

INTRODUCTION

The need for algal control is well known. Algae can produce taste and odor in finished water, cause unacceptably short filter-run times, and possibly be correlated to contaminants such as halogenated hydrocarbons. Currently used monitoring techniques do not provide a useful picture of what is going on.

If algae were uniformly distributed throughout the reservoir, monitoring growth would be simple. Unfortunately, this rarely is the case. Most reservoirs of depth greater than about 5 meters will be thermally stratified for at least a portion of the year, usually about 9 months (1). In such stable reservoirs, the algae typically concentrate in thin horizontal layers. The reason for this layering is not well understood, but it is common for these strata to be 20 cm (8 inches) or less in thickness. Locating and monitoring the growth of such thin layers is a practical impossibility by any technique that does not provide instant "on site" mapping.

A simple technique for locating and measuring algae has been in use by oceanographers and limnologists for 20 years (2). It is called "*in-vivo* fluorometry (IVF)", and is based on the direct measurement of the fluorescence of the chlorophyll in the living algal cells. It is performed simply by lowering a sample hose and pumping the water through an instrument called a fluorometer (3). An instant "on site" profile is obtained. This is discussed more thoroughly in the section at the end of this article, METHODS OF CHLOROPHYLL DETERMINATION. The Institute of Water Resources at the University of Connecticut has extended the use of this research tool to the practical management of reservoirs and lakes (4). This report is not "theoretical" in nature. The procedure presented was developed in actual field studies of four reservoirs of the South Central Connecticut Regional Water Authority, with the support and assistance of SCCRWA personnel. Subsequently, the SCCRWA has continued to use *in-vivo* fluorometry as a management tool, and is actively pursuing studies to refine its use (5).

A detailed "how to do it" handbook is available (6). This very readable handbook gives details on equipment and procedures, and additional information on interpretation of the data.

In-vivo fluorometry can be used to measure algal concentrations in a reservoir or lake to:

- • Increase Filter-Run Time
- • Reduce Algaecide Required
- • Predict When Algaecide Treatment Will Be Needed
- • Monitor Trihalomethane (THM) Precursors and Total Organic Carbons (TOC)
- • Improve the Quality of Water Supplied

INCREASE FILTER-RUN TIME

In many cases, the first indication of an algal problem is plugging of the filter. *In-vivo* fluorometry permits monitoring of algal growth so that corrective action may be taken before the algae become a problem. In one reservoir studied by Rich (4), when the fluorometer was not in use in the reservoir, it was used to continuously monitor the intake water. This proved to be a very effective way of documenting trends and provided early warning of excessive algae.

Corrective action to prevent unacceptably short filter run-times need not always involve treatment with algaecide. As discussed in the next section, a thorough knowledge of the system may permit a much less expensive alternative.

REDUCE ALGAECIDE REQUIRED

In one instance, treatment was avoided altogether simply by changing the depth of the intake. This required the knowledge that the algae was layered and that the intake was at the level of the layer. Since only small changes are required, even systems which are not designed for it can easily be rigged with siphons to vary intake depth.

In-vivo fluorescence provides a means of monitoring the effectiveness of algaecide treatment. Given a stable stratified condition, experiments can be run in a remote section of the reservoir to determine the optimum quantity and means of application. This can markedly reduce the annual cost of algaecide.

Failure to recognize that algae are layered deep below the surface may result in the use of insufficient algaecide at the surface. A killing concentration does not reach the layer, and the treatment is wasted. However, if it is known that the algae is concentrated in a thin layer a specific distance below the surface (8 meters for example), then

surface application is probably not the best course. Why add excessive algacide to produce a killing concentration in the enormous volume of water above the "target" layer?

Instead, equipment for controlling the depth of application of a towed bag of copper sulfate, for example, is relatively inexpensive. Laying a fraction of the amount of algacide in the active growth zone (about 1 meter above the layer) is more effective than surface application and provides tremendous savings. It should be noted that in all cases studied, the layers were constant in depth throughout the reservoir, making such "targeted" application practical.

PREDICT WHEN ALGAEICIDE TREATMENT WILL BE NEEDED

The ability to plan ahead is a primary requirement of an efficient operation. Even a few days notice of the development of a bloom permits corrective action to be taken to prevent clogged filters and adverse effects on the quality of water delivered to customers. Knowledge of predictable seasonal or annual trends is valuable in deciding on management strategies.

The *in-vivo* fluorescence method was used to monitor four Connecticut reservoirs weekly during the summer and fall of 1983 (4). It proved valuable in identifying, up to three weeks in advance, the onset of growth conditions which would eventually require algacide treatment.

