Engineering and Industrial Experiment Station

Advances in Water and Wastewater Treatment
BIOLOGICAL NUTRIENT REMOVAL

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PREFACE

Biological nutrient removal systems are relatively new technologies with the potential production of high quality effluents. In some areas, high quality effluents are required before discharge to receiving waters or before land application. Social and health problems associated with eutropic conditions in our nation's waters require greater removals of nutrients. These eutropic conditions have precipitated increased water pollution control requirements from point and nonpoint sources. At this time, in most cases, biological nutrient removal provides a means that can be most cost-effective. This reference volume has been planned to present state-of-the-art biological nutrient removal alternatives. This is done by incorporating results of recent research with design and operational details.

Eight of the chapters in this text were adopted from presentations at a conference on Biological Nutrient Removal Alternatives held at Florida Technological University in March 1978. Two papers are essentially the same as the presentations. Three chapters were added after the completion of the conference. The editors and authors express their gratitude for the support work received from their associates in the final compilation of the papers. The resources and services of the Florida Technological University are appreciated. In addition, the organizational help of the Florida Engineering Society and the Florida Section of the American Society of Civil Engineers was valuable in the conduct of the conference and the encouragement to publish this volume.

M.P.W. & W.W.E.

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1. PROCESS SELECTION FUNDAMENTALS

W. M. McLellon, Civil Engineering and Environmental Sciences Department, Florida Technological University, Orlando, Florida

ABSTRACT

Selection of a process for wastewater treatment requires detailed evaluation of quality parameters of influent and effluent. The objective is to select a process train which will produce quality changes necessary, reliably, while under varying conditions of flow, and at minimum cost.

INTRODUCTION

In approaching a topic of this type, it is of interest in the beginning to consider the overall task. The purpose is to examine nutrient removal, which was, in the past, generally an ignored segment of the wastewater treatment problem. Concern with nutrient removal goes back within the last two decades to the realization by many, that fertilization of receiving waters by effluents, whether point source or nonpoint source, creates severe down stream problems, upsets the ecological balance, and can lead to detrimental impact on man's activities, but more importantly, his water resources. Thus the rising tide of action on effluent quality control, extending beyond removal of oxygen demanding organics. What this effort has represented is a recognition, however belatedly, that a cyclic system is involved, and that all segments of the system are of importance. This facet is critical to solution of water quality problems inherent in man's interaction with the environment.

It is noted that legal recognition of the importance of wastewater in the systems concept certainly occurred in the development of PL92-500[1], Federal Water Pollution Control Act Amendments, passed in 1972. The law's provisions set out not only the reason why topics such as nutrient removal must be considered, but also the required goals in attainment. For example, it is stated that there shall be achieved,

1. "....not later than July 1, 1977, effluent limitations for point sources....which shall require application of the best practicable control technology currently available...."
2. and, "....not later than July 1, 1983, effluent limitations for point sources,....which shall require application of the best available technology economically achievable...."
3. and, also, "....the national goal that discharge of pollutants into the navigable waters be eliminated by 1985."
4. continuing, "....the objective of the Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters,...."
5. further, "....water management methods applicable to point and nonpoint sources of pollutants to eliminate discharge...."
6. and, "....develop, refine, and achieve practical application of....advanced water treatment methods applicable to point and nonpoint sources...."
7. lastly, "To the extent practicable, waste treatment management shall be on an area wide basis and provide control or treatment of all point and nonpoint sources of pollution...."

As is evidenced by the foregoing, the system requirements are extensive, including both point and nonpoint sources, escalating process performance with time, culminating with elimination of pollutant discharges by 1985, consideration of chemical, physical, and biological parameters, advanced waste treatment, and lastly, consideration of best available technology economically achievable. All of these things compound into a stiff task for the design engineer. And this task is constrained by and dependent on the effluent limitations set by regulatory authority under the law.

Note that under the Clean Water Act of 1977 the actions of PL92-500 have received some fine tuning corrections, for example, redefinition of time schedules, but the basic tasks remain.

It is instructive now to examine the system fraction associated with point sources.

