BACTERIA, CARBON DIOXIDE, AND ALGAL BLOOMS

L. E. Kuentzel

Bacteria and Blue-Green Algae—A Mutualistic Symbiosis?

College textbooks reveal that blue-green algae (phylum Cyanophyta) and bacteria (phylum Schizophyta) are descendents of the most ancient and primitive of living creatures. Yet, in spite of some two billion years of evolutionary history, they are still the simplest and least evolved of all living organisms. If "survival of the fittest" has any place in evolution, the biologist is attempting to deal with a very "fit" species in blue-green algae and should not be surprised if the task is a difficult one. Moreover, since there are reported to be 2,500 different species of Cyanophyta widely distributed in nature and capable of healthy growth under widely differing conditions, nuisance growths can be expected at any time conditions foster a "population explosion." Measures taken to eleminate one species may produce optimum conditions for encouraging a different species to take its place. Also, it is fundamental that aerobic bacteria require oxygen to degrade organic matter and produce carbon dioxide (CO_2), that algae require CO_2 to photosynthesize organic matter and produce oxygen, and that both aerobic bacteria and algae require similar environments of temperature and minor nutrient concentrations to grow properly. This is a nearly perfect mutualistic symbiosis that has been going on for millions of years. Once established in a given body of water, such a cycle would be difficult to break so long as temperatures approach optimum and the sun continues to shine. This must be nearly the situation in Lake Erie's western basin where, according to Harlow (1), algae produce nearly 10 bil lb (4.54 bil kg) of organic matter per year. This is some 18 times as much as contributed by all wastewater effluents to Lake Erie combined. Moreover, according to Harlow (2), Lake Erie now has excessive amounts of phosphorus in its waters and vast amounts stored in its sediments. Therefore, since P may be used and recycled many times in a growing season and "nutrients which accumulate in the bottom sediments constitute a vast reservoir apparently capable of supporting plant growth in the event all input is shut off" (3), the task of reducing algal growth via control of P in wastewater effluents could be long and very likely an impossible task. Compounding the task via P control are reports of healthy algal growths on amounts of P that are an order of magnitude less than the minimum found in Lake Erie (4) (5) (6). Ferguson (6) and a task group (7) indicate that sources of nutrients are so widespread that "control would be difficult if not impossible." Thus, consideration must be given to all aspects of algal growth and control if an effective means of reducing nuisance blooms is to be achieved. The role of biologically produced CO_2 has been neglected almost completely in the literature.

There is a tremendous volume of literature on the subject of lake eutrophication and algae. An excellent

L. E. Kuentzel is Research Associate, Wyandotte Chemical Corporation, Industrial Chemicals Group, Wyandotte, Mich.

bibliography by Mackenthun and Ingram (8) lists over 400 references to material on algal growth factors other than N and P—but not one appears to concern itself with CO_2! Of several hundred papers, books, and reviews covered in this survey, only one paper reported laboratory work that demonstrated the bacteria-algae symbiosis and suggested that this relationship might be responsible for the rapid growths that resulted in blooms. Lange (9) (10) described experiments that strikingly demonstrated the beneficial effects of adding sucrose to *Microcystis aeruginosa* cultures which harbored bacteria while additions of organic matter to axenic algal cultures had no effect on growth. Additions of CO_2 to the cultures induced similar increases in algal growth while additions of P had no effect. Clearly, CO_2 was the limiting factor and bacterial action on sucrose or CO_2-enriched air provided the additional amounts necessary for continued growth. This should not come as a surprise as it long has been known that CO_2 is a major growth-limiting factor for all types of plant life. Quinn and Jones (11) report the successful increase in yields and growth for many plants resulting from enriching the atmosphere around them with CO_2. Thus, when other factors are optimum, nature limits all plant growth to the available CO_2. This operates no less effectively in natural waters where the dissolved CO_2 is normally in equilibrium with atmospheric CO_2.

