WATER SUPPLY AND BIOLOGY*

By Prof. W. H. PEARSALL, F.R.S.
University College, London

WATER supply undertakings are primarily concerned with the production of an adequate supply of water of purity suitable for human and industrial consumption. Three features require attention. For human consumption it is of prime importance that the water must be free from deleterious substances and from disease-causing organisms. Secondly, for any purpose, uniformity of quality is a great virtue, and the quality must be such as to include freedom from unpleasant tastes or smells as well as from the more noticeable forms of chemical contamination. (We may leave on one side the question of the suitability of certain types of water for particular industrial uses.) Thirdly, the volume of water required is becoming an increasingly important factor in the problems of supply.

Great Britain has long enjoyed the provision of an admirable water supply. This is now taken for granted, and its advantages are so rarely realized that little credit is given to those responsible. We owe it primarily to the labours of the Rivers Pollution Commission in the 1850's and 60's.

The problem at that time was associated with a series of epidemics of typhoid fever and dysentery. It had been recognized that these were probably water-borne diseases, although due to germs which were excreted in human fæces. All water supplies which could be contaminated by human or animal excretions might thus be suspect, and the Rivers Pollution Commission was called on to investigate the matter and to survey the water resources of the country from this point of view.

They tackled the problem mainly by chemical methods, making use of the fact that animal organic matter is rich in nitrogen, a feature in which it contrasts markedly with plant materials. Thus in the former case the organic C/organic N ratio is low—and this is, in practice, coupled with a high rate of transformation of the material by bacteria to oxidized and inorganic forms of nitrogen-like nitrates. Two chemical features thus make a water suspicious from this point of view—a high nitrogen content and the presence of organic matter with a low C/N ratio.

I mention these activities of the Rivers Pollution Committee because their appreciations and methods were far in advance of their time, and 60–70 years were to elapse before it was generally realized that their technique for describing the origin and breakdown of organic matter was a fundamental one.

The attack on the problem of contamination by fæcal matter led also to the recognition of the fact that almost all surface waters were potentially dangerous. No better illustration of this fact can be given than what happened in Glasgow. There, in 1859, a public water supply from Loch Katrine replaced the numerous shallow wells that had formerly been used. Prior to 1859 a series of three typhoid epidemics had each resulted in the loss of more than two thousand lives. In epidemics, after that date, the number of lives lost fell to about one hundredth of the former number, and in all cases the infection was found to be associated with the continued use of the original supply from shallow wells.

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The chemical methods formerly used for determining the character of water supplies have gradually been supplemented and largely replaced by biological methods. These make use of the fact that animal excreta constantly contain certain bacteria which survive for a time in water; but are unable to multiply materially under natural conditions. Particularly useful in this respect are forms like *Bact. coli.* and *B. welchii.* Thus use is now made of the presence or absence of such organisms under prescribed trial conditions to test for the freedom of the water examined from possibly dangerous contamination. To these testing methods have been added the use of bactericidal treatments, which have reduced the dangers from water-borne disease bacteria to vanishing point. Under modern conditions even isolated cases of typhoid fever or of other water-borne diseases are almost unknown, and they cause great consternation when they occur, as in the case of the Croydon epidemic just before the War. The freedom from such epidemics is due to the efficient methods of treatment and bacteriological control now employed.

The most recent developments in water supply problems are also associated with biological matters. Many of the difficulties in the way of efficient water-supply result from the large volumes required. These have risen steadily not only owing to improved methods and standards of sanitation but also to the development of industrial processes with a high water requirement. The aggregation of population in industrial Britain has greatly exaggerated the tendency, and it is becoming increasingly difficult to envisage the continuation of the present conditions without some system of overall planning, for all the larger centres of population must import water from a distance.