WATER RESOURCE SYSTEM

For many years, because of plentiful water, smaller population, and less technological impact, water supplies and effluent disposal problems were separately evaluated and were not really considered connected. Information now extant on trace chemicals in water, production of chloroform, and similar, finally have demonstrated that the water resource system must be examined, rather than its isolated parts. This system can be described as shown in Figure 1. Water taken from a source

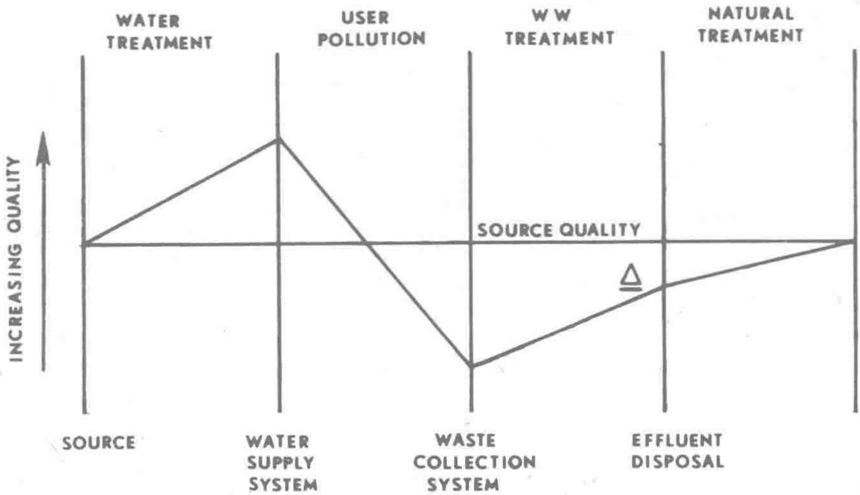

FIGURE 1. WATER RESOURCE SYSTEM
Note: Adapted from McLellon, et al. (7)

is improved in quality, delivered, degraded, collected, improved through wastewater treatment, then polished by the natural environment. A delta function exists, which in the past has been extensive. This delta function gradually is being reduced with the improvement of old wastewater treatment plants and construction of new ones. Basically, within the 1977 goal of PL92-500, the delta function amounted to the residuals from secondary treatment, with 90% BOD reduction, leaving residual nutrients of nitrogen and phosphorus, along with the enrichment resulting from the processing of remaining BOD by the natural environment.

The design engineer in this less complex case had available to him several process selections, such as the activated sludge variants or trickling filters, along with solids separation techniques, to adequately handle most problems. Process selection in many cases was routine. Later developments have included the biodisk surface contactor technique, aerated lagoon variants, and similar applications of biological and physical treatments.

This system interrelation has become more stringent as the complexities of modern chemical technology have impacted. Thus the objective of reducing the undesirable parts of the delta function, i.e., pollutants, to zero discharge by 1985. Realistically this cannot include similar reduction of the mineralization by soluble items such as sodium or chlorine but must be restricted to such things as the nitrogen, phosphorus, and BOD, which have immediate serious impact. It could be extended to treatment produced pollutants, such as the chlorinated compounds, which again impact on the process design. The task of the design engineer simply becomes harder and he must have greater knowledge and understanding of the biology and chemistry of design, and their process interactions. Increasingly also, more careful attention will need to be paid to the detailed measurable quality parameters both before and after treatment. It is useful here to consider the general design problem.

GENERAL DESIGN PROBLEM

The design engineer is faced with a quality conversion necessity in treatment, usually operating at a high hydraulic rate. The problem might be reduced to the simple diagram of Figure 2. In the past much standardized design for municipal

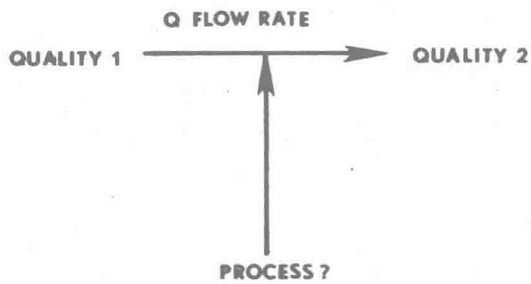

FIGURE 2. GENERAL DESIGN PROBLEM

waste treatment was done to a large extent on the basis of hydraulics, witness the design either of trickling filters or activated sludge processes for general reduction of BOD. BOD was recognized as a gross biological loading in design calculations. Over the past decade or so however, considerably more attention has been focused on the process details and the reasons for, or methods of, making quality changes. This has been spurred by recognition of downstream effects, hence studies of fate of pollutants have been emphasized, along with increasing application of improved instrumentation to determine parameter levels at critical points in the treatment and disposal process.