Carbon Dioxide—A Limiting Nutrient

That an adequate supply of CO_2 is a key factor in healthy algal growth is indicated by a number of publications. Among several papers concerned with the photosynthetic process, West and Todd (12) detail the role played by CO_2 (not HCO_3^- or CO_3^{--}). Clement (13), in establishing optimum conditions for growing algae in synthetic media, reports that improvements in the cultures resulted from reductions in CO_3^{--} and HCO_3^- concentrations or by completely replacing them with CO_2. Optimum growth results when air enriched with one-percent CO_2 by volume is passed through at a rate of one liter/min/liter of culture. Soltero and Lee (14) describe automatic equipment to control pH in algal cultures so as to obtain maximum growth. Such apparatus controls the passing of CO_2-enriched air through the cultures. Several others report the need to aerate with CO_2-enriched air to achieve good growth rates, but the reasons given usually involve pH control rather than nutrient supply. A large scale example of the need for added CO_2 has been provided by Eliassen and Tchobanoglous (15). They describe extensive efforts to remove N and P from agricultural run-off waters in California by, among other methods, growing and harvesting algae in large artificial ponds. The water is relatively rich in N and P and inorganic salts, but low in organic matter. Preliminary experimentation revealed that algae would not grow satisfactorily without supplemental supplies of CO_2 although there was ample access to atmospheric CO_2. Blue-green algae require a slightly alkaline medium for optimum growth (16) (17). Therefore, under equilibrium conditions, relatively small amounts of free CO_2 exist (4) (18), and the removal of CO_2 by algal growth causes the pH to rise (5) (19) (20) until growth is retarded or stops. Gaseous CO_2 is practically insoluble at pH 9 and above.

The availability of CO_2 from natural inorganic sources is precisely stated by Hutchinson (4) as follows:

> At equilibrium, regardless of pH, the quantity of free CO_2 is a function of gaseous phase in contact with the water, its pressure and temperature, and the concentration of salts in solution. Both

> from theory and as far as can be ascertained empirically the quantity of free CO_2 present will ordinarily lie between 0.4 and 1.0 mg/l.

Also, quoting Hutchinson (4):

> At temperatures over 10°C, at no reasonable value of the atmospheric content of the gas will the free CO_2 in equilibrium be as great as 1 mg/l, even at sea level.

Moreover, the natural establishment of equilibria to restore the free CO_2 that is removed by algal growth takes time. Hutchinson (4) states that the movement of CO_2 in and out of a water interface is a slow process. Also, the replacement of free CO_2 by carbonate salts in slightly alkaline media is a relatively slow process. The wide variations of pH with depth that can exist in a given lake over extended periods of time indicate that restorations of equilibria via ionic processes in tranquil lakes are indeed slow. Thus, the available free CO_2 from natural inorganic sources (at pH of 7.5 to 9) probably never exceeds 1 mg/l, and it becomes available at a rather slow rate.

CO_2 Requirements for Massive Blooms

The massive algal blooms that result in floating mats of odorous organic matter involve tens and hundreds of thousands of cells per milliliter (21) to millions of cells per milliliter (22). Thus, in Mackenthun's (21) description of algal growth in Lake Sebasticook, Maine, the maximum bloom involved some 211,550 cells/ml, 56 mg/l dry weight,* most of which grew in a single August day. From algal mass data supplied above and the application of the $C_5H_7NO_2$ biological mass relationship (15) (18) it is calculated that some 110 mg/l of CO_2 must have been delivered to the algae during their growth period. If the stoichiometric relation reported by Stumm and Morgan (23) of C:N:P ratios of 106:16:1 were used, the CO_2 requirements for this growth would be even higher. Obviously, this could not have come from natural inorganic sources delivering a maximum of one mg/l over a period of several days. However, just 30 mg/l of organic carbon and bacterial action would suffice since ample quantities of oxygen would come from the fast-growing algae. It also might be noted here that at no time did the soluble P exceed 0.01 mg/l in the upper 20 ft (6.1 m) of the lake where the growth took place, except in midwinter when a value of 0.011 mg/l was reported. Sawyer (24) indicates that nuisance blooms may be expected when the soluble P exceeds 0.015 mg/l.

Bacteria—CO_2—Algae

The thesis of this paper is that bacterial action on decomposable organic matter in close proximity to the algae supplies the required CO_2 for massive algal blooms and that when such a massive CO_2 supply exists, very small amounts of P suffice. Close scrutiny of the literature provides considerable support for this thesis although no one states the proposition as clearly as does Lange (9). Also, there are statements in the literature that indicate an awareness of the situation such as those by Hutchinson (4) who, after discussing the well-known nutrient factors (not including CO_2), concludes:

> Some accessory substance derived from land drainage or sewage may promote the development of large populations (of algae) in nature. . . . It would seem likely, therefore, that unknown chemical or biological factors are involved.

* Note: It has been confirmed by private communication with Mackenthun that on page R78 there is an error in the published derivation of phytoplankton volume (ml/l). The final factor should have been 10^{-9} rather than 10^{-6}. This makes the values for the wet weight of algae, Table III, to read milligrams per liter rather than grams per liter. This correction was made for calculations used in the present paper.

