ENGINEERING ASPECTS OF PROBLEMS IN THE AQUATIC ENVIRONMENT RELATED TO EXCESSIVE NUTRIENTS

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(Presented at a meeting of the Sanitary Section, B.S.C.E., October 6, 1965.)

Introduction

Water pollution control is entering a new phase. For these many years, the major concern has been with limiting the amounts of organic matter discharged to receiving waters so as to maintain reasonable dissolved oxygen levels for the support of fish or, at least, for the avoidance of the production of obnoxious odors.

Over the course of the years many observers have noted that treatment of waste waters for the removal of organic matter to satisfactory levels did not always insure that the quality of the receiving waters was not impaired. A major complaint has been related to the development of excessive plant growths, algae and rooted aquatics, which have given rise to offensive conditions or otherwise impaired the use of the waters. Gradually, it has been established that the magnitude and extent of these plant growths is related to the degree of fertilization of the aquatic area involved. In other words, aquatic plants respond to the same stimuli as do land plants.

Studies have shown that waste water treatment plants designed to remove and destroy organic matter do little to remove the fertilizing matters, nitrogen and phosphorus, so essential to plant growth. This is particularly true of treatment plants employing anaerobic digestion as a means of sludge disposal.

The literature is replete with articles which describe the degradation of lakes and reservoirs because of excessive fertilization due to domestic and industrial waste water discharges. These problems were first recognized in Europe and a summary describing some of the cases was published by Hasler (1). The situation which existed in the lakes at Madison, Wisconsin, is quite notorious and was studied extensively by Sawyer (2). Lake Washington at Seattle has received

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considerable attention because of its gradual degradation due to waste water discharges as the city and its suburbs grew in size (3). Other areas with problems which have received some publicity or study are: Lake Zoar in Connecticut (4), Detroit Lakes in Minnesota (5), Lake Winnisquam in New Hampshire (6), Spring Creek in Pennsylvania (7), and Boston Harbor (8).

In the light of our present state of knowledge, it is quite generally conceded that the biological productivity of any body of water is directly related to the degree of fertilization by plant nutrients. For this reason the term—"nutrient problem"—has come into use and those concerned with water resources of the future are giving more and more attention to it. It is this concept, plus a growing realization that serious deterioration of lakes and reservoirs occurs rapidly once the process starts, that has led to the inauguration of preventive programs in some areas. A notable example is at Lake Tahoe (9) where domestic waste waters are to be given extensive tertiary treatment to remove prime nutrients in order to avoid unnecessary fertilization of the lake. Increasing attention is being given to the Great Lakes presumably for the purpose of preventing eutrophication and degradation of those great bodies of water (10).

At this stage in our discussion, it would be easy but erroneous to conclude that the removal of fertilizing elements from all domestic and industrial waste waters would solve all our problems due to algae and rooted aquatic plants in our lakes, reservoirs, and streams. Reference to the literature will show that there are some instances where waters with little or no waste waters of human or industrial origin are highly productive of nuisance algal growths. One such lake is Klamath Lake in Oregon (11), another is Lake Okoboji in Iowa. Undoubtedly, there are many others not known to this writer.

It becomes mandatory, therefore, from the engineering viewpoint, to study each situation so as to establish the nutrient budget for each body of water and ascertain the amounts contributed from natural land drainage in opposition to that from unnatural sources such as waste waters, which might be brought under control. Once the amount of nutrients originating from the various sources is known, it becomes possible to make an appraisal of corrective measures. Any sound assessment of a given situation involves employment of engineering and analytical chemical skills of a high order.

Flow Measurements

Gaging and Sampling.—The base for the quantitative evaluation of the nutrient budget of any body of water depends upon measurement of the inflowing waters. This is by all means the most difficult aspect of any survey and taxes the ingenuity of the engineer to the utmost.

The discharges of waste waters are in most instances metered, or flow through conduits which are readily adaptable to the installation of gaging devices, so constitute no great problem. The gaging of storm sewer and sewer overflow discharges poses an almost insurmountable problem. Rivers and streams can be gaged in a variety of ways. In any event, gaging of tributary rivers and streams seldom measures the total flow, because gaging stations with any degree of reliability require reasonable approach, discharge and cross-sectional characteristics, plus accessibility. Even under the best of conditions it becomes necessary to measure flow from a part of the drainage area and extrapolate the data to obtain the flow from the total drainage area in any watershed.

Although the use of continuous water level recorders is highly desirable, there are two situations which interfere with their reliability. One is related to varying downstream water levels which may result from weed growths clogging the channel or back waters from varying water elevations in the receiving body of water. The other is related to wind effects which can actually retard or enhance the flow depending upon wind conditions. Reversal of flow can actually occur at times in rivers with a very slight gradient.

Experience will often show that the measurement of flows in relatively small streams is not necessary. This is particularly true if the waters are relatively free of nutrients. Where other streams in the vicinity are under measurement, the flow in the small streams can usually be estimated with a reasonable degree of accuracy, if the drainage area is known.