Note that in the general design problem, the engineer must consider the following:

<u>Quality 1</u> - Unless some type of regulatory control exists upstream, the treatment plant to be designed must accept all quality variants recognized in an annual flow. But beyond this the plant must be prepared to treat, with some possible process

improvements, of course, over its life span of possibly 20 to 30 years. Thus the design engineer doing the process design should, of necessity, have detailed quality information of high reliability, with projections if practicable.

Quality 2 - Acceptable levels of quality for critical parameters are those set by regulatory authority based on the best available scientific and engineering advice. Note that the advanced waste treatment standards published in Florida are 5-mg/l BOD, 5-mg/l SS, 3-mg/l N, and 1-mg/l P at present. These published levels provide guidance, but one should recall the national goal in PL92-500. It gives as a goal zero discharge of pollutants by 1985. For the design engineer there is a world of difference in the two, i.e., the difference between zero and one, for example. Hence, the Quality 2 parameters for design can be only those that are stipulated by some regulatory function, based on future expectations, where critical items such as nitrogen are involved. It is not possible technically or economically to say zero; instead, some value different from zero must be used that is reasonably attainable. As indicated by Barth,[2]

> "....no matter what process or sequence of treatment processes is applied to municipal wastewater there remains a residual of 1- to 2-mg/l of soluble organic nitrogen in these effluents."

Barth also notes this residual is not removed well by activated carbon and it is resistant both to chemical and biological oxidation. This particular nutrient also is received naturally in rainwater; thus, a low, realistic level is indicated, not zero.

Process - What is wanted is a process train that will solve the known problem, i.e., conversion from quality one to quality two for each parameter at risk. But beyond this the process should be adaptable and flexible, in view of the fact that it will receive currently unknown but estimated insults and, additionally, must handle the quality challenges of many years hence. This process train will be a combination of physical, chemical, and biological operations and processes in most cases. Note that it can be extremely varied, extending as it does from closely controlled processes such as those of a restricted treatment plant site to natural environmental segments included in a process train. An example of the latter could be a series of land disposal steps.

Now this general design process can be applied to the case at hand, i.e., the Biological Nutrient Removal Alternatives. It is of interest to consider first the types of cases.

NUTRIENT REMOVAL CASES

Since large investments currently exist in operating wastewater treatment plants, it is apparent that several different conditions occur in the nutrient removal field. The first is an existing, modern secondary plant requiring upgrading to tertiary treatment standards. A second is the new plant design replacing several currently inadequate plants, perhaps on a regional basis. Cases also exist of incorporation of these plants into an upgraded plant scheme, as differentiated from simply tacking on an application of tertiary treatment to accomplish nutrient removal. These cases apply primarily to point sources of pollutants. Lastly is the application of treatment techniques to nonpoint sources. The latter sources are identified in discharge location in many cases but are disperse and of large number, hence their collection into large process streams is difficult and expensive.

Now in the new plant, point source case, the process design naturally can be wide ranging, commencing with the Quality One input from the delivery sewer. Note at this point, some substantial fraction of the nitrogen and phosphorus would be present in the suspended solids and the remainder generally as ammonia in solution. As an example, for medium strength domestic sewage, Metcalf and Eddy[3] list 15-mg/1 organic nitrogen and 25-mg/1 ammonia, with nitrite and nitrate, the oxidized forms, absent. Organic phosphorus is listed as 3-mg/1 and inorganic as 7-mg/1. Nutrient removal commencing at this point extends to the designer's options in suspended solids removal as well as conversion in chemical form as an intermediate step. Thus a complete chemical-physical system could be devised, considering the parameters existing. The designer would have the widest latitude of choice with the constraint of reduction of BOD/COD and similar. With a selection of initial biological conversion instead, unless complete nitrification occurs, the tertiary treatment problem shifts somewhat because of the reduced carbon source present after the biological treatment step. The BOD has been removed. In either case, the process selection must proceed in the same fashion as the general design case, i.e., consideration of

- Quality 1 - In detail, with the forms and levels of pollutants present, particularly BOD, N, P, SS, etc.
- Quality 2 - The objective, in detail, which depends on the use of the effluent and the regulatory climate, currently tertiary treatment standards for BOD, SS, N, P.
- Process - Alternative process trains for accomplishing the result are developed.
- Economics - The feasibility of accomplishment of each alternative is investigated.