Continuous monitoring of the intake gave instant notice of the presence of algae in the incoming water, and was valuable in identifying short-term variations and long-term trends.

MONITOR TRIHALOMETHANE (THM) PRECURSORS AND TOTAL ORGANIC CARBONS (TOC)

A number of papers have shown the utility of a fluorometer in detecting the breakthrough of THM precursors and other organics from charcoal filters, or in monitoring control by powdered activated carbons (7, 8, 9). In one of the papers (7), fluorescence was used to evaluate the relative adsorption efficiency of four types of commercially available granular activated carbon in six different water sources. The relative efficiencies were not the same in different water sources. The fluorometer provided a simple means for balancing costs against removal efficiency to determine the most economical purchase for each individual water treatment plant. The authors concluded, in essence, that a flow-through test on the actual mix of trace organics present in the water is more significant than a test using one or two specific compounds.

The fact that simple measurement of fluorescence of the water (without chemical treatment of any kind) yields a measure of total organic carbon (TOC) has been generally treated with skepticism. In particular, two careful studies by well respected researchers have shown excellent correlation between fluorescence and TOC (9,10).

A simple change of optical filters is required to convert the fluorometer to this use.

IMPROVE THE QUALITY OF WATER SUPPLIED

Fluorometric methods enable you to correct potential problems before they become problems in the form of customer complaints or non-compliance with regulations. The added benefits include saving cost and amount of algacides, reducing costs of activated carbon (where applicable), and less frequent regeneration of filters.

EQUIPMENT

The technique involves pumping water from varying depths through a flow cell in the fluorometer and reading (or recording) the fluorometer's output.

Battoe, in his Handbook (6), lists the specific equipment he used. While his choices were excellent, most of the equipment is now outdated. For the fluorometer, he chose the Turner Designs Model 10-000R. This instrument has been replaced by an improved digital version, the Model 10-AU-005, which is water resistant and will withstand temporary immersion. The AlgaeWatch Online Fluorometer, which can also accomplish the task, is an on-line continuous monitor. This unit features a non-contact, non-fouling flow cell that requires little maintenance - a major advantage in the field. The AlgaeWatch Online Fluorometer also uses a bubble trap which allows water saturated with air to release the dissolved gas without introducing the bubbles into the sample line.

Fluorometer: Either the Model 10-AU-005 Field Fluorometer (portable, when the fluorometer must be moved from site to site) or the AlgaeWatch Online Fluorometer (fixed site monitoring), equipped with the 10-096 *in-vivo* chlorophyll optical kit.

Data Collection: Internal or external data collection can be used. The Model 10-AU's Internal Datalogging and Electronic Chart Recording option is very useful for use with field studies, because of the large storage capacity (up to 64000 data points). The Model 10-AU can also be used with a computer or with an analog chart recorder. The AlgaeWatch Online Fluorometer's has a 4-20 mA output for data collection, including the possibility for remote data access.

Pump: Capable of pumping 500 ml/min or more, 12V DC.

Tubing: For the Model 10-AU Field Fluorometer, a flexible opaque plastic tubing of suitable length to sample at the depth desired is needed. The type of green garden hose which has a black opaque inner lining works well. The AlgaeWatch Online Fluorometer does not require opaque tubing because the sample intake is separated from the light detector.

Power: The Model 10-AU-005 may be powered with a heavy duty lead-acid battery, a boat battery if it has a charger, or AC power. The AlgaeWatch Online Fluorometer requires AC power.

Optical Kit: The AlgaeWatch Online Fluorometer comes equipped with the proper optical kit for *in-vivo* algae measurement. If you are using the Model 10-AU or the Trilogy Laboratory Fluorometer, please consult the Ordering Information Guide for the optical kit that best matches the studies you will be performing.

Sample Adaptors: You will almost certainly be measuring some extracted chlorophyll or other individual samples to correlate to the *in-vivo* studies. Extracted chlorophyll requires the use of borosilicate cuvettes and a 13 mm adaptor for the Model 10-AU if 13 x 100 mm cuvettes are to be used or a 12 mm adaptor for the Trilogy fluorometers.

METHODS OF CHLOROPHYLL DETERMINATION

Cell Counting Method. One method of following algal growth is to take samples for microscopic counting and identification. There are several well-known drawbacks to this approach.

First, it is expensive in that it requires many samples to be analyzed to follow trends by a highly-trained person. Thus, many water companies send the samples to a water lab, which requires valuable time. By the time the results come back, they are frequently just an "after-the-fact" confirmation of a problem, which has already produced clogged filters or a taste and odor problem.

