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Concepts for Effective Management of Water Quality in Connecticut

Roy Bartlett Anderson

Connecticut Department of Environmental Protection

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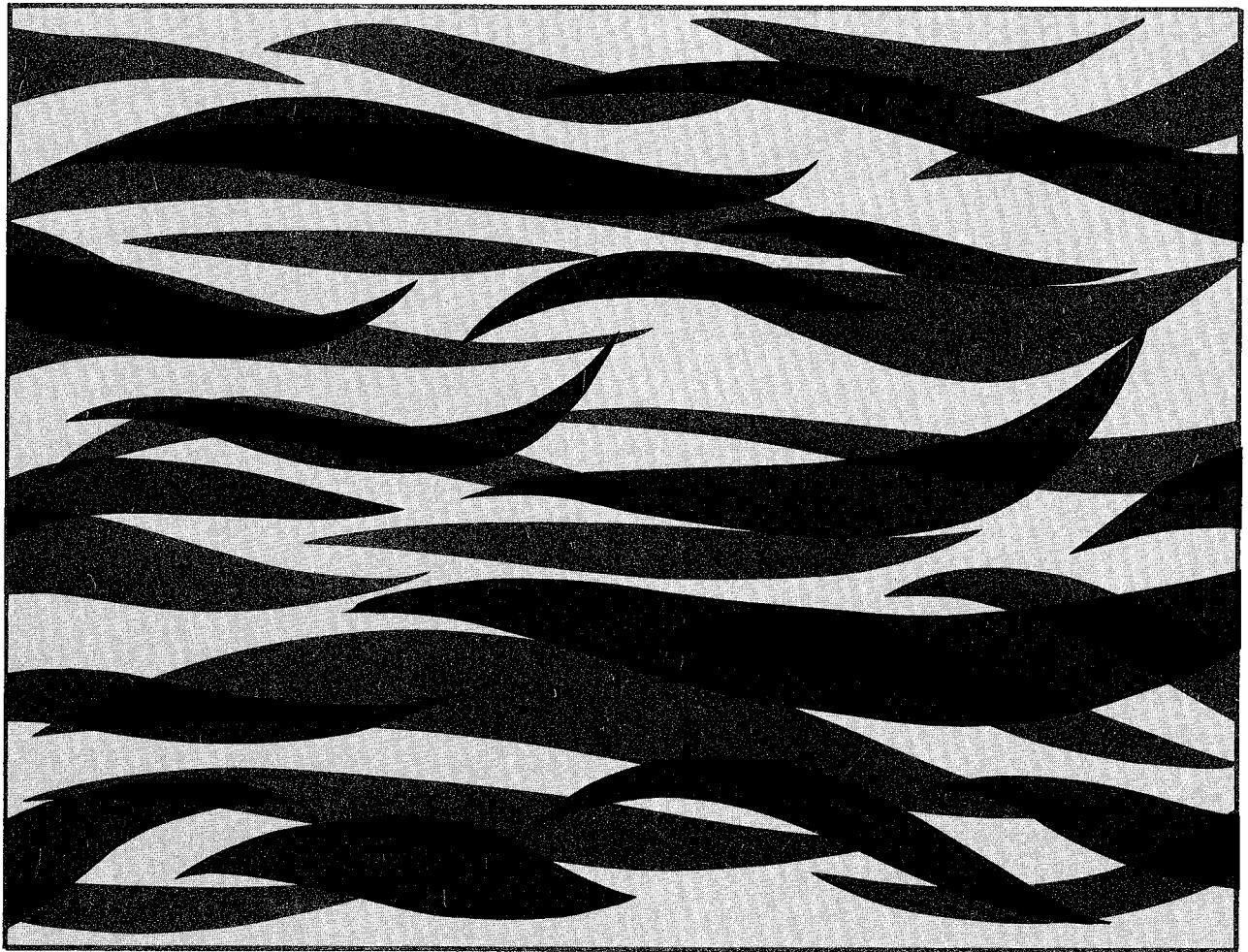
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CONCEPTS FOR EFFECTIVE MANAGEMENT OF WATER QUALITY IN CONNECTICUT