It is not, perhaps, generally realized that, in many rural areas also, existing population nearly or quite suffice to use all available supplies. In some areas, Derbyshire for example, no further increase in the rural population is possible. The difficulties in the way of obtaining adequate volumes of water have various effects. In southern England it has long been necessary to use river waters always more or less contaminated by sewage and by manurial treatments on the agricultural country through which they flow. It is only possible to use these waters safely because of the great improvements in bactericidal treatment and control now available.

The maximum amount of water available in any one place is the difference between the amount falling as rain and that evaporated back to the air. It is usually equivalent to about 10–12 inches of rain per annum in southern England. Rainfall is seasonal, so that it must be stored until required in the summer. The storage can be natural, underground stores as in the case of porous rock strata like chalk or limestone. The alternative is to utilize impounding reservoirs, and because these offer a habitat for plants and animals to grow in, many of the biological problems of water supply centre around the control of impounding reservoirs.

The organisms that appear may impart unsuitable quality or unpleasant tastes and smells to the water; but even if they do not, their presence necessitates filtration, and the quantities that at times must be removed add greatly to the difficulties of the water engineer. The algæ are the principal offenders in this respect, particularly diatoms and blue-green algæ. Some indication of the magnitude that the problems of filtration may assume may be gleaned by the following example, illustrative particularly of conditions near London. A reservoir receiving water from the Thames and containing about 7 thousand million gallons might contain at times 110 tons of a single alga, *Fragilaria crotonensis*, measured as dry matter, and roughly a thousand tons as live algæ. From the volume of water normally filtered this involves a daily removal of at least a ton of dry weight, roughly equivalent to at least 10 tons of living alga.

It will be realized, then, that during periods of abundant algal growth, the algæ alone greatly complicate the problems of a waterworks engineer, for rapid replacement of filters becomes essential. Similar problems are sometimes presented by other aquatic organisms, notably the Cladocera or water fleas. However, the algæ and other aquatic plants have an especially important role because they are the producers of organic matter in fresh water, utilizing light energy and dissolved salts in building up new organic materials. As a general rule the abundance of sub-aqueous life is correlated both with the abundance of algæ and also with the amounts of certain mineral nutrients which are likely to limit their growth. The concentrations of bicarbonates, of nitrates and of phosphates are particularly important in this respect; but in some cases, as in some of the English Lakes, the continued growth of the diatom, *Asterionella*, is apparently limited by depletion of silica, which must exceed a concentration of 0·5 parts per million. There is also some evidence that the presence of high proportions of blue-green algæ in a water can be correlated with an abundance of dissolved organic matter.

Although there are many gaps in our knowledge of the factors which make for algal abundance, it is quite clear that as a general rule certain algal types are indicative of certain water conditions. It is known, for example, that the course of recovery from organic pollution in a stream can be traced by the sequence of algæ found below the pollution source. The influence of the dissolved salts on the algal flora is equally evident in unpolluted waters. In mountain regions, as in some Connemara lakes studied, the different floras characterize the more calcareous waters, and there are distinct elements indicative of peaty waters; while it was long ago noticed by Dr. G. S. West that the faintest traces of pollution by animal fæcal matter results in an abundance of diatoms. In fact, the organic life of a body of water is far more sensitive to traces of pollution than is usually supposed. The biological character of a piece of water depends so much on salts like nitrates and phosphates, the oxidized products of organic matter, that even traces of a completely oxidized sewage effluent usually suffice to change the flora and fauna qualitatively, and they will certainly enrich it quantitatively.

It follows from these facts that the biological analysis of the algal flora is capable of giving information of great value as to the quality of a water supply. At the same time, the recognition of the importance of the reservoir as a biological system would do much to simplify the water engineer's problems, and it may be useful to outline the problem from this point of view. Any deep body of water consists of two depth zones, an illuminated zone producing algæ and organic matter and well aerated as a result of photosynthesis, and a deep zone in which organic matter is broken down and oxygen is consumed. The rate of the latter processes is normally highest at the surface of the bottom mud, and consequently, as the temperature rises, the mud and the water above it may become devoid of oxygen or *anaerobic* whenever there is a large supply of organic matter. Under anaerobic conditions, nutrient salts rapidly diffuse from the mud to the water, ultimately to become available once more for plant growth in the surface layers of the water. If, however, conditions remain such as to maintain a higher oxygen supply at the mud surface, little or no diffusion of nutrient salts to the supernatant water is possible. The development of anaerobic conditions at the mud surface thus greatly increases the rate of circulation of plant nutrients, and especially the size of the vernal algal phase. The matter has a considerable bearing both on reservoir design and filtration difficulties.