Finally, such examination may not even show the problem. Because very thin horizontal layering is common, samples taken without guidance will probably miss the "hot" zones.

Fluorometric Methods. The fluorometric determination of chlorophyll both by extraction and *in-vivo* measurement is the subject of an extensive review article (3). Chlorophyll is a fluorescent molecule. It absorbs light in the blue region of the spectrum (about 440 nm), and emits light in red region (about 680 nm). This provides an extremely sensitive means of measurement. Fluorescence is a very common analytical tool whose typical sensitivity is in the parts-per-trillion range.

Extractive Methods. A traditional means of chlorophyll measurement is to filter the organisms, grind, extract with acetone, and measure at three wavelengths using a spectrophotometer. After a historic paper by Yentsch in 1963 (11), it became popular to measure the acetone extract in a fluorometer. This considerably increased the speed and ease of measurements, as it was necessary to filter far less sample.

In-vivo Methods. Later, Lorenzen showed that filtration and extraction were not necessary (2). A fluorometer can be used to measure chlorophyll directly and continuously in a water sample. The water is simply pumped through a flow cell in the fluorometer, and the readings are recorded (automatically on a computer or other data collection device, if desired). For a depth profile, the sample hose is lowered steadily, noting the depth periodically. Correction must be made for the delay time as the sample flows through the hose. This is a fixed offset in time, and Battoe describes a simple means of determining its value (6). Samples from interesting zones detected by the fluorometer may be collected from the discharge for further examination.

In-vivo measurement was an instant success with oceanographers and limnologists, as it permitted chlorophyll profiles to be recorded continuously in the field. It not only replaced the equivalent of thousands of discrete measurements, but permitted more accurate mapping. As mentioned earlier, phytoplankton typically stratify, usually in extremely thin layers. Discrete sampling, unless recorded at highly resolved depth intervals, can easily miss the strata. To locate stratified phytoplankton using a fluorometer, simply record fluorescence responses, looking for increasing readings, while profiling vertically or horizontally through the water column. If you wish accurate quantitative measurements, take occasional grab samples for later extraction and analysis using the fluorometer (12) or another analytical method.

The fluorescence of a given amount of chlorophyll in the living organism is affected by a number of things, the most important of which is the amount of light the organism received recently. What this means is that the fluorometer readings are converted to chlorophyll by a conversion factor which must be determined under the conditions that exist during the readings. This is done by taking occasional samples to be analyzed for chlorophyll by a technique which is not affected by the conditions of the live sample. Sometimes these samples are analyzed by the fluorometric acetone-extraction method (12) or by the spectrophotometric method (3). When a researcher is studying small effects, such as the effect of nutrients, concentration of standards might be determined by the spectrophotometric method, but numerous field samples would be read using the faster, more sensitive fluorometric method.

Reservoir Management. In reservoir management, however, strict quantitative information is seldom necessary. Frequently, what is required is the location of algae or warning of a bloom so that adequate treatment may be applied. In such cases, watching for peak fluorometer readings will provide the necessary information. For more quantitative information, calibrate seasonally to correct for local conditions by the spectrophotometric method or by sending occasional samples to a commercial water lab. Thereafter, calibration could be done by the relatively simple fluorometric extraction method (1). This method is discussed in detail in U.S. Environmental Protection Agency Method 445.0, which provides a step-by-step procedure for determining chlorophyll *a* and pheophytin *a* (12).

In-vivo Fluorometry (IVF) was investigated for its potential value as a chlorophyll monitoring system for use in the drinking water industry (4). Water column chlorophyll concentrations were monitored in four Connecticut reservoirs by IVF and acetone extractions during summer and fall 1983. At low chlorophyll concentrations (less than 10 µg/L), background fluorescence and temperature effects were significant. (Note, however, that the Model 10-AU's 1990's electronics permit better blanking capability and temperature compensation is available as an option.) At higher chlorophyll concentrations, IVF provided an accurate, fast, and relatively simple estimate of extracted chlorophyll, and documented the vertical distribution of algal chlorophyll in the reservoirs. The onset of algae growth conditions which eventually required algaecide treatment was traced for up to three weeks prior to recognition by currently employed procedures. Algaecide treatment was verified by IVF. Alternative management was achieved by changing the depth of the treatment plant intake to avoid algae concentrations located by IVF. Raw intake water monitoring by IVF at the treatment plant correlated well with changes in chlorophyll content in the reservoir.

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