Report No. 18

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INSTITUTE OF WATER RESOURCES
THE UNIVERSITY OF CONNECTICUT

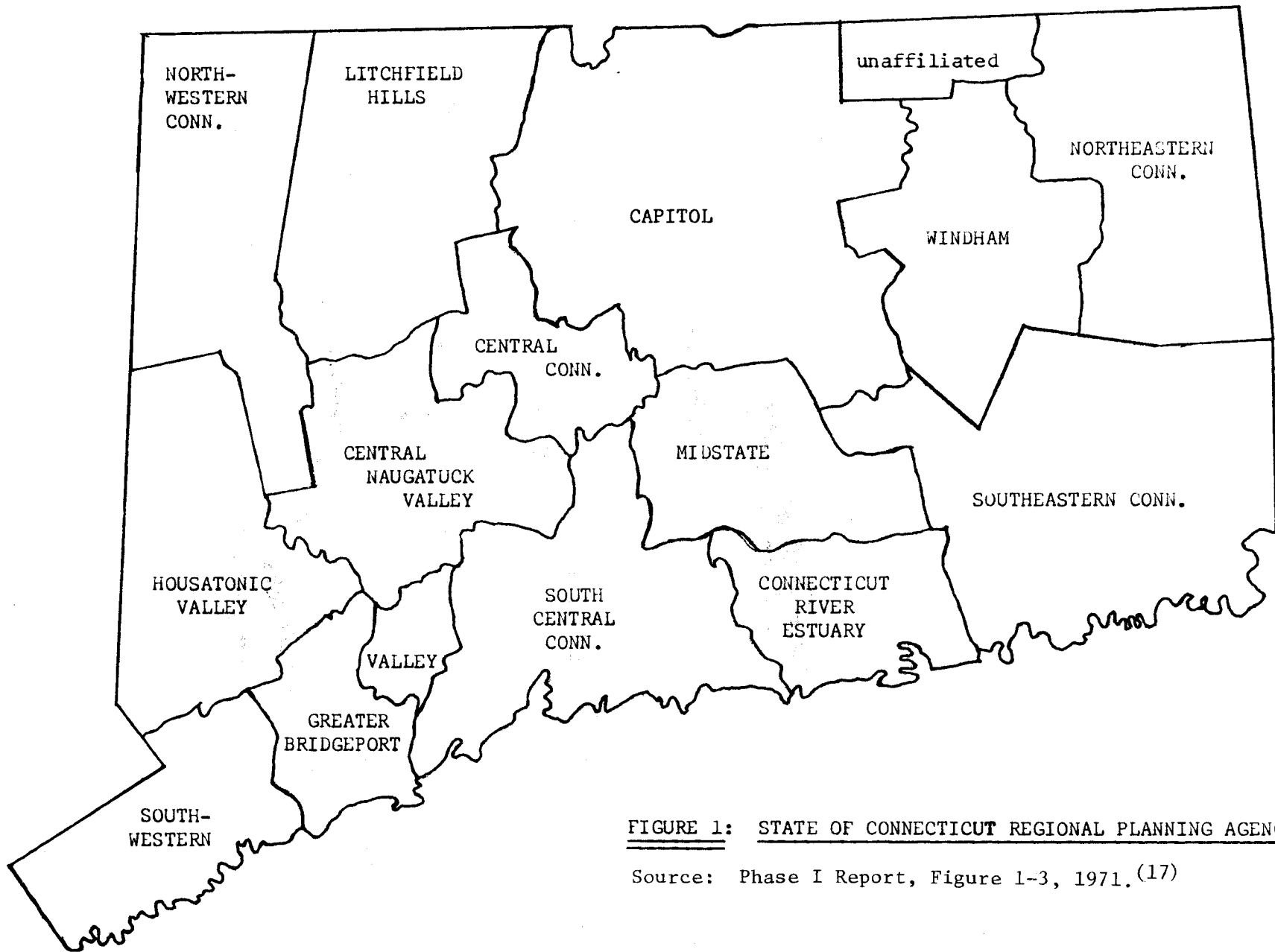


FIGURE 1: STATE OF CONNECTICUT REGIONAL PLANNING AGENCIES

Source: Phase I Report, Figure 1-3, 1971. (17)

CONCEPTS FOR EFFECTIVE
MANAGEMENT OF WATER QUALITY
IN CONNECTICUT

by

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INTRODUCTION

The effective management of future water quality in Connecticut is of major importance. Present water quality control measures taken by Connecticut are fulfilling current objectives; however, there is reason to believe that the continuance of these programs as presently constructed will not provide future water quality efficiently and effectively. Although present water resources are adequate, population and commercial and industrial development are anticipated to continue to expand, thereby imposing impressive demands on Connecticut's water resources. This continuing pressure for expansion, if not limited by other factors, will ultimately result in a progressive depletion of water resources for most uses. Problems may be compounded in that, as the depletion grows more intense, increased costs are required to maintain a given quality of water.

