plankton) suspended in the water.

TURBIDITY UNIT. A unit of measurement for describing the amount of turbidity in the water.

UNBALANCED FISH POPULATION. Refers to a population of sport fishes which produces few fish of large enough size to be considered harvestable. A sport fish population which produces poor fishing.

UN-IONIZED. Not ionized, elemental, not electrically charged.

UN-IONIZED AMMONIA. This form of nitrogen has the formula NH_3. Un-ionized ammonia is toxic to fish.

VARIABLE. A characteristic subject to change, having no fixed quantitative value.

WARMWATER POND FISH. Fish that normally survive, grow, and reproduce in warm water (25° to 32°C).

WATER ANALYSIS. A determination of the quantities or amounts of certain water quality variables in a body of water.

WATER QUALITY. All the physical, chemical, and biological factors which influence the beneficial use of water.

WATER QUALITY VARIABLE. Any changeable characteristic of water which affects the survival, growth, production, or management of fish.

WATERSHED. The land area draining into a river system or body of water.

WETTABLE POWDER. A finely ground solid pesticide that can be mixed with water before application and use.

ZOOPLANKTON. Microscopic aquatic animals which are suspended in water.

METRIC AND ENGLISH EQUIVALENTS

Length

Metric	English
1 millimeter	0.0394 inch
1 centimeter	0.3937 inch
1 meter	3.281 feet
Weight	
1 milligram	0.00035 ounce
1 gram (1,000 milligrams)	0.0353 ounce
1 kilogram (1,000 grams)	2.205 pounds
Area	
1 square meter	10.76 square feet
1 hectare (10,000 square meters)	2.471 acres
Volume	
1 milliliter	0.0338 U.S. liquid ounce
1 liter (1,000 milliliters)	1.057 U.S. liquid quarts
3.785 liters	1.00 U.S. liquid gallon
Other	
1 kilogram per hectare	0.892 pound per acre
1 milligram per liter	1 part per million
1 milligram per kilogram	1 part per million

CELSIUS TO FAHRENHEIT DEGREES

°C	°F	°C	°F	°C	°F
0	32.0	14	57.2	28	82.4
1	33.8	15	59.0	29	84.2
2	35.6	16	60.8	30	86.0
3	37.4	17	62.6	31	87.8
4	39.2	18	64.4	32	89.6
5	41.0	19	66.2	33	91.4
6	42.8	20	68.0	34	93.2
7	44.6	21	69.8	35	95.0
8	46.4	22	71.6	36	96.8
9	48.2	23	73.4	37	98.6
10	50.0	24	75.2	38	100.4
11	51.8	25	77.0	39	102.2
12	53.6	26	78.8	40	104.0
13	55.4	27	80.6		

CHEMICAL SYMBOLS OF SELECTED ELEMENTS

Element	Symbol
Aluminum	Al
Arsenic	As
Boron	B
Carbon	C
Calcium	Ca
Chlorine	Cl
Copper	Cu
Iron	Fe
Hydrogen	H
Mercury	Hg
Potassium	K
Magnesium	Mn
Manganese	Mn
Nitrogen	N
Sodium	Na
Oxygen	O
Phosphorus	P
Sulfur	S
Silicon	Si
Zinc	Zn