Billaud (19) is quoted as follows:

> The role of bacteria in the algal cycle is unfortunately little known. . . . In Sanctuary Lake there is important inflow of sewage-laden water with varying nutrition concentrations, which seem to influence the algal periodicity. . . .

Also, Eberly (25) states:

> A second problem concerns the role of bacteria in the nutrition of blue-green algae. . . . Only a few workers have attempted axenic cultures of blue-green algae. . . . In some cases algal cultures grew poorly or not at all in axenic bacteria-free cultures. Whether any symbiotic dependency on bacteria exists in planktonic blue-green algae is not known yet.

Gorham (26) reports observations of the close association of bacteria and algae but without revealing any CO_2 connection. Safferman (27) tried to eliminate bacteria from algal cultures but could not. Holm-Hansen (17), in performing an experiment designed to test the possible heterotrophic growth of blue-green algae, added sucrose to half of a number of cultures then placed half of each of the two groups (with and without sucrose) in complete darkness and left the rest exposed to light. At the end of a month there was no sign of growth in any of the cultures stored in the dark. Of the rest, those having sucrose additions showed twice as much growth as the cultures without sucrose. He then concluded that heterotrophic growth was possible in the light but not in the dark. Since part of the experiment closely parallels Lange's work (9), it would seem reasonable to attribute the increased growth of the sucrose-fed cultures to bacterial generation of CO_2 and the lack of response in the dark to inhibited photosynthetic processes. Clesceri and Lee (28) demonstrated that algae with bacteria grow much faster than algae from which the bacteria substantially have been removed. Their cultures had ample supplies of orthophosphate and carbonates (pH of 8.3), yet bacteria-free cultures achieved normal growth only after an additional 100 hr as compared to the algae-bacteria cultures.

Wastewater (Organic) Pollution and Blue-Green Algae

There is much general agreement in the literature that wastewater pollution of lakes and excessive growth of algae go hand in hand, but such growths usually are attributed to the inorganic nutrients rather than to the decomposable organic matter that always accompanies it. However, Fogg (16) observes that "blue-green algae are of frequent occurrence in environments rich in organic matter and in freshwater lakes a distinct correlation exists between their abundance and the concentration of dissolved organic substances." Taylor (29) states that bacterial activity is related to the amount of decomposable carbohydrate present and that the activity of bacteria in a lake can be controlled by the amount of organic matter present. Sawyer (30) says:

> CO_2 feed-back from bottom deposits and the role of bacteria must be taken into close consideration when considering nutrients (for algae) and their sources.

Dean (31) observed decreasing algal growths at increasing distances from a hydraulically overloaded wastewater plant discharging into a lake. Sigh (32) reports India's lakes to be polluted badly and in constant bloom, and observes that *Microcystis aeruginosa* always is associated with the highest organic pollution. Fitzgerald (33) reports that blue-green algal blooms in reservoirs and lakes usually are associated with wastewater effluent. Torpey (34) makes effective use of the bacteria-algae symbiosis in explaining the effects of reducing pollution in the Thames estuary. He has diagrammed a normal situation showing the flow of organic carbon (pollution) to the bacteria to produce CO_2 which then flows to the algae for the production of oxygen. The oxygen, with some dissolved from the air, then flows to the bacteria to complete the cycle. Omitted as having negligible influence on the cycle are CO_2 from the atmosphere and dissolved salts as well as the minor nutrients N and P, for the latter are always in adequate supply in the river water. However, of significance is the fact that CO_2 becomes a limiting growth factor under some circumstances. Such a situation occurs in the presence of autotrophic nitrifying bacteria where pollution contains considerable amounts of organic nitrogen. The diagrammed presentation shows the nitrifiers competing with the algae for available CO_2 with the result that diminished algal growth and oxygen generation cause a reduction of dissolved oxygen in that portion of the river. Schulze (35) describes an interesting "pilot plant" scale experiment to measure the effectiveness of a simple tertiary treatment for the removal of organic matter from the effluent of a secondary activated sludge plant. It simply consisted of a holding tank with screens on which slimes, protozoa, rotifera, etc., could develop and consume the residual organic matter. It worked so well that, at times, in excess of 99-percent organic matter was removed. He then set up a second experimental tank to receive the effluent from his efficient tertiary process, aerated it with air, and tested these waters for support of aquatic life. Fish thrived as did aquatic plants that had access to the surface. However, blue-green algae would not grow. He concluded that carbon (CO_2) in the water had become a limiting nutrient. It would have been interesting to test the effect of adding a little CO_2 to the aeration stream; however, this was not reported as having been done.