It seems clear that the reservoir form ought to be one of low surface volume ratio designed to avoid oxygen deficiency in the lower layers, with an oxygen reserve sufficiently large to give a margin over the summer oxygen consumption, while the small surface should allow comparatively little production in the surface layers. Pertinent data here would presumably be obtained from estimates of the 'biological oxygen demand' and the potential algal or zooplankton production.

The development of oxygen deficiency in the deeper waters of a reservoir has direct effects on the water quality, as well as the indirect ones which result finally in greater algal production. One of these is that ferrous iron compounds appear in solution. These are at some later stage oxidized and redeposited in the ferric state, often in the pipes of the supply system. The processes involved are catalysed by certain iron bacteria, and they not only lead to the blocking of supply pipes but also to the unsightly staining of bathroom furniture.

Equally common under these conditions of oxygen deficiency is the presence of hydrogen sulphides or of other metallic sulphides, with particularly unpleasant smells. These cause great trouble in some calcareous waters containing much organic matter, and they have been a particular source of trouble in the filter beds of tropical and sub-tropical regions.

It is evident, from whatever angle it is approached, an important biological problem in water-works is that of reducing production. In southern and eastern England, where the drainage water is mainly from fertile land, the water works engineer must, if surface water is to be used, resign himself to the need for filtering off large quantities of algal and other organic material. In this case, topography and the need for bacteriological and chemical control of the product usually prevents even an approach to the ideal in reservoir form, while the use of the drainage area for agriculture prevents any attempt to sterilize it or reduce the productivity of the inflowing waters. It can be asked of the freshwater biologist that he forecasts the probable periods of greatest load in the filtering plant, a possibility dependent upon the recognition and maintenance of a seasonal rhythm in algal growth as well as an increased knowledge of the physiology of the organism concerned.

It is, however, also reasonable to inquire whether these steps wholly exhaust the possibilities. A profitable line of inquiry would be to consider whether the intensity of production at peak periods could be reduced and spread out over a longer period or diverted into other channels.

A reduction in algal growths has usually been brought about by the use of algicides, of which copper sulphate is most popular. There is some justification for employing such methods to retard algal growth, but little or none, other than dire necessity, for using them to destroy heavy growths, for the result is almost certainly to result in overtaxing the oxidizing agencies in the reservoir or filtration system, leading to the establishment of anaerobic conditions. In practice, moreover, copper sulphate is known to have other disadvantages; one of them is that more resistant algæ replace the earlier growths, and in some cases these are small enough to pass through filters. A second disadvantage is that there is an increase in the sulphur content of the bottom mud, and when oxygen deficiency develops, the bottom water acquires a high concentration of sulphides. To this agency, also, has been ascribed the later appearance, in some quantity, of sulphur bacteria.

Particularly striking effects are due to these organisms when they are pigmented forms such as *Rhodococcus*, which at times may colour water pink.

From the point of view of water supply, north-western Britain has the great advantage of being an area of high rainfall, of mountain and moorland, and of soils and water of low fertility. The control of reservoirs in such an area presents quite a different series of problems. The first of these is that though the initial fertility of a water is almost always low, yet it is already known that after 30–50 years reservoirs have developed algal production to a high degree. This falls in line with the discovery that certain of the English lakes are accumulating nutrients (nitrogenous materials, for example). In summer more nitrogen enters the lake by the inflows than goes out down the outflow, and it seems that this state of affairs must be not infrequent. Moreover, in winter, the amount of available nitrogen (for example, nitrates) in a natural water is generally at a maximum. If we store this water instead of allowing it to escape to the sea we are, in effect, putting a trap for plant nutrients into the system, so that the annual production is in any case likely to rise.