The reliability of any water level recorder or of a simple staff gage from which periodic readings are made depends upon the development of rating curves derived from actual stream flow measurements with current meters for the reasons expressed above. A continual program of stream gaging must be maintained to check the validity of the rating curves and develop the necessary correction factors.

Indirect Methods of Flow Measurements.—Under some conditions, especially where backwater effects are serious, it may be possible to use the concentration of some chemical component in the water as a means of estimating flows. The writer in his surveys of the Madison, Wisconsin lakes found a relationship between alkalinity and flow on some small streams with relatively small drainage areas (12). It is likely that other criteria might be used, such as chlorides, hardness, etc., but it is unlikely that the method would apply to streams with large drainage areas, except in unusual cases.

Sampling.—Ideally, sampling should be done by automatic samplers with portions taken at frequent intervals in proportion to the flow. This is impractical for several reasons: First, such equipment would in most cases have to be battery powered. Second, the equipment would be inoperable under freezing conditions. Third, the equipment and installation would be difficult to protect from acts of vandalism. Fortunately, stream flows do not vary so radically or the chemical content fluctuate so much that samples need be taken more than once per day, or twice per day at the most. Under low flow conditions weekly sampling may be adequate.

The cost of sampling streams at frequent intervals can often be kept to reasonable levels by hiring some local person to collect samples at the desired intervals. Where staff gages require reading, the sampler can fulfill this need also. If the samples are properly preserved, they need be collected only once per week for analysis.

The sampling of storm sewers constitutes a real problem, particularly because the first flush of water usually carries the greatest concentration of nutrient materials, mainly due to bird and animal droppings. If this first flush is not sampled, the results are not representative. Furthermore, seasonal variations are quite significant and year round surveys are required. For example, some cities allow the burning of leaves in the street. The ashes are rich in phosphorus and do a great deal to enrich storm waters during the autumn months. Others allow the dumping of leaves along the edge of the street to facilitate mechanical collection. The materials leached from them during storms can add materially to the nutrient content of storm waters.

Where multiple storm sewer discharges occur, which is usually the case, it is impossible to sample all without an army of personnel. It is far better to concentrate on sampling a few representative ones thoroughly and apply the data to the others on a basis of judgment.

Chemical Analyses.—All of the great effort expended on flow measurements and sampling will be wasted if the samples are not carefully analyzed for those materials of importance to algal growths, i.e., the nutrient elements. Chemical analyses of various forms of algae have shown them to consist mainly of carbon, hydrogen, oxygen, nitrogen, and phosphorus. Certain forms, such as the diatoms, contain appreciable amounts of silica. Minor elements are sulfur, potassium, calcium, magnesium, and iron. Of these elements, most natural waters contain adequate amounts to support intense algal growths, except for nitrogen and phosphorus. Many studies have shown these elements to be critical in the nutrient problem. One of the more recent is the work of Shapiro and Ribeiro (13). Any analyses of water samples which do not include a complete analysis for all forms of nitrogen and of phosphorus, therefore, will defeat the objectives of a survey.

Nitrogen.—Nitrogen exists in natural waters and waste waters principally in the form of ammonium ion, nitrate ion, and organic forms. In some instances it may occur in significant amounts as nitrite ion. Water samples should be analyzed for all forms. The determination of ammonia, nitrite, and organic nitrogen poses no particular problems. The determination of the nitrogen in the form of nitrates does, however, since chlorides interfere seriously when the popular phenol disulphonic acid method is employed. This is particularly significant in the analysis of both domestic and many industrial waste waters because of their relatively high chloride levels. Many analysts do not correct for chloride interference and low nitrate nitrogen values are obtained. The engineer must insist that nitrates be determined by the most accurate method possible in order to obtain reliable results.

Phosphorus.—This element exists primarily as ortho phosphate and organic phosphorus in most natural waters and there is usually no reason to analyze for other forms. Because of the use of synthetic detergents, domestic and many industrial waste waters contain complex phosphates in addition to ortho phosphates and organic phosphorus. Although the complex phosphates are measured along with the organic phosphorus, they do hydrolyze in water eventually to form ortho phosphate and, therefore, should be measured separately and reported as part of the inorganic phosphorus along with the ortho phosphate. The engineer should insist on having all samples of waste waters analyzed for ortho and complex phosphates as well as organic phosphorus.

Duration of Survey

The time period over which surveys are run are often determined by the funds available to conduct the studies. Ideally, they should continue for a period of at least one year if a good evaluation from natural sources is to be obtained. This is particularly true in areas where drainage from agricultural lands is a significant factor. There are some instances where a period of two years would be desirable in order to evaluate the effect of certain agricultural practices with respect to climatic conditions. One relates to the disposal of animal manures upon frozen versus unfrozen ground.

In the usual case, time limitations or a lack of funds dictates that a relatively short survey of two or three months duration be conducted. If time is not a factor, the engineer must decide whether the greatest return for a given effort will result from a short intensive survey or from a longer term less intensive survey. A good knowledge of the local situation and previous experience aid greatly in making the proper choice.

