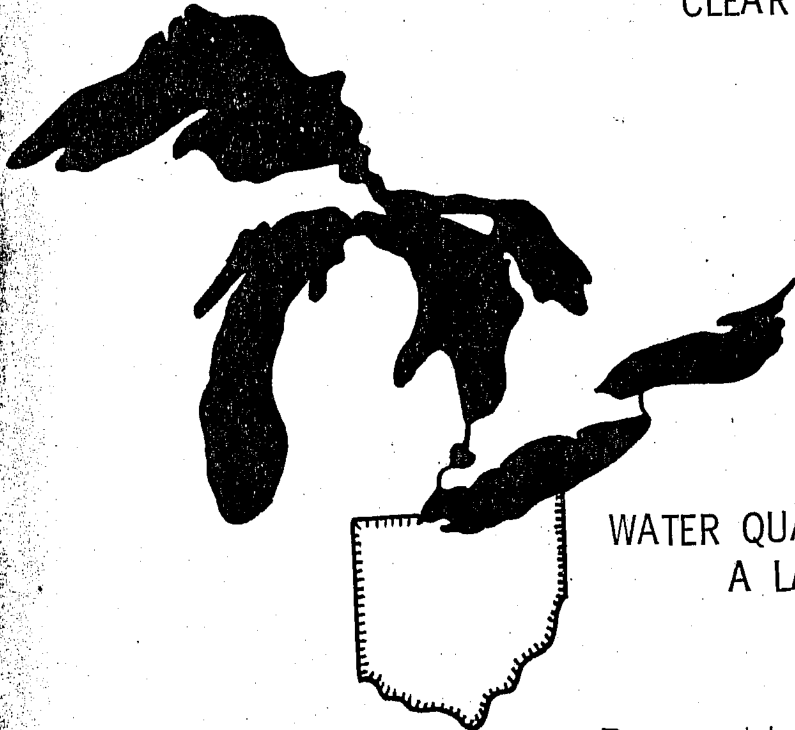

WATER QUALITY AND LAKE PROCESSES: A LABORATORY GUIDEBOOK

Prepared by

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WATER QUALITY AND LAKE PROCESSES

Water Quality

The water quality of a body of water such as Lake Erie depends on many things. The sun gives it heat, the winds give it waves and circulation, the atmosphere gives it precipitation and gasses, and tributaries give it dissolved and suspended substances. All of these external inputs plus the physicochemical and biological processes that are constantly at work within the lake determine its water quality. As you can imagine, this is a very complex subject when all of the combinations and interactions are considered. The following guide is intended to explain some of the more fundamental components of Lake Erie's water quality and the processes active in the lake. The components we will consider are dissolved solids, dissolved gasses, and suspended solids.

Dissolved Solids

As fresh water returns to Lake Erie down the rivers and creeks, it dissolves a great deal of land materials. This dissolved material forms the nutrients which are essential for life processes. Unfortunately, excess amounts of these nutrients can cause excess growths of aquatic plants which can result in a number of water quality problems. Attached algal masses can clog water intakes, form unsightly mats on bathing beaches and reduce boat speeds by growing on the hull. Planktonic (floating) algae in excess can cause color, taste and odor problems in public water supplies. During algal blooms unsightly surface scums are formed and when they die and decay they cause odor problems along the shore and result in oxygen depletion in deep water.

Solids dissolved in water are usually present as ions. For example, table salt or halite (NaCl) becomes ionized into sodium ions (Na^+) and chloride ions (Cl^-) when stirred in water. Salt comes out of solution as a solid again when the water is slowly evaporated. Lake Erie water contains many ions in a dilute solution. The most abundant ions and their average concentration in western Lake Erie are listed in Table 1.

Several relatively simple methods are available for the measurement of dissolved solids in water samples. The most widely used is conductivity. Other tests such as alkalinity and hardness yield measurements of specific types of dissolved solids which represent a

TABLE 1

COMMON IONS PRESENT IN
WESTERN LAKE ERIE WATER[1]

large percentage of the solids found in Lake Erie water. Each of these methods will be discussed below.

Conductivity. Since dissolved solids in water exist as ions, their solution can conduct an electrical current (see Experiment). The amount of conductivity is directly related to the concentration of ions and hence, to the total dissolved solids in a water sample. This relationship for water in western Lake Erie is approximately 0.6:1.0, in that if the conductivity of a water sample is measured in micromhos per centimeter (umhos/cm) and then multiplied by 0.6 the result will be the total dissolved solids (T.D.S.) value for that sample given in parts per million (ppm). This ratio has been determined experimentally by averaging the results of thousands of tests in which, on the same sample, conductivity was measured with a precise meter and total dissolved solids was found by evaporating a known quantity of water and then accurately weighing the solids left behind.

Conductivity (as a measure of total dissolved solids) is an indicator of the potential productivity of water, since it is a measure of the nutrient material dissolved in the water. In general, high conductivity (200 - 500 umhos/cm) is associated with fertile lakes such as Lake Erie, and low conductivity (less than 200 umhos/cm) with relatively infertile lakes such as Lake Superior. In situations where the conductivity is considerably above 500 umhos/cm there is likely to be gross pollution from an inorganic source such as brine. Drainage from salt mines and wells near Painesville, Ohio has polluted the Grand River to such a degree that conductivity values over 2000 umhos/cm have been measured in Lake Erie at the river's mouth.

Conductivity can best be measured with a conductivity meter. This instrument measures the ability of the water to conduct an electrical current, which, in turn, depends on the number of ions in the water. A simple type of conductivity measuring device is illustrated in Experiment 1 outlined below. This is not a true meter however, because there is no way to apply a value to the measurement. An actual conductivity meter is available in the laboratory which will measure the capacity of a water sample to convey an electrical current. This meter has a dial readout in standard conductivity units, micromhos per centimeter (umhos/cm). Readings are affected slightly by the temperature of the water, therefore, to standardize results, scientists have agreed to report all findings as if the water temperature was at 25^{o}C. A correction table for adjusting the conductivity reading for the standard temperature is presented in Table 2 of this Guidebook.