Future water problems can be alleviated only if a planning approach is used. This report will propose the use of the techniques of water quality management, which include both planning and implementation measures. Most of the concepts and practices under water quality management are relatively new and, consequently, are an active research area⁽¹⁾.*

Water quality management is subdivided into two stages for descriptive purposes. In the application of water quality management techniques, however, they are interrelated. The first stage, water quality management planning, uses economic, population, and other projections to determine future needs, identifies resultant deficiencies, identifies alternatives for meeting the deficiencies, and performs the engineering-economic evaluations of

*Footnotes refer to citation under "Literature Cited," p. 51.

these alternatives under some specific constraints. The selected alternative constitutes the plan. The second stage, water quality management practice, is the implementation by government of the plan through structural and non-structural measures, to produce the desired result at the lowest cost⁽²⁾, relative to capital and operating costs.

The intent of a water quality management plan is the achievement of workable measures which will attain the desired water quality for least cost, consistent with specified constraints⁽³⁾. Evaluation techniques are extensively used in a complex situation. Mathematical stream quality models are used to predict the stream's response to various types and concentrations of waste inputs^(4,5,6,7). For more complex physical and loading systems, the prediction is increasingly difficult. Additionally, the least-cost solution is determined by an optimization model. For uncomplicated situations where the choice of alternatives is almost obvious, a simple cost comparison of waste treatment schemes based on capital and operating costs can yield a least-cost solution. Complex economic systems, however, must use optimization models to evaluate the alternatives^(8,9,10). Constraints of stream quality models and optimization models are social well-being, environmental quality, and institutional factors^(3,11).

Institutions, referring to the hierarchy of governmental agencies responsible for planning, implementing, financing, and operating water quality management programs, impose regulations and laws which may interfere with the attainment of technically viable and least-cost solutions. These institutional constraints or regulations, however, may be very desirable in that they represent a wide range of factors outside the consideration of engineering-economic

models. It is important that their costs, in terms of deviation from optimization, be known. Institutional performance itself is amenable to optimization and studies have been made^(12,13). If the costs (economic and non-economic) of some regulations cannot rationally be justified, there is reasonable basis for modification or elimination of such institutional constraints.

Water quality management is an element in the larger context of resource development and use. Water quality management is effective if it encourages the use of the more reclaimable portions of waste while permitting appropriate treatment and introduction of not immediately reclaimable portions of waste into the aquatic environment⁽¹⁾.

The water quality management approach in a general sense may be contrasted with present regulatory functions in Connecticut. These functions may be termed water quality control, not water quality management. The distinction is principally an institutional one: if the management approach is undertaken in an economically and technically sophisticated manner, true water quality management is achieved; if water quality is attained principally through regulations and prohibitions, water quality control or water pollution control results.

Water quality management would not phase out regulations entirely, it would merely widen the scope of options available. It would involve continuing examination of the validity of regulations and policies on the books, and the choice of the least-cost approach to attain water quality under social and environmental constraints. Provided that only those viable constraints are satisfied, optimal allocation of resources also requires the greatest incremental water quality improvement for every incremental expenditure of funds⁽³⁾.

The concept of water quality management in this report involves providing for the sometimes competitive needs of wastewater disposal, water supply, water-based recreation. Water quality management plans provide a significant basis for implementation of pollution abatement programs as all basic decision information is set forth. An intent of this report is to promote the water quality management concepts necessary for the evolution of an effective water quality plan. It will be shown that the result of this approach will be an improved ability of decision-makers in government to cope with future problems.

This report will also attempt to demonstrate that the present water quality control approach administered by the Department of Environmental Protection has been effective in terms of its charge — the accomplishment of treatment — but more importantly, it will be demonstrated that an integrated water quality management approach is needed to assure satisfaction of both the short-range and long-range needs of Connecticut.

PRESENT WATER QUALITY MANAGEMENT IN CONNECTICUT

A. Institutional Aspects

The water quality control program administered by the Department of Environmental Protection, referred to as the Clean Water Program in this report, has four aspects of planning significance. The first is the provision for the establishment of Water Quality Standards which can be used as a planning goal. The second aspect is that stiffer enforcement provisions are stated in terms of the ability of the State to require treatment of wastewater discharges. (It is significant to note that the Water Quality Standards are not keyed to the enforcement provisions; the enforcement would function unchanged without the Water Quality Standards. The Water Quality Standards presently serve as a statement of the anticipated stream quality at the end of the construction program in 1974.) The third major aspect in the Clean Water Program is the provision for State subsidies for municipal sewerage works investments, which in conjunction with federal subsidies, can amount to as much as 85 percent of the total eligible costs when regional considerations are made. The fourth provision of planning significance in Connecticut's law is that towns are required to make provisions in their construction for the acceptance of present or anticipated future waste flows from adjoining municipalities. This provision has effectively established a working relationship between the State government and the Regional Planning Agencies (RPAs) which perform water quality management planning on an intermunicipal level.