McIntire, however, does report (36) the effects of added CO_2 in experiments conducted over a six-year period. His procedure was to divert part of a natural stream through his laboratory in troughs where he could control flow rate, temperature, light intensity, and turbulence and measure their effects on algal growth. Natural concentrations of CO_2 were reported to be less than two mg/l, and McIntire states:

> If ionic forms of carbon dioxide diffuse through cell membranes much less readidly than do neutral carbon dioxide molecules, rates of photosynthesis of algae in the laboratory streams as well as in natural streams may be limited by low concentrations of available form of carbon dioxide.

The addition of CO_2 to the natural waters produced the following observation:

> An increase in molecular carbon dioxide markedly increased the photosynthetic rate of the light-adapted community at illumination intensities between 1,000 and 2,000 ft-c (10,764 and 21,528 lumens/sq m).

McIntire concludes:

> One important effect of community organization is the retardation of diffusion in the microspaces adjacent to the metabolizing cells. Apparently, the compact growth form of the community explains the susceptibility of these communities to effects of carbon dioxide deficiency.

From this information, it may be concluded that it is an intimate mixture of algal cells, bacteria, and organic matter that provides localized sources of CO_2 to support massive growths of algae in stagnant lakes without much need for diffusion.

Controlling Factor—Carbon Dioxide or Phosphorus?

Many papers reporting investigations and studies attempting to clarify the role of P in algal growth problems give evidence that CO_2 well may be an unrecognized factor. Thus, Sylvester and Anderson (37) report that Green Lake in Washington has offensive algal blooms, yet the concentration of P is seldom above 0.01 mg/l.

Measurements on dissolved organic matter and bacteria are not reported. Tucker (38) reports that in lakes he has examined he finds no evidence that P is a limiting factor in the growth or reproduction of phytoplankton since there always seems to be enough. He further states that some other nutrient is more important, but does not identify it. Wohlschlag (39) reported an observation on Lake Mendota, Wisconsin. He noted increased algal growth after strong winds in areas exposed to the winds but not in areas that were protected, i.e., coves, etc. He suggests that the winds stirred up nutrients from the sediments. It is also possible that the increased aeration dissolved sufficient additional CO_2 to make a contribution to this growth. Pennak (40) states:

> Adequate nutrients remain in the epilimnion during the summer months, therefore it is suspected that light, temperature and organic matter (bacteria) play important roles in plankton activity fluctuations.

Hamilton (41) observed of Cayauga Lake that despite the low levels naturally present, augmented phosphate concentrations were not stimulatory to photosynthesis and some evidence is presented for inhibition by phosphorus. Shapiro and Riberio (42) report the effects of adding secondary wastewater plant effluent to Potomac River water which already contained 0.23 to 1.09 mg/l of P. As the authors explained, they intended to show that the addition of more P via the secondary effluent would have no effect on algal growth in water that already was overloaded with P. However, marked increases in algal growth immediately followed such additions of effluent water whereas additions of soluble P alone resulted in growth increases only after considerable delays in time. It would seem logical to attribute the rapid initial growth with the added effluent water to a fresh supply of organic matter and bacteria, whereas increased growth on addition of soluble P alone had to depend on CO_2 generated by the slower physical-chemical processes.

Bacteria are Essential

The textbooks are clear on the importance of bacteria in aquatic processes. Kendeigh states (43):

> Basic to the food cycle (in lakes) are the bacteria. A few occur free-floating in the water. For the most part, however, they are attached to algae, to other plankton organisms, to submerged objects or occur in the bottom as part of the benthos.

Ward and Whipple (44) add emphasis:

> The food supply of the whole plankton of fresh-water streams and ponds is therefore dependent upon the activity of bacteria, and the share of these organisms in producing or modifying the conditions under which all aquatic life is possible can never be ignored.