Evaluation of Data

The day finally arrives when all the flow and chemical data must be translated into terms related to the nutrient problem. At this time the irrelevant data which the engineer may have allowed to be collected at the expense of time and money will be relegated to the waste basket and the focus will be upon the prime nutrients—nitrogen and phosphorus. Because it is known that all inorganic forms of these elements are completely available for the support of phytoplankton and other plant growths and that organic forms are never completely available, even after extensive biological degradation, it is customary to report survey results in terms of amounts of inorganic and organic forms of each of the elements, separately. A highly satisfactory method is by means of bar charts which indicate relative amounts from the various sources. These are readily understood by laymen without technical training, and with whom the engineer must often deal.

Once the data have been resolved into pounds or tons of nutrients originating from the various sources, the engineer has the responsibility of evaluating the data prior to making his recommendations. This may be a very difficult task in some instances and one which will tax the imagination and knowledge of the engineer.

The writer would like to illustrate the evaluation of data by citing two cases from his own experiences, one where the decision was relatively easy and one where the decision was somewhat difficult. These relate to the situation in Lake Waubesa at Madison, Wisconsin, as of 1944, and the other to the situation in Lake Winnisquam at Laconia, New Hampshire, as of 1960. The pertinent data are given in Table 1.

TABLE 1
ALGAL NUTRIENT CONTRIBUTIONS TO LAKES WAUBESA AND WINNISQUAM

	Nitrogen				Phosphorus			
	Inorganic		Organic		Inorganic		Organic	
	Lb/Yr $\times 10^3$	%	Lb/Yr $\times 10^3$	%	Lb/Yr $\times 10^3$	%	Lb/Yr $\times 10^3$	%
Waubesa								
Rivers & Streams	225	25	192	66	16	13	35	70
Waste Waters	688	75	100	34	113	87	15	30
Winnisquam								
Rivers & Streams	121	59	227	80	14	32	40	52
Waste Waters	83	41	57	20	30	68	8	8

A study of the data will show that Lake Waubesa received 75 per cent of its inorganic nitrogen and 87 per cent of its inorganic phosphorus from waste waters, which, in this case, was the biologically treated effluent from the Madison Metropolitan Sewerage District treatment plant. In addition, the treated waste waters contributed 34 and 30 per cent, respectively, of the organic nitrogen and phosphorus. This information alone was sufficient evidence to indict the waste waters as the major source of the nutrient problem in Lake Waubesa. Another supporting factor was that the main tributary river, the Yahara, was expected to carry less and less nutrients into Lake Waubesa as waste water discharges were eliminated upstream in Lake Monona.

The study of Lake Winnisquam showed that 41 per cent of the inorganic nitrogen and 68 per cent of the inorganic phosphorus were contributed by the settled waste waters of the Laconia State School and City of Laconia primary treatment plants. They contributed only 20 per cent of the organic nitrogen and 8 per cent of the organic phosphorus. In only one instance, the case of inorganic phosphorus, did the contribution from the waste waters exceed that from natural drainage.

From a casual study of the data on Lake Winnisquam, one might be led to the conclusion that the contributions from waste waters are a minor factor in the nutrient problem there. Engineering judgment, however, dictated otherwise. This judgment was based upon two facts which became major considerations in the evaluation. The first is related to the nature of the rivers and streams flowing into Lake Winnisquam. About 94 per cent of the flow into the lake comes from Lake Winnipesaukee and it carries with it in excess of 92 per cent of all the nutrient materials contributed by natural streams. Since Lake Winnipesaukee including Paugus and Opechee Bays through which its waters flow, have always been well behaved in terms of freedom from algal blooms, there is no reason to believe that waters derived therefrom will behave differently when they reach Lake Winnisquam. On this basis alone, one can conclude that the problem in Lake Winnisquam is due to nutrients supplied by waste waters. A second factor which adds to the argument is related to inorganic phosphorus, of which 68 per cent originated in waste waters. Studies by Sawyer and Ferullo (14), Shapiro and Ribeiro (13), and others have shown that phosphorus can support blooms of nitrogen fixing blue-green algae such as those which have caused trouble in Lake Winnisquam.

Recommendations

If the survey results show that the nutrient problem in any given situation is due to sources which can be brought under control by sound engineering practices, the engineer has the responsibility of evaluating them in terms of cost-benefits for the purpose of making recommendations to the client. In general, this would involve methods of waste water treatment and disposal but would not preclude sanitary waste water overflows, storm water, agricultural drainage, and even farming practices. Most, or possibly all, enter into every problem.

With respect to the treatment or disposal of waste waters, the engineer will often be faced with two alternatives: whether to divert them to some other location or whether to provide tertiary treatment for the sole purpose of removing the offending nutrients. The former may be the more economical solution in many cases but is fraught with legal and political implications of a wide variety. The latter can be expensive from the standpoint of both capital and annual operating costs and its effectiveness is largely unproven. The engineer is often in a dilemma when the matter of recommendations confronts him. Political and legal knowledge must supplement engineering and scientific knowledge at this point.

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