Secondary treatment was chosen as an across-the-board minimum for all waste discharges. This has provided for some degree of convenience in enforcement. An industrial treatment facility must produce at least secondary

effluent quality, where the influent is based on an average strength municipal waste. Treatment beyond secondary can be used if, in the opinion of the Water Resources Commission, additional treatment is needed.

Two goals of the Clean Water Program exist: one in the realm of water quality management enforcement, and the other in the area of water quality management planning. The major enforcement goal of the Clean Water Program is achieving waste treatment and not the attainment of the Water Quality Standards. The planning goal of the Clean Water Program, however, is to examine the uses to which the streams may be put after 1975. For planning purposes, waste treatment is viewed as merely the means for attaining a stream quality goal.

Although the Clean Water Act is geared to the correction of existing pollution problems, long-range planning considerations are considered to a limited extent. The fact that treatment facilities and sewers are constructed per se has future implications. Treatment facilities are normally designed for a life of 25 years and sewers for 50 years. Orders issued under the Clean Water Program require correction of not only existing problems but also an allowance for correction of any future problems. An order can not only require immediate regionalization but also require that a municipality provide treatment plant capacity for future sewer service to neighboring towns.

A municipal sewerage plan prepared in response to an order must be reviewed for consistency with regional plans. It is important from a planning viewpoint to communicate with regional planners and concerned State agencies in a very early stage of project development, so that factors outside of engineering consideration are weighed. During the early stages of the Clean Water Program especially, this procedure was infrequently followed.

An engineering report may contain alternatives for correcting a community sewage problem. There may be a description of the various schemes with alternative treatment plant locations involving one or more municipal systems, with corresponding variations in sewer routings, alternative sewer routing to areas which may develop, and potentials of providing regional service effected by either accepting adjoining towns into the system or tying into an adjacent sewerage system. The selection of the final alternative is usually determined by cost comparisons based on capital and operating costs, consensus as to areas having a short-range need, and usually a qualitative examination of water quality based on some familiarity with alternative treatment plant locations. Occasionally the evaluation of alternatives is more detailed but the level of detail is normally determined by the amount of available time and staff. But for effective planning the level of detail should ideally be determined principally by the nature of the problem. RPAs have participated to a limited extent in this process. At present fifteen designated planning regions of the State exist, fourteen are actively organized and twelve have done active water quality management work (See Figure 1, inside Front cover).

The Clean Water Program will probably be complete by 1974, barring any discontinuance of funds or administrative problems. This will include providing new sewer service or extended sewer service to municipalities experiencing problems, the elimination of major combined or raw sewage overflows, and the treatment of private and industrial wastes.

Water Quality Standards⁽²⁰⁾ set up by the former Water Resources Commission take into account the various uses to which the streams may be put. Biological, chemical, and physical criteria define each classification. A summary of the requirements for each use is presented:

T A B L E 1
WATER USES BY CLASSIFICATIONS

Water Type	Water Class	Water Uses (See Appendix A in <u>Source</u> for details)
Inland	A	all water uses including potable supply with appropriate treatment
	B	bathing, other recreation, agriculture, industrial, cooling, fish and wildlife habitat, potable supply with appropriate treatment
	C	recreational boating, selected industrial, cooling, fish and wildlife habitat
	D	navigation, power, selected industrial, cooling, fish migration
	E	waters not suitable for any purpose
Coastal and Marine	SA	water contact sports, shellfish harvesting
	SB	water contact sports, cooling, fish and wildlife habitat
	SC	aquatic wildlife habitat, boating, cooling
	SD	navigation, power, selected cooling, fish migration

Source: Phase I Report, 1971, Table 3-2. (17)

B. Current Planning Status

Water quality management planning is necessarily a major element of effective water resources planning. The purpose of water resources planning is to reconcile the conflicting uses of water resources in some rational manner. To illustrate how water quality interfaces with water resources

planning, consider that it may not be very efficient to consider using a stream accepting treated municipal wastes for water supply if a pure stream exists. The anticipated uses of a stream also influence future water resource development projects, such as water supply reservoirs and flood control structures which could provide local flow augmentation for water quality control and recreation.

In 1967 shortly after the passage of the Clean Water Act, the General Assembly passed Public Act 477, known as the Long-Range Water Resources Planning Act⁽¹⁶⁾. It was recognized that the Clean Water Act was aimed primarily at solving water quality problems for the short-range and that for the long range, water quality management planning, and more generally water resources planning, was required.