It seems clear, therefore, that any measure which will tend to reduce fertility in these waters will be valuable. Even if it were only possible to remove a small percentage of the circulating nitrogen and phosphorus, for example, it might suffice to remove the annual accumulations in the lake system.

The question of how to remove part of the annual crops of organic matter becomes a very important one in this particular instance. The obvious way of cropping a reservoir and of obtaining some financial return for the labour involved is to take a crop of fish or of some other cash product from it. The annual crop should equal the annual gains of nitrogen, for example, or else should help dissipate it. From the point of view of the economy of the country as a whole, indeed, the whole of the valuable nitrogenous compounds could profitably be removed from the water. What are the conditions and limitations of this ideal? In effect, the production of organic matter in water passes along a series of food chains—starting generally from algæ, passing by various stages, such as plankton, molluscs and insect larvæ, for example, into fish. Now in each of these steps there is a considerable loss of production. To take a more familiar example, a mature sheep has eaten about ten times its own weight during its growth and development. Thus if this sort of difference is usual, a food chain, containing four steps: *a* (algæ), *b* (insects), *c* (small fish), *d* (larger fish), would give relative productions as percentages of the initial production mechanism of:

(*a*) 100, (*b*) 10, (*c*) 1, and (*d*) 0·1.

(It is, however, perhaps likely that the ratio of weight of food to weight produced is less than that used; about 5 to 1 has been suggested for freshwater creatures.) Generally speaking, water-works practice does not favour fish production in their impounding reservoirs, and to this extent it limits the possible food chains. Clearly, also, the method of operation collects the primary producers (algæ), and so has to deal with the largest weights, though at the same time it probably removes the largest amounts of carbon and nitrogen. However, the algal maxima are short-lived, and it would be advantageous to be able to crop at any time. This means using long-lived creatures for crop-taking.

In contrast, those interested in fish production may obtain higher yields by the shortening of the food chains. It would, for example, greatly increase the yield if, say, the fish (*c*) could be taken rather than another piscivorous fish (*d*); and better still, herbivorous species of fish should give higher production than any carnivorous species.

The piscicultural and the water-works problems are thus both different aspects of one which has equally important bearings on our natural economy to-day—for in these lean times, we are deeply concerned with obtaining the maximum yield from our diminishing acres. It may, therefore, be interesting to collect data comparing the productivity of water and of land in comparable terms.

Yields in lb. per acre

Land: Meat only, 190.
Wheat, 1,800–2,000*.
Beet (as sugar), 3,000*.

* Approximately equivalent to *dry* weight.

Water: Thames water—*c.* 1,400–2,000* maximum algal.
Lake Mendota—Total plankton, *c.* 10,000*.
Algæ in water, say, 6,000*.
Submerged shore-weeds, 1,500–1,800*.

* Dry weight.

Fish: 6–10, Alpine lakes.
170–180, Illinois river.
180–200, carp ponds (manured).

The estimates for Lake Mendota plankton assume that it is renewed weekly. I think this may be two or three times too often. The data for average dry weight of green plants on the shores of this lake suggest that algal production in the plankton might be 2–3,000 lb. per acre as dry weight, a somewhat similar figure to the estimate for vernal production in Thames water.

It will be seen that the productivity of fertile waters approaches that of the fertile lands from which they drain and the richness of which they contain. From the point of view of conserving natural resources there is much to be said for exploiting the reserves of nitrogen and phosphorus which are otherwise being washed away to the sea. It may be that when we use fertile surface waters for water supply purposes, some system of preliminary crop-taking might be introduced—shallow reservoirs the bottom mud of which could be often removed, or used for a system of water-meadows or for fish-cropping. At any rate, it seems that the desirable biological control of water resources involves consideration of these matters.