EXPERIMENT 1

ELECTRICAL CONDUCTIVITY OF WATER

1. Equipment and Materials:
   a. lamp, 110 volt bulb
   b. extention cord
   c. 110 volt outlet
   d. glass beaker, 1 liter
   e. glass stirring rod
   f. 2 short strips of copper
   g. table salt (NaCl), 200 gm
   h. distilled water, 1 liter

2. Procedure:
   a. split extention cord wires for about two feet near center and cut one side
   b. bear wires on each side of cut and attach copper strips (electrodes).
   c. fill beaker with distilled water and insert electrode in such a way so they do not touch.
   d. attach lamp to one end of extention cord and plug other end into 110 volt outlet
   e. add measured amounts of salt to the water (10 gm at a time) while stirring until enough current is passed through the water to light the bulb.
   f. continue to add salt until the maximum brightness is attained.

TABLE 2

CONDUCTIVITY CORRECTIONS FOR STANDARD TEMPERATURE (25°C)[1]

Primary Production

Primary production in an aquatic ecosystem is the rate at which energy from the environment is utilized to form organic compounds through photosynthesis. In lakes, as on the land, the light energy of the sun intercepted by the green pigment (chlorophyll) in plants is used to bring about the reduction of dissolved carbon dioxide (CO_2) to carbon, and thence to carbohydrate. In Lake Erie there never seems to be a shortage of carbon dioxide, for the abundant bicarbonate ions ($HCO_3^=$, as determination) can split off carbon dioxide as soon as free dissolved carbon dioxide begins to be used up.

The reaction for photosynthesis can be summarized in the following equation, which is probably the most important reaction in the world:

$$6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

By this reaction, plants transform inorganic substances into complex organic compounds. In this formula $C_6H_{12}O_6$ is a carbohydrate known as glucose sugar. Because energy has been put into the reaction, the product, glucose, contains potential energy which can be recovered. When a cube of sugar burns, which it does fiercely as can be seen in the laboratory, it gives back the energy stored at its formation. But in plants, energy is recovered slowly, under control by the action of enzymes, to build up larger and larger molecules, until at last living matter is formed.

The other product of photosynthesis is oxygen which is released as a gas and generally becomes dissolved in the water if the plant is submerged. Dissolved oxygen in water is relatively easy to measure when compared to the problems of measuring glucose production. Therefore, by determining the amount of oxygen produced by photosynthesizing plants per unit of time within a certain volume of lake water an index of primary production can be achieved. Returning to the formula for photosynthesis, the atomic weights of the various components are given below:

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

$$264 \quad + 108 \quad = 180 \qquad + 192$$

This information permits the calculation of a ratio of glucose to oxygen produced by this process, 0.94 to 1.00. In other words, for every 10.0 milligrams of oxygen released to the water, 9.4 milligrams of glucose are manufactured within the plant cells. The procedures for conducting primary productivity measurements by this method are given in Experiment . A correction for normal respiration must be applied to the results of this experiment. During daylight hours when plants are active in photosynthesis they are also respiring. This oxidation process requires oxygen and produces carbon dioxide in the same way that this reaction takes place in animals. At night plants only respire. Therefore, it is necessary to determine the rate of respiration (or oxygen depletion) during the period of photosynthesis before the oxygen production method of primary production can be used. A technique for applying a respiration correction is given in Experiment .

Although the higher aquatic plants, such as cattails, water lilies and water milfoil, do play a part near the lakeshore, by far the most important part in aquatic photosynthesis is done by microscopic plants, the diatoms and other phytoplankton, and also by ultramicroscopic flagellates called nanoplankton. The rate of this primary production often depends on age of the lake. When Lake Erie was first created by the scowering action of the last glacier, its water probably only contained minute traces of certain chemical nutrients. Nitrates and phosphates were then only present in small amounts and supported only a sparse plant community. At this time Lake Erie would have been classified as oligotrophic, meaning unproductive. Today, the western basin of Lake Erie is at the other end of the scale with high concentrations of all compounds needed for life processes. Lake Erie is now called euthrophic, meaning productive. Lake Erie is characterized by blue-green algae in the late summer and fall. This group is responsible for blooms (massive populations of algae which are visible to the unaided eye) in the nutrient-rich and polluted waters. They often give the water the appearance of pea soup, leaving a green wake behind boats, and produce an unpleasant smell and taste. When the algae die and sink to the bottom, the oxygen depletion resulting from bacterial growth has rendered large portions of Lake Erie unfit for fish life. This is particularly true in the central basin of the lake where thermal stratification precludes mixing of the surface and bottom waters (see section on Thermal Characteristics).

EXPERIMENT

PRIMARY PRODUCTION IN AN AQUATIC ECOSYSTEM

1. Equipment and Materials:
   a. 3 glass bottles, approx. 300 ml with glass stopper or air-tight lid
   b. aluminum foil or black tape
   c. float, string and anchor
   d. water sampler, 3 liter
   e. dissolved oxygen meter of test apparatus

2. Procedure:
   a. during daylight hours obtain a water sample (3 liter) from a specific location and depth in the lake and carefully fill the three bottles so as not to introduce additional oxygen.
   b. determine the dissolved oxygen (D.O.) in one of the bottles immediately.
   c. stopper the other two bottles and cover one with aluminum foil
   d. suspend the two stoppered bottles from a float at the same location and depth where sampled. Note: in the uncovered bottle both photosynthesis and respiration will continue, while in the covered bottle only respiration will occur.
   e. after a specified period of time (1 to 24 hours) recover the bottles and analyze the water for D.O. and record these values.
   f. calculate the total oxygen produced for the time interval by summing the differences between the D.O. content at the start and finish in each bottle.

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Suspended Solids

The concentration of suspended solids in any aquatic habitat is an important physical parameter. In terms of asthetic qualities, it exerts the major control over water color and frequently is the determining factor for odor. It also contributes to taste, although dissolved solids probably determine that quality most frequently. More importantly, the concentration of suspended solids has a tremendous impact on the productivity of any body of water.

Effects. The term productivity, or more accurately: "primary productivity," refers to the conversion of inorganic material in an aquatic system into organic material within a living organism. This is usually accomplished by small green plants, algae and diatoms. Two of the major factors that control the rate at which this process proceeds are availability of inorganic nutrients and availability of light. The concentration of suspended solids exerts an influence on both factors.

Suspended solids contribute nutrients to an aquatic system. This is because phosphorus, and nitrogen to a lesser extent, are readily adsorbed on the surface of small particles of earth which make up a considerable portion of the suspended solid load. In this context, the suspended solids increase productivity. Conversely, they decrease productivity by reducing the amount of light available to the suspended green plants (phytoplankton) at lower depths of the water column. It is interesting to note that in this regard, the organisms themselves are part of the suspended solid load.