Bacteria can supersaturate natural waters with more than 20 mg/l of free CO_2 (18). The large bloom described by Mackenthun *et al.* (21) would require CO_2 delivered at a rate in excess of 5 mg/l/hr during the final 10-hr growth period. This could be achieved only if a massive "bacterial bloom" preceded or accompanied the algal bloom. That such bacterial blooms do precede algal blooms has been shown by Silvey and Roach (45). Extensive population counts on bacteria and algae over a period of 10 yr provide data for a number of graphs showing the population variations plotted against time over 1-yr periods. Significant is the fact that in every case, large increases in the numbers of gram-negative bacilli always preceded explosive growths of blue-green algae. In a typical graph, gram-negative bacilli showed a steady growth in numbers beginning in April which reached a peak about August 25 to September 1, followed by a rapid decline through September. Blue-green algae in the same lake showed no increase, just minor fluctuations, until August when an explosive growth developed to reach a peak about September 1 to 5 and then declined along with the bacteria through the rest of September. The authors make the following observations regarding this particular set of data:

> There appears to be some interdependent relationship between the two types of organisms (blue-green algae and gram-negative bacilli), . . . Even though the interdependence appears to exist, the authors have not been able to show its purpose in their laboratory investigations. . . . One notes, in careful observation, that the gelatinous covers of the blue-green filaments contain high concentrations of bacteria, most of which are gram-negative bacilli.

A logical explanation seems to be that the bacteria developed a condition of supersaturation in the surface waters with respect to CO_2 at a time when the algae, somewhat more sensitive to temperature and light conditions, found such conditions optimum in August and proceeded to grow explosively. This phenomenon continued as long as the bacteria were supplied with sufficient organic matter to maintain CO_2 production. When the supply of organic material finally failed, first the bacteria and then the algae, for lack of CO_2, terminated their explosive growths and then both declined to low levels for the winter months. These data were obtained from lakes in the southwest where temperatures were too high to cause winter stratification. Consequently, there was no fall turnover to bring nutrients from the sediments to the surface waters which some have indicated to be the cause of algal blooms. It should be pointed out that, while either aerobic or anaerobic bacteria degrade organic matter at the bottoms of lakes to produce high concentrations of CO_2 locally, because of thermal stratification this CO_2 is not readily accessible for rapid algal growth at the surface of the lake except at times of spring and/or fall turnovers.

Full-Scale Studies

Returning to the massive algal bloom described by Mackenthun *et al.* (21) in Lake Sebasticook, it must be concluded that massive bacterial activity must have preceded or accompanied the algal bloom. Although the authors report no measurements on the amounts of non-refractory organic matter in the lake, they went to some length to describe extreme organic pollution flowing into the lake from untreated municipal wastes, woolen mills, and a potato canning plant (21):

> Dye wastes colored the water purple and luxuriant growths of aquatic slimes, wool fiber mats and potato sprouts and rotting potatoes were visible in certain areas. Floating masses of wool dotted the surface waters and rising gas bubbles from decomposition pock-marked the stream reach.

This is what was discharging into the lake. It is obvious that, with the gross organic contamination reported, this lake would have little difficulty supporting the sizeable bacterial bloom necessary to provide ample CO_2 for the excessive algal bloom—even in the presence of minimal amounts of P. Yet, the authors concluded that "a reduction in the phosphorus contributed to the lake by industrial and municipal wastes is necessary to reduce the severe algal nuisances and to increase the lake's recreational use potential."

Another lake in the news is Minnesota's Lake Minnetonka. It has been under close observation since 1962. According to Orr (46), in June 1966 when the testing program was enlarged, "Symptoms of gross pollution are not present in the lake. . . . Swimming, boating, water skiing and fishing abound during the summer months." Yet, analysis for soluble P averaged 0.013 mg/l which is more than that found in the polluted waters of Lake

Sebasticook. Clearly, Lake Minnetonka was a fertile lake as far as N and P were concerned (0.56 mg/l N and 0.013 mg/l P). It needed only bacteria and organic matter to supply the necessary CO_2, and then massive algal blooms probably could be expected. Later, 1968 newspaper articles (47) (48) (49) revealed rapidly worsening conditions with some areas of the lake experiencing algal bloom problems. All agreed that pollution is the problem, but as one public official expressed it, "When we say pollution, the thing that all of us are worried about is nutrient pollution—nitrates and phosphates." This ignores the role of organic matter and bacteria. However, remedial activity recommended includes better control of septic tanks, lawn fertilizer, dead fish, boat toilets, etc., all of which also will effect reductions of organic matter reaching the lake. A recognition of the role played by organic pollution and bacteria in the production of algal blooms might prompt efforts to control sources of organic pollution not necessarily associated with gross amounts of P.