Beyond these I believe there are two points affecting the design which need further consideration and often are not mentioned. They are

Instrumentation and Control - Whether sophisticated, automated, etc.

Operating Capability of Client - What reasonably can be accomplished in operation by the client agency and how does this impact the design?

The latter two items are important, in my opinion, from observation of plants and trends. Our technology is advancing rapidly. It is not apparent to me that our operating capability is advancing in like fashion, so this certainly affects the process design.

The other alternative cases would be approached in the same way as the preceding, commencing with detailed analysis of the end points and identification of process selection alternatives. It is noted though, that some additional complications have developed over recent years. That is, in addition to protecting the environment through effluent quality control, increasing emphasis is being placed on use of the environment as the whole or as a part of a treatment plant. Mr. Costle, EPA Administrator, recently reemphasized the EPA desire for land disposal to be a major alternative considered. What this amounts to is the designer applying agricultural (farm) and chemical process techniques to the treatment problem. It also adds to the need for knowledge, aimed at providing design guidelines, criteria, and standards, of the pathways and fate of pollutants in natural systems of various types. In Florida this could include intense agriculture, citrus, pasture, swamps, and other land variants. Data on pathways, fate of pollutants, and derived design criteria currently exist only in part for the U. S. Much work remains to be done because of large variation in physical, chemical, and biological features of topography, and the fact that releases to environments become uncontrolled in such cases, compared to a treatment plant flow. Thus, another requirement is placed on the designer because of this. In as complete a set as possible, data are needed on the site conditions - geology, hydrography, soils, etc., projected cover crop - trees, grains, grasses, etc., and lastly the operating capability. In this case an organized farm may exist where the operation cannot be neglected, just as with a treatment plant. As one other point, surveillance techniques, part of the design, must be developed. Reiterating, also, for any release, such as to a cypress bayhead, where final disposal is uncontrolled, good information is needed on the pathways and fate of pollutants, otherwise it is no different than a lake or river discharge with unknown results. Design implies producing a known end instead, with consideration of the overall system.

In all of these cases, it is obvious that the quality change by a selected process train is the important facet. The quantity of flow is secondary, though the quality conversion process must function properly at all ranges of flow. The process must be reliable and flexible throughout its life, which places stringent demands on all segments handling the flow and producing the quality changes.

GUIDANCE

It is refreshing to note the large volume of information which is developing on treatment processes, particularly those for nutrient removal. The literature is replete with examples such as the "Process Design Manual for Phosphorus Removal", EPA 625/1-76-001a, April, 1976 and similar, under the Technology Transfer Program. The literature is being extended into areas of uncertainty. A critical example of the latter is the use of natural topography such as a cypress swamp or other natural environment for physical, chemical, and biological treatment, with uncontrolled end point. Recent proposals in the Kissimmee River basin, leading to restoration, and prevention of nutrient loading of Lake Okeechobee, provide other examples. Investigative efforts are planned in that basin to examine effects of such things as shallow ponding of nonpoint source runoff, plant growths, and delay structures.

NONPOINT SOURCE RUNOFF

Since it is unlikely that most wastewaters of this type will be treated by conventional treatment plants in any reasonable future time, treatment to reduce nutrient impact must rely on minimal structural corrective measures such as percolation or detention basins, then uncontrolled natural treatment and disposal. This amounts to land disposal of effluents from diverse locations using delay, plant growth, soil filtration, adsorption, and similar, to reduce nutrient impact. This work is in its infancy but is related to the land disposal of treatment plant effluents. Again, the unknown for the designer is the fate of pollutants in such things as swales and other commonly used structures, along with end points. The design problem is more uncertain than that of a point source, pending accumulation of additional information on the performance of corrective measures. Thus it is not possible to design to a Quality Two end result with certainty, but only at this time to employ land disposal measures which will improve effluents. As time passes experience should add to specific knowledge and allow a better predictive design. The requirements of PL92-500 for application of management techniques to nonpoint sources can be effected without stipulation of a fixed end result.