It should be noted that light is the source of energy which enables primary productivity to occur and that solar radiation is the only true energy input to our environment. Dr. Eugene Odum has recently determined the flow of energy in an aquatic ecosystem at Silver Springs, Florida (very clear water). In that optimum habitat, only 24% of the incident light is absorbed by plants. Of this amount, only about 5% is converted into material within a living organism (biomass) while the rest is lost as heat. Thus only about 1% of the incident light winds up in the biomass at the primary trophic level. This energy is further utilized as a food source by subsequent trophic levels from the small grazing animals (herbivores) through the top carnivores. Some energy loss is associated with each step until only 3.5×10^{-4} percent of the incident light energy is incorporated as biomass at the top carnivore level.

While the effect of suspended solids on productivity has received some attention, less is known about the effect at higher ecological levels. There have been estimates made of the effect on fisheries but the mechanisms by which an effect is expressed have not been definatively identified. One hypothesis is that there is an abrasive effect on fish eggs. In any event, the following rough estimate was recently made at an international fisheries conference.

0 – 25 ppm: no effect on fisheries
25 – 80 ppm: somewhat reduced fish yield
80 – 400 ppm: not likely to support good freshwater fisheries
> 400 ppm: only poor fisheries at best

Sources

As alluded to earlier, a major component of the suspended solid load is composed of plankton. The major inorganic component is sediment, and the major source of sediment is soil eroded from agricultural land. Dissolved nutrient runoff from fertilizers is well recognized, but less attention has been paid to introduction of components of the land itself into aquatic systems. It has been estimated that from 337 to 1149 pounds/acre/year are washed from agricultural land into an adjacent waterway. Certain components of this land are more easily eroded than others. These include organic matter and clay particles. The clay particles have a great tendency to adsorb inorganic phosphorus and nitrogen that will later become nutrients to algae and diatoms if the clay particles are introduced into an aquatic system. When soil particles are introduced into an aquatic system, they settle out to the bottom in deeper, still water. They then release the adsorbed minerals, at some fairly slow rate, into the water column. In shallow, active water, they are held in suspension longer or are repeatedly resuspended in the water column by wave action after they have settled to the bottom. They still contribute previously adsorbed minerals to the water column whether they are in suspension or have settled out.

Measurements

The direct measurement of the concentration of suspended solids is accomplished by filtering a known volume of water through some filter medium. The mass of filtered material is then determined with an analytical balance.

Indirect methods of measurement depend upon an observation of the amount of incident light that penetrates a given distance through the water. The simplest of these measurements involves use of a device called a Secchi disc. A Secchi disc is a flat circular plate with alternating black and white, wedge-shaped sectors. This disc is lowered into the water until a depth is reached at which the light intensity has been reduced to a point at which the alternating light and dark zones of the disc are indistinguishable. This depth is called the Secchi depth.

A somewhat more quantitative method involves the use of a submersible photometer. This device is lowered to various depths and the light intensity at each depth is represented by the electrical current developed from the photocell detector of the photometer.

Another device for measuring light penetration is the transmissometer. This device is lowered to a given depth and the percentage of light transmitted through a fixed length of the water column is determined.

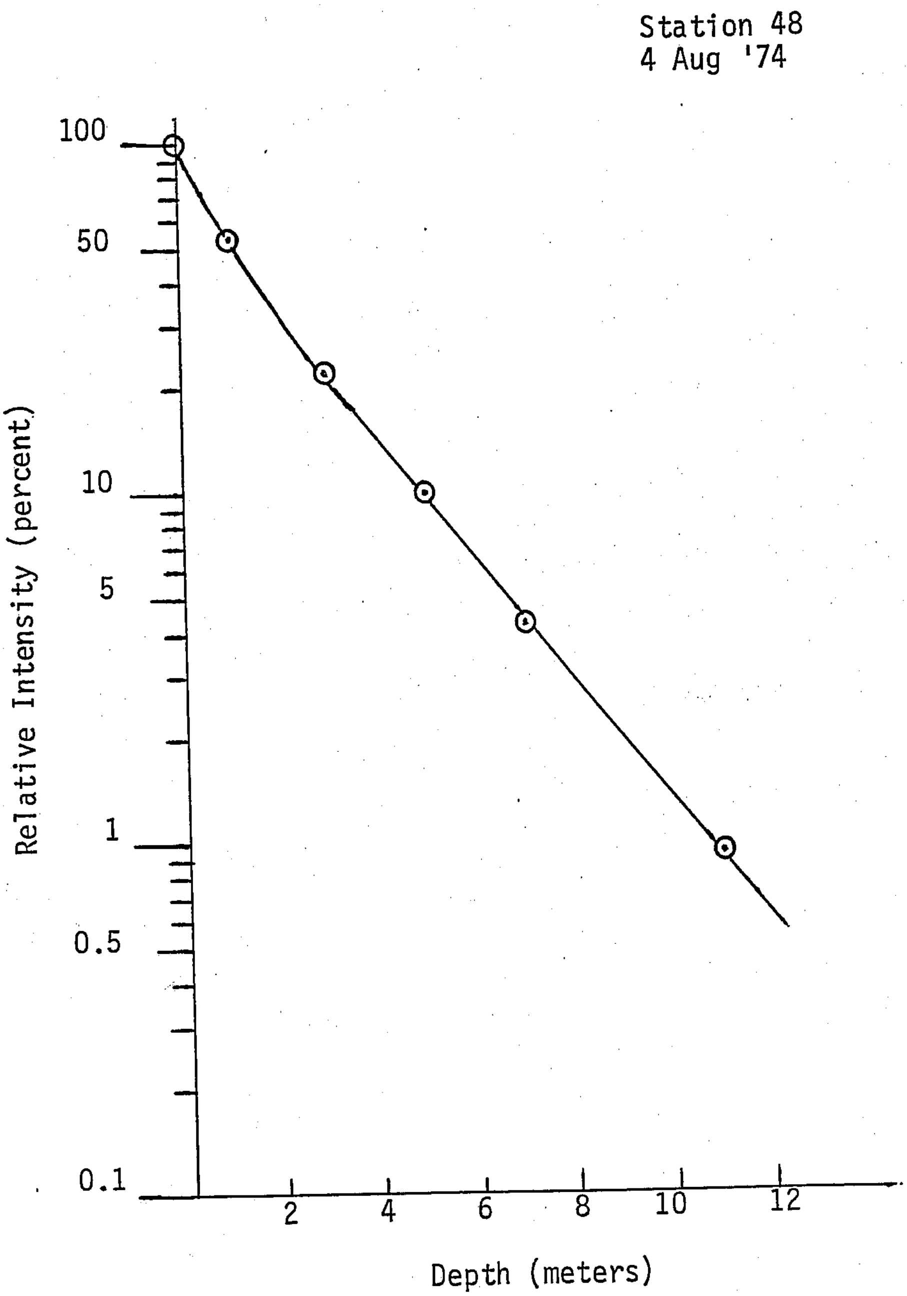
All of these indirect measurements must be calibrated against a direct measurement if concentration of suspended solids is the parameter to be determined.