A final example comes from Wells (50) who reports detailed observations made on a 1,350-acre (547-ha) reservoir over a period of 5 yr. The water is used as condenser cooling water for a power plant and there is concern that algal growths might cause problems in the future. The voluminous records include periodic measurements of pH, phosphate, biological oxygen demand, coliform bacteria, and algae. While the pH consistently averages around 8.5 and there is ample access to Texas sunshine and air, there have not been excessive algal growths although the waters are well seeded with both algae and bacteria. Moreover, the phosphorus content of the water fluctuates between 0.30 mg/l and 0.07 mg/l—well above the minimum required for massive algal blooms. A reason for the low bacterial and algal activity lies in the low level of organic matter found in the waters—consistently two to four mg/l. Yet the author recommends that:

> . . . a close check should be maintained to see that there is neither a great increase (of phosphates) in the hypolimnion nor an increase in soluble phosphates in the upper portions of the lake. If conditions seem to be deteriorating with regard to phosphates and excessive biological growths, then immediate consideration should be given to some means of removal of the phosphate rich bottoms.

Conclusions

In summation, the following conclusions appear to be supported by the published literature:

1. In natural waters, blue-green algae and certain bacteria always are found in close association. Attempts to separate them in the laboratory prove detrimental to the algae.

2. Massive algal blooms always are associated with excessive amounts of decomposable organic matter. Much of the literature relates wastewater and organic pollution with blue-green algal blooms.

3. Carbon dioxide is the major nutrient required for algal growth. It takes about two grams of CO_2 to produce one gram of algae.

4. The large amounts of CO_2 required for fast-growing massive algal blooms of blue-green algae cannot come from the atmosphere and/or dissolved carbonate salts via the normal physical-chemical processes. At most, about one mg/l of free CO_2 accumulated over a period of many hours to days can be expected.

5. The action of bacteria on ample amounts of organic matter can supply as much as 20 mg/l of CO_2 in a supersaturated state. Explosive, logarithmic growth rates of bacteria under favorable conditions can deliver large amounts of CO_2 required for algal bloom development.

6. While phosphorus is a necessary element for algal growth, the amounts required to support massive blooms are quite low, about 0.01 mg/l (10 ppb) or less.

7. The widespread distribution of P in nature and its wide use by man will make reductions and limitations of soluble P in lakes to 0.01 mg/l extremely difficult. Even this would not prevent nuisance blooms in the presence of excessive amounts of decomposable organic matter and bacteria.

8. In well documented instances involving large lakes, the presence of decomposable organic matter and bacteria have produced massive algal blooms in waters containing not more than 0.01 mg/l soluble P. In other waters containing more than 0.01 mg/l soluble P but relatively free from organic pollution, there were no nuisance algal problems. Thus, the availability of adequate amounts of CO_2 via the action of bacteria on decomposable organic matter determines massive blue-green algal growth even in the presence of excessive amounts of soluble P.

These conclusions indicate that attempts to reduce massive algal blooms by limiting phosphorus in wastewater effluents will not be very effective unless equal emphasis is placed on removing biodegradable organic matter. Since a great number of lakes in this country already have in the neighborhood of 0.01 mg/l of soluble P in them, control of organic pollution is of prime importance. Fortunately, removal of phosphates usually is accompanied by more effective removal of organic matter from sewage effluents. However, the importance of the role played by organic matter and bacteria in the production of massive algal blooms should not be lost sight of in the rush to remove phosphorus. Although Fruh (51) has stated that "light and CO_2 as necessary ingredients for algal growth cannot be controlled," it is true that man has been largely responsible for the organic pollution that leads to and supports massive growths of blue-green algae. Such blooms present the most serious problem in the nation's eutrophic lakes, and certainly man can become more effective in reducing such organic pollution.

Finally, the bacteria-algae symbiosis opens up another possibility for reductions in algal growth via control of bacteria. It is easy to conceive that control of bacteria by means of a suitable bactericide would limit the availability of CO_2 for algal growth to produce massive blooms. This would result in sizeable reductions in lake-generated organic matter and would be followed by lower levels of bacteria-algae activity as long as levels of organic matter remained under control.

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COAL REPORT AVAILABLE

The Department of the Interior, Bureau of Mines, announces the availability of the report, "Use of Coal to Enhance Metabolic Treatment of Sewage." The document (23 pages plus 127 tables) describes tests performed on the proposed wastewater treatment process in which coal particulates are suspended in mixed liquor and recirculated with activated sludge. Efficiency of biodegradation by the wastewater microorganisms appears to be increased by the process.

Copies of the report ($3.00 each, or $0.65 for microfiche) can be obtained only from the Clearinghouse for Federal and Scientific and Technical Information, U. S. Department of Commerce, Springfield, Virginia 22151.