OPERATING CAPABILITY

Advanced wastewater treatment and nutrient removal in a point source plant add to the complexity of the treatment process. Since reliability and flexibility are needed to insure production of a fixed minimum quality result in the effluent, in the face of varying input, a requirement for stringent process control is placed on the plant. This has a concomitant requirement of adequate instrumentation, with timely, accurate, intelligible, and interpretable results, packaged into an analyzable form. Thus the instrumentation requirements may be formidable. But these requirements cannot be considered independently of the operating capability, i.e., of the client management and personnel of the plant, however much the design engineer would like to do so. The process design, physical facilities, instrumentation, operating personnel, and operating manual are intimately connected and this fact cannot be ignored. As just one example, consider the startup of a new plant, which is a complex chemical process industry equivalent. It has been estimated[4] that a sum equal to 5 to 15% of capital investment may be needed for startup. What is involved? A host of things are needed such as instrumentation checks and calibrations, equipment operating tests, pressure tests, and unit checks, extending into unit operation and process startup, then extending segment operation into plant operation and shakedown as a whole. Presumably the client agency provides the operating crew for startup and continuing operation. But note that while startup involves a mix of design personnel, manufacturer/supplier/contractor personnel, and client operations staff, the final continuing result depends on the client staff. In addition, an operating manual and conversion training are necessary to insure competent operation of the plant. The latter operating and training need must be extended into consideration of the number, types, and quality of operating staff and their continuing training program. Lastly is a check by design personnel at periodic intervals after startup to insure proper process operation.

It is unreasonable, in my opinion, to establish a process design, complex and sophisticated instrumentation level, and severe operational need, without very close cooperation with the client operating staff. A wastewater treatment facility which is publicly owned has a different operating capability from a plant of the chemical process industries. It is not intended to imply here that competent staffs cannot be attained. However, it is noted that the problem is more difficult and if it can be alleviated by alternatives in the design process well and good. Close contact is indicated between designer and operating personnel through the design process to insure a design that can be started up with minimum trauma, then can be operated reliably by the client operating staff to a successful end result. The designer has a stake in the latter to a greater extent than in the process design itself, which is worthless unless operated properly. Thus the designer, in establishing the design alternative to be used, must keep this operating need paramount.

COSTS

Nutrient removal is expensive, which means that the process alternatives must be thoroughly investigated. In particular, because of EPA guidance, wastewater treatment by land application will be an alternative which must be considered. It is noted that the EPA has issued guidance on costs in the 1976 report entitled "Costs of Wastewater Treatment by Land Application".[5] In that document, performance of land application is listed as 85 to 99% BOD and SS removal, to 90% nitrogen removal, and to 99% phosphorus removal. Bouwer, et al.,[6] in a recent 1978 paper, cite removal by land treatment as a viable alternative to secondary or tertiary plant treatment. Thus, since process performance of alternatives may be equal, cost will be one of the major deciding factors. The trickling filter and activated sludge processes have been main process techniques in earlier wastewater treatment. Now, with the extension into nutrient removal, with many more process variants, more stringent effluent limits, and complex technology, cost comparison of alternatives should become even more important to the designer. In this connection, it is believed that increasing need will exist for applied research and analysis on many problems, thus adding to the cost before process alternatives adequately can be assessed. This is so because of current uncertainties in technical solutions.

CLOSURE

The subject of process selection involves consideration of the influent and effluent quality parameters in detail. The rate of flow is a secondary factor which must be satisfied hydraulically, and where interrelated with the chemical or biological process, such as in recycling streams in a plant to maintain a culture concentration. The objective is to convert the quality at minimal cost, using a process train which is reliable, flexible, and capable of operation by client staff. Inexorably, process trains, instrumentation, and controls are growing more complex. This means that client operating staff must be of sufficient caliber and trained to satisfy these needs. The designer, in approaching the process design, related instrumentation, startup, and operation, must consider the client operation capability as a factor in process design decision. Lastly, with the growth in number of process alternatives, including the land application alternative of EPA interest, and the rising costs of technology, a most critical part of process selection will be preparation and use of valid, detailed cost estimates.

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