<u>Penetration</u>

The principal factors affecting light attenuation are: suspended microscopic plants and animals, silt, debris, dissolved or suspended pigments, and detergent foam. Even "clean" water attenuates light. One hundred meters of distilled water provides 98 - 99% attenuation. The relationship between depth and light penetration is approximately logarithmic. A representative measurement made in the Central Basin of Lake Erie during August, 1974 with a submersible photometer is shown in Figure .

Ice cover makes a considerable difference in the amount of light available for primary productivity. A transmission factor of 84% has been measured for a 7 1/2 inch-thickness of clear ice. A transmission of only 22% was measured for the same thickness of ice made cloudy by air bubbles. Snow cover also makes a difference. The transmission through the same thickness of clear ice was reduced to 7% by a 1" cover of snow and to 1% by 2" of snow.

The whole point to measuring light penetration is to determine the amount of productivity possible at a given depth. The distance from the air-water interface to the maximum depth at which significant primary productivity occurs is called the <u>euphotic</u> or <u>trophogenic</u> zone. The lower limit of this zone is considered to be the depth at which light attenuation reaches 99%. Several investigators have attempted to relate the Secchi disc depth to the lower limit of the euphotic zone. An average of their several values indicates that the lower limit of the euphotic zone is about four times the Secchi depth.



FIGURE

RELATIONSHIP BETWEEN LIGHT PENETRATION AND DEPTH IN THE CENTRAL BASIN OF LAKE ERIE to relate the Secchi disc depth to the lower limit of the euphotic zone. An average of their several values indicates that the lower limit of the euphotic zone is about four times the Secchi depth.

Source Material

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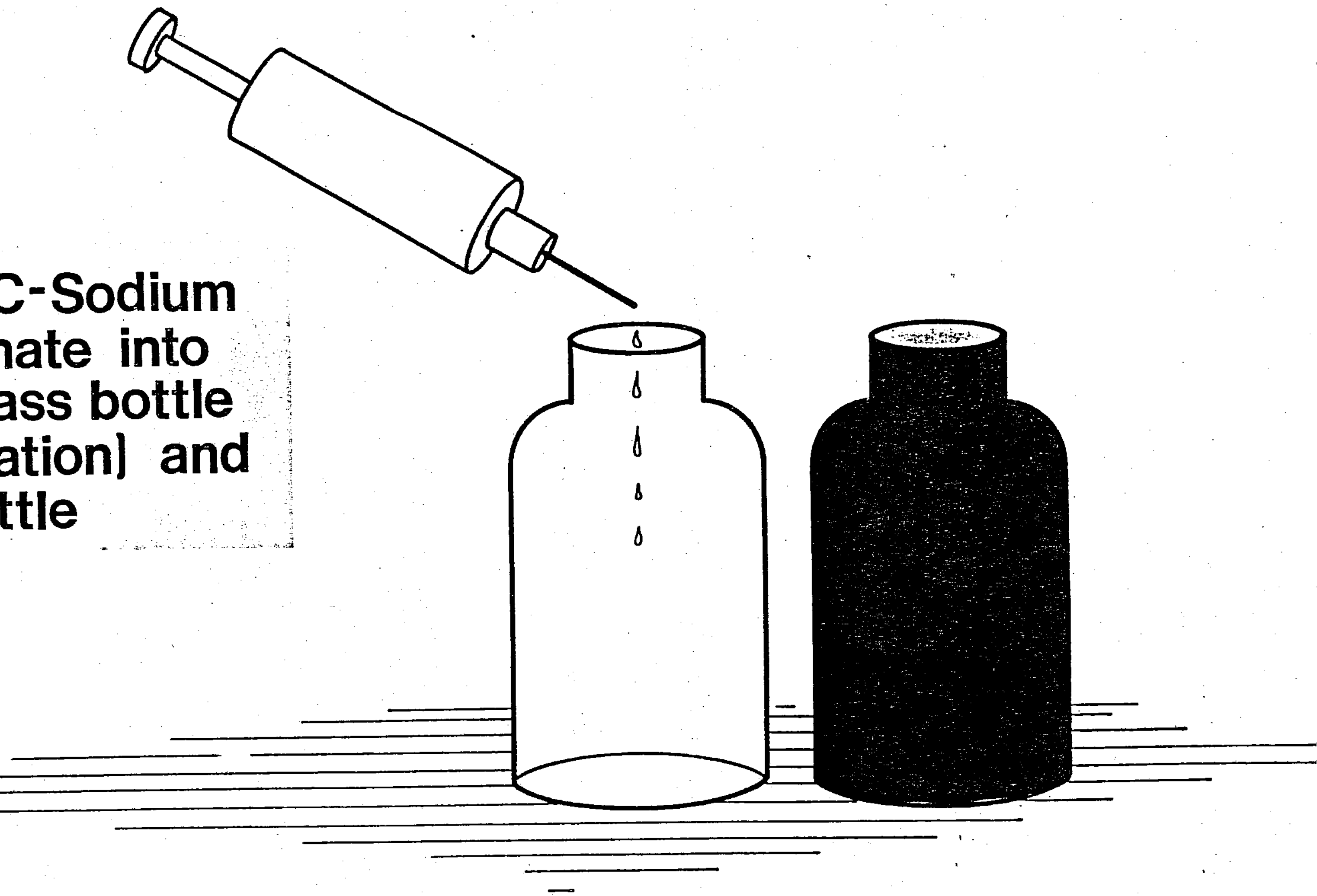
2. The Flow of Energy in the Biosphere by David M. Gates; Scientific American; Vol. 224, No. 3; September, 1971.

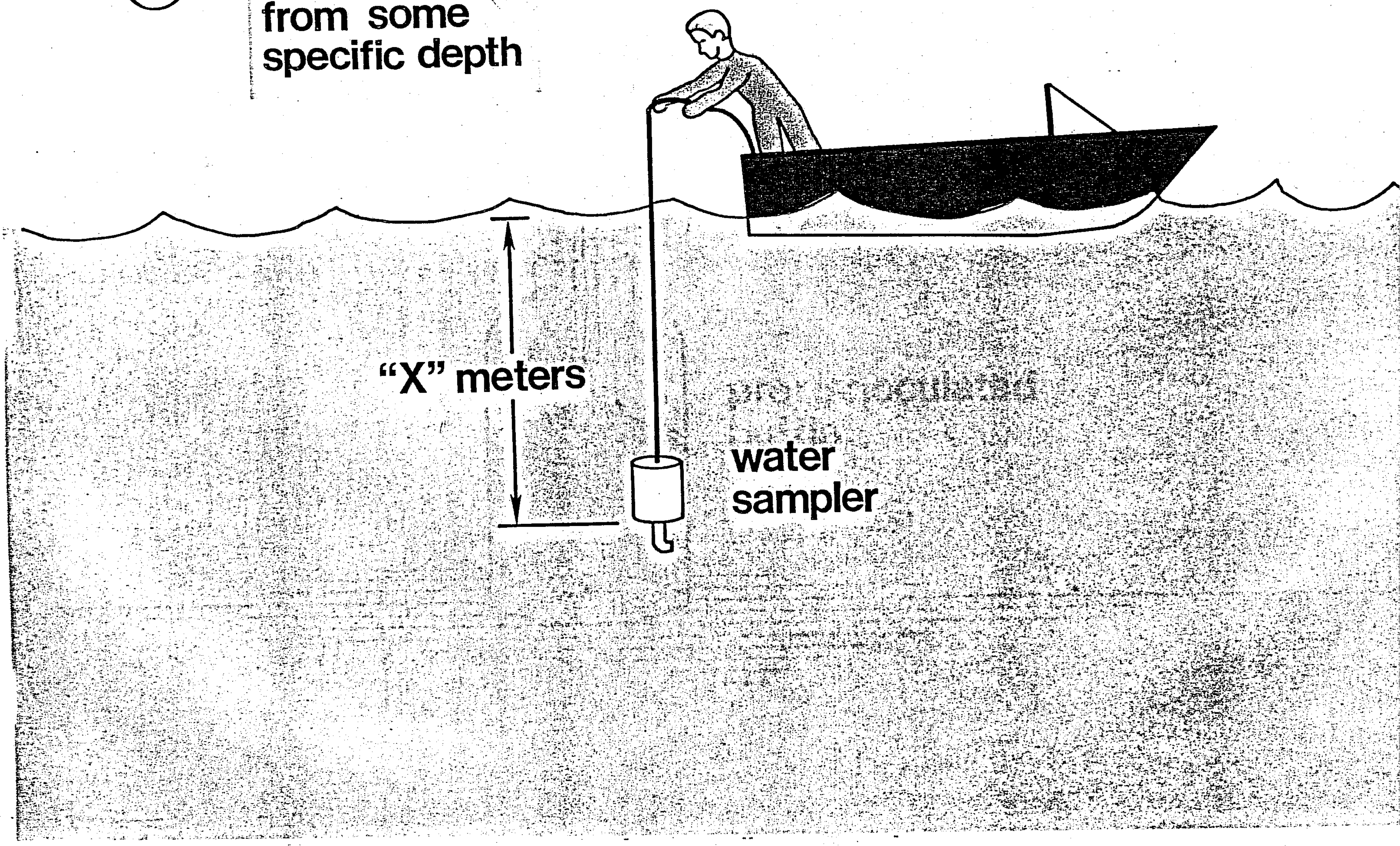
3. Biochemical Ecology of Water Pollution by Patrick R. Dugan; Plenum Press, New York - London, 1972.

1

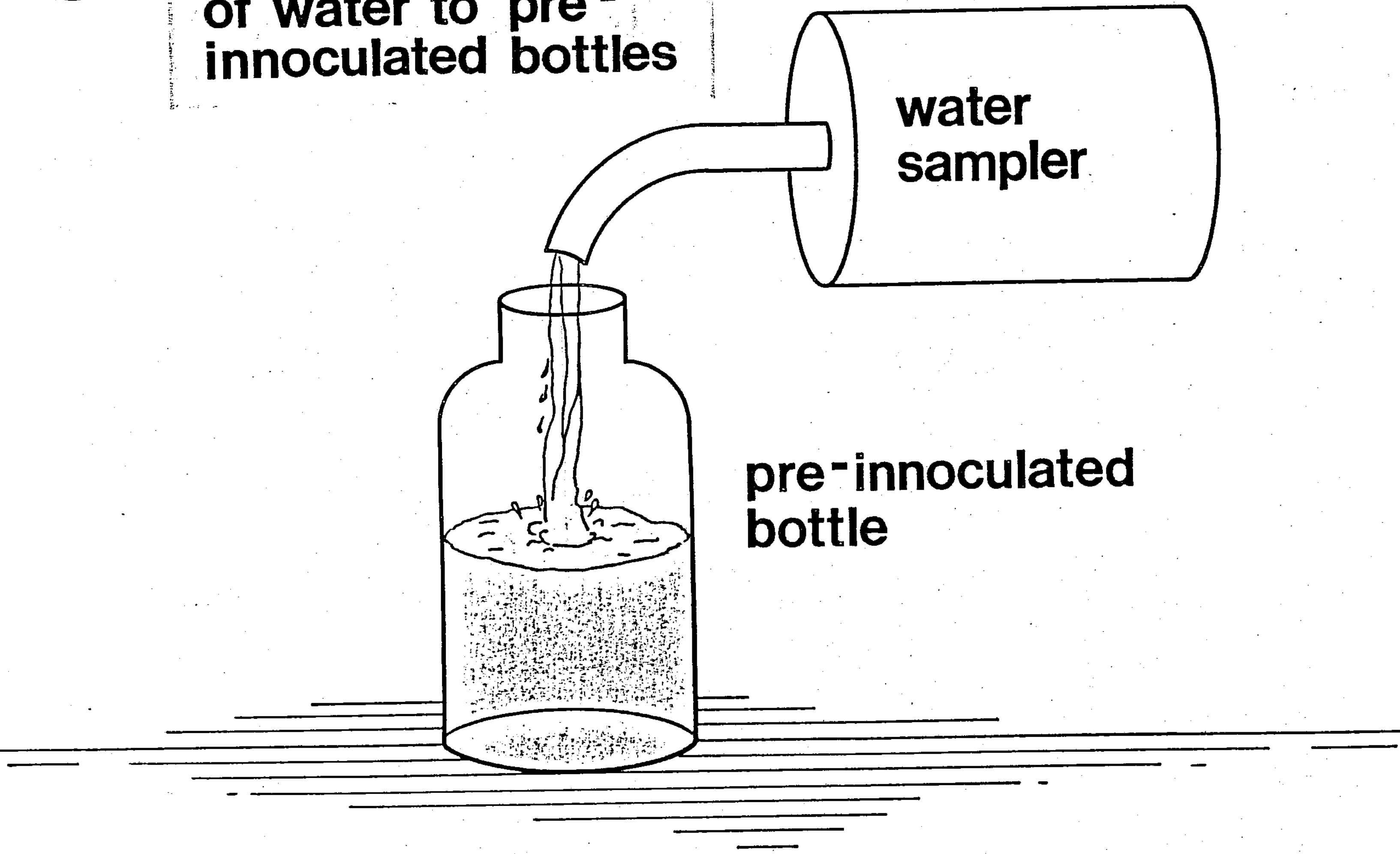
Inject ^{14}C-Sodium Bicarbonate into clear glass bottle [innoculation] and dark bottle



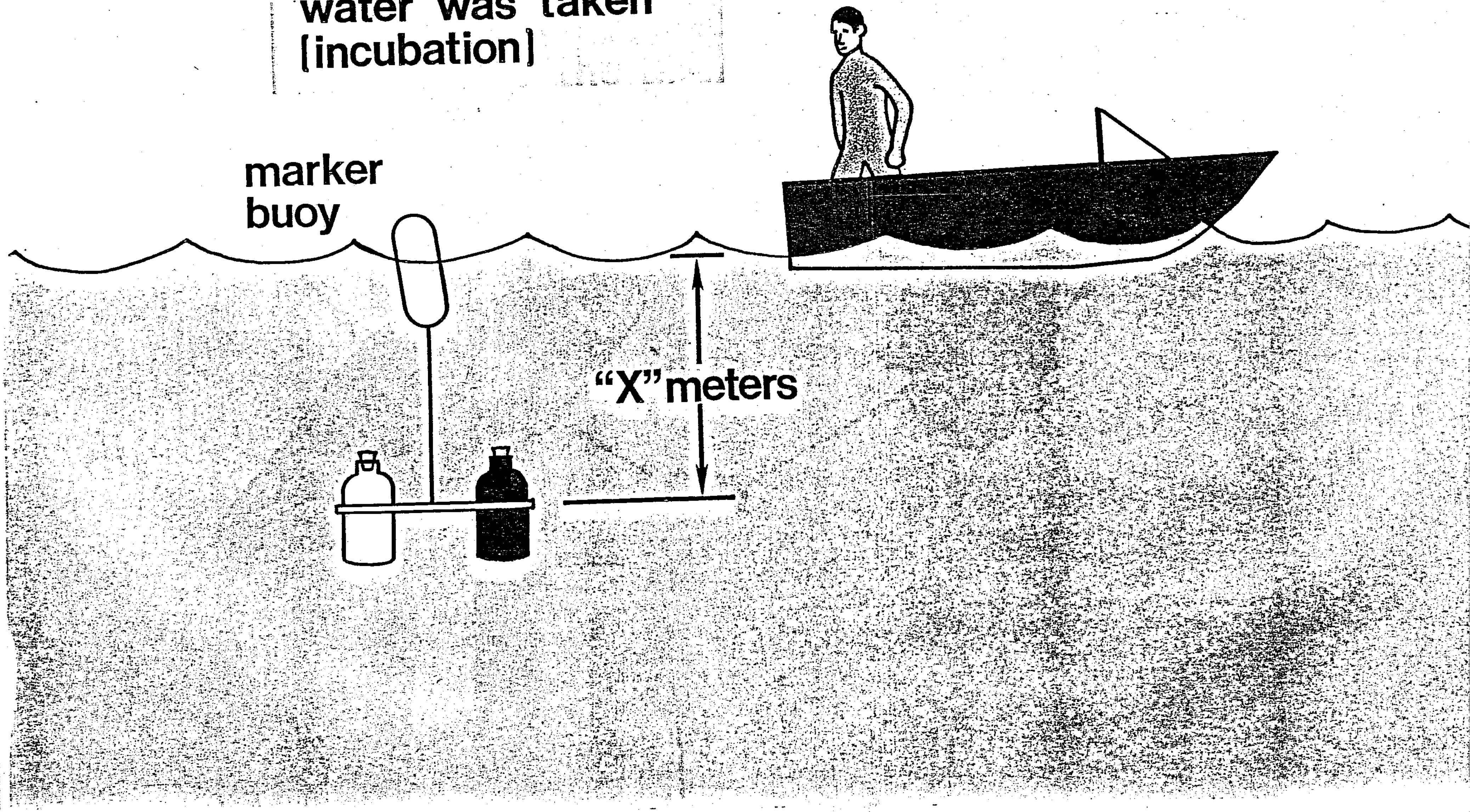
② Sample water from some specific depth



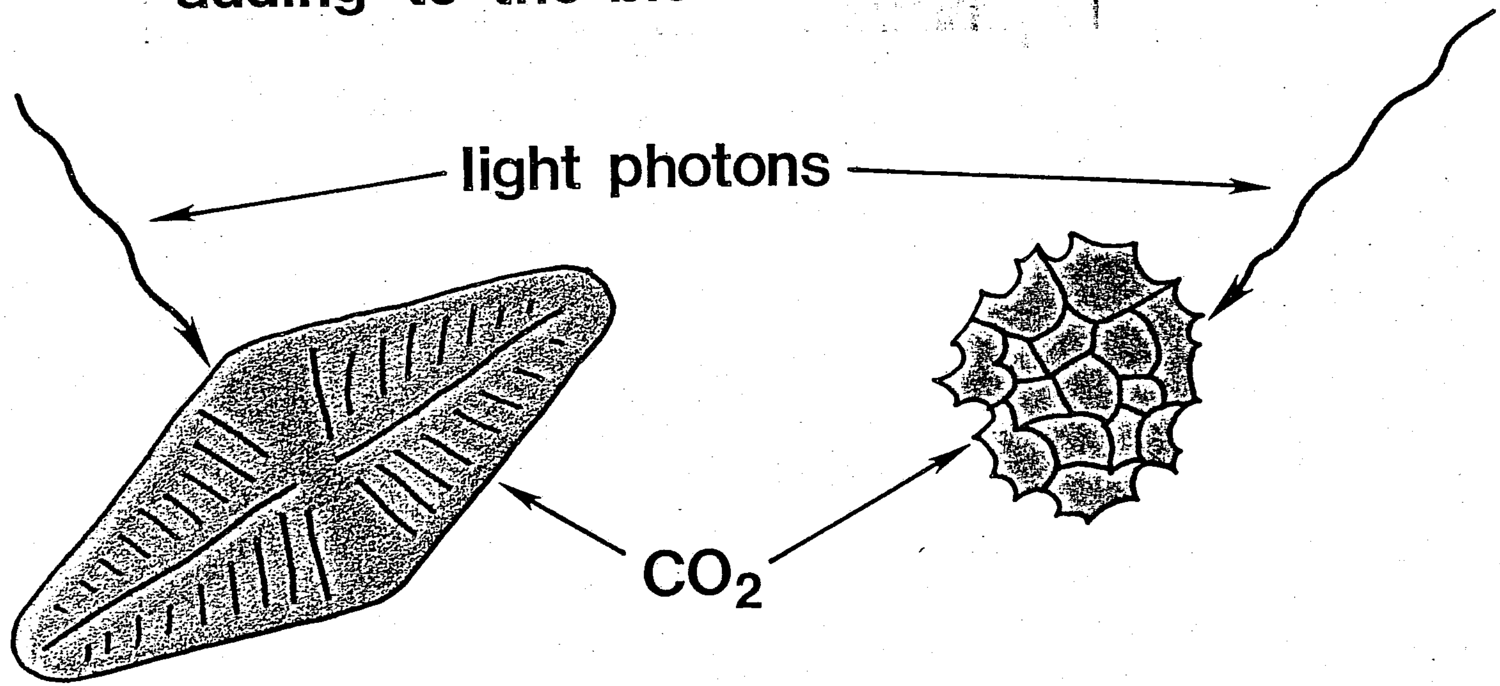
(3) Add known volume of water to pre-innoculated bottles



④ Suspend bottles at depth from which water was taken [incubation]

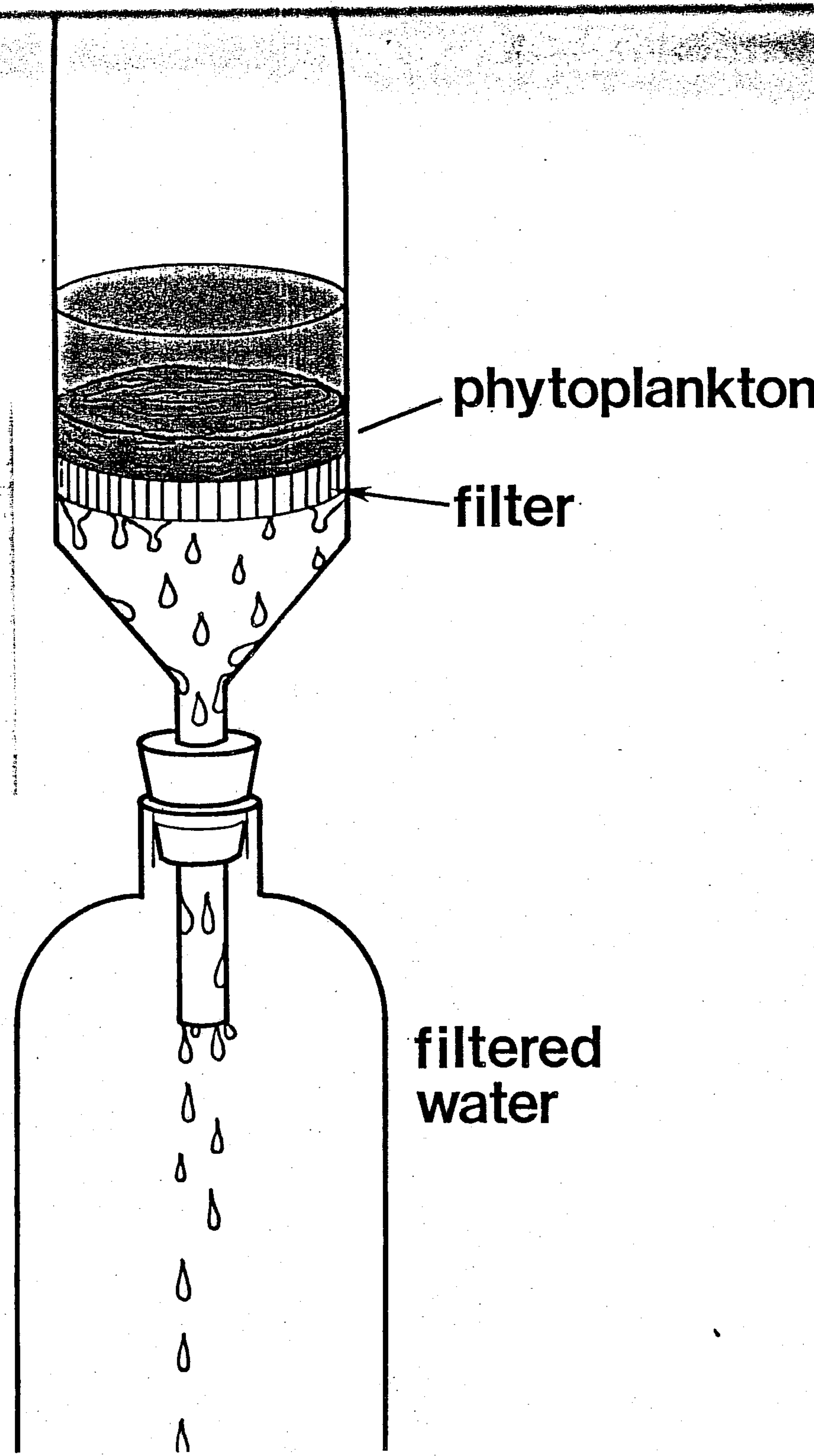


(5) Phytoplankton use sunlight for energy to incorporate inorganic carbon into organic molecules, adding to the biomass

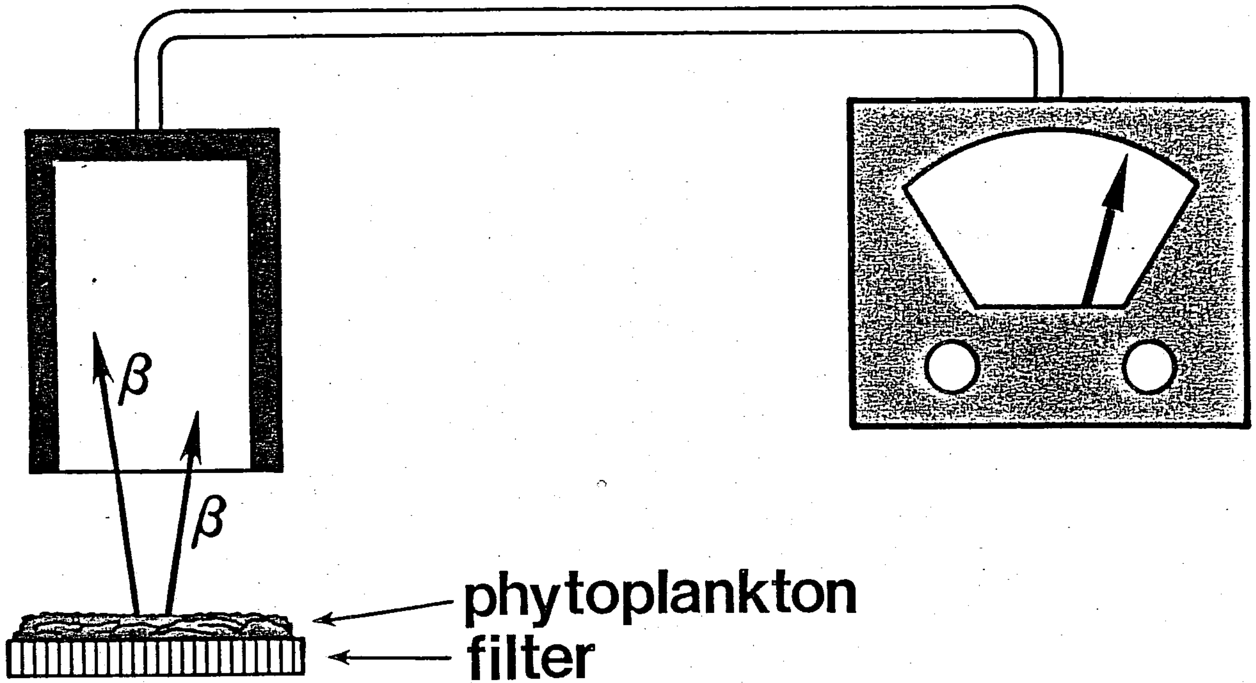


6

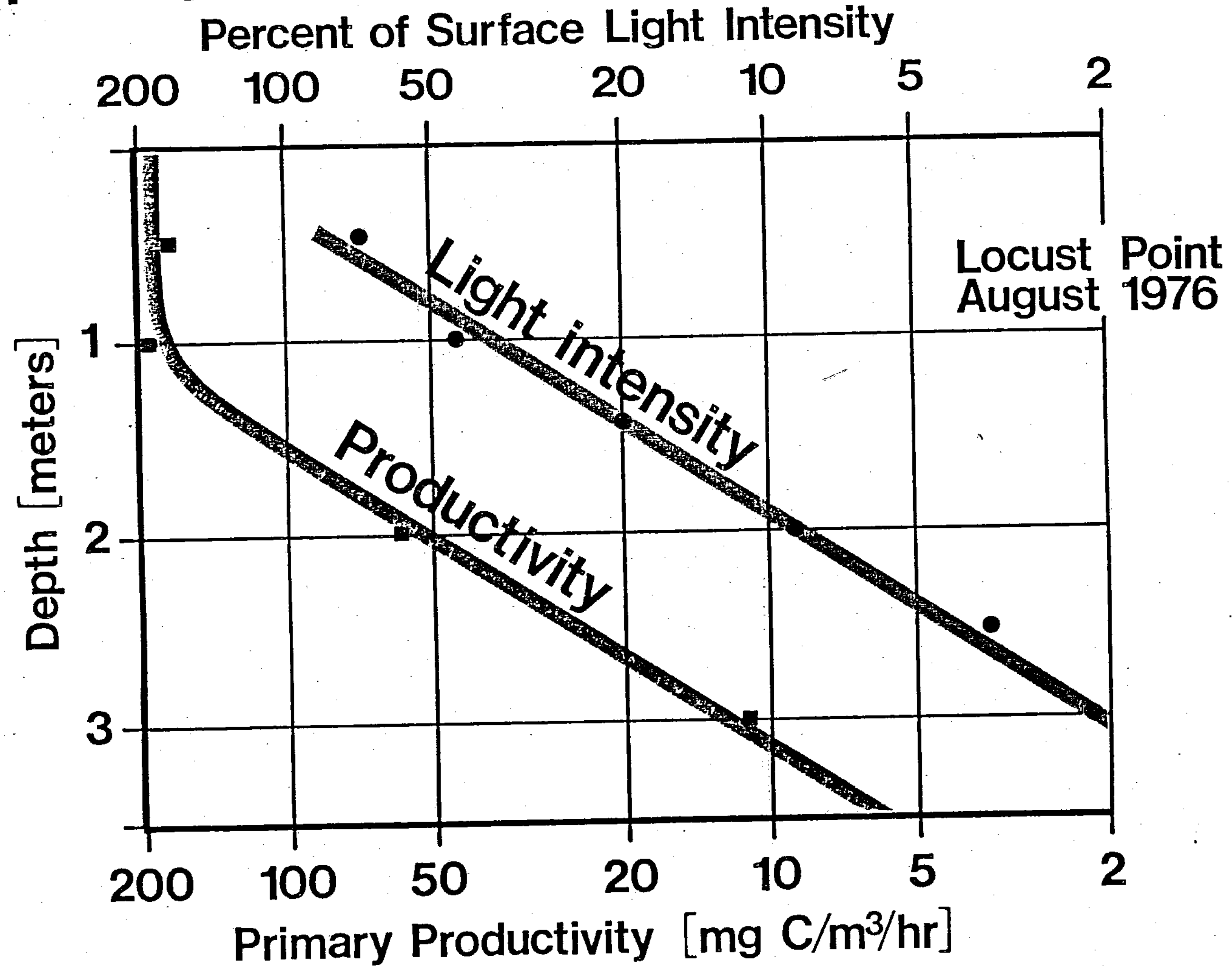
**After incubation, the bottles are recovered and the water is filtered ...
the phytoplankton stay on the filter**



(7) The filter is then counted with a beta particle detector to determine how much C-14 has been taken up by the phytoplankton



(8) The inorganic carbon incorporated through photosynthesis is expressed as Productivity [mg C/m³/hr]



9 Pyramid of Biomass