An intent of the planning resulting from Public Act 477 is to establish a functional plan which, if followed, would encourage people to locate where major water resource problems would be minimized. However, if people move into areas where their presence is less desirable from the viewpoint of minimizing water resources problems, the nature of difficulties likely to occur will have been studied nevertheless, so that consequences will be known. (This plan has assumed the programs under the Clear Water Act as existing conditions.)

The plan contains an inventory of wastewater treatment facilities, as well as a delineation of existing and proposed sewer service areas by the year 1980. This includes the sewerage and treatment facilities existing and constructed under all State and federal programs. These facilities have been designed principally to correct existing pollution problems and to accept flows from neighboring towns where a need has been identified. The plan also includes population projections for the year 2000 that were prepared by the

Connecticut Interregional Planning Program in 1965 using four conceptual growth models. The first of these was the linear concentration model, assuming linear growth through the urban spine of Connecticut (see Figure 2). The second was the multiple urban centers concept which assumed clustered growth (Figure 3), followed by the third projection (Figure 4) which assumes growth in accordance with present trends, and the regional plans composite (Figure 5) which assumes growth following the predictions of the local regional planning agencies. The first two may be considered "hypothetical" and the last two more "realistic." Consideration of the disparate models provides an opportunity to view problems which could develop under extreme conditions. (The projections were reworked so that population distributions were portrayed in areas possessing densities of 2,000 persons per square mile or about somewhat above three persons per gross acre. It was assumed that these areas would require both sewer and water service. Treatment and collection facilities to satisfy these population developments were then depicted for each of the four concepts, based on the maximum use of existing sewerage systems, maximum gravity flow for sewer lines, the ability of streams to accept secondary effluent, and minimization of the total number of discharges in the State to diminish management problems.)

The four alternative sewer service areas based on the alternative population projections will be used in the evaluation process to choose a final State plan.

The plan will also identify ways of accommodating scarce water resources to the needs of water supply, recreation, and waste disposal.

A major purpose in generating a State wide plan is to eliminate future problems in such a way that an accelerated pollution abatement program such

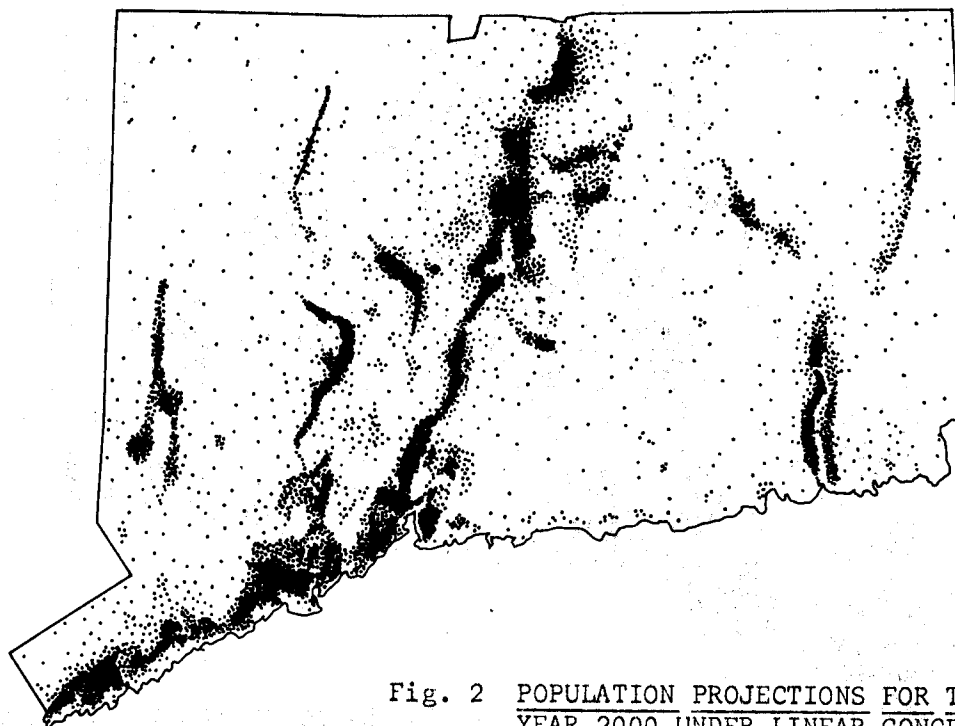


Fig. 2 POPULATION PROJECTIONS FOR THE
YEAR 2000 UNDER LINEAR CONCEPT

Each dot equals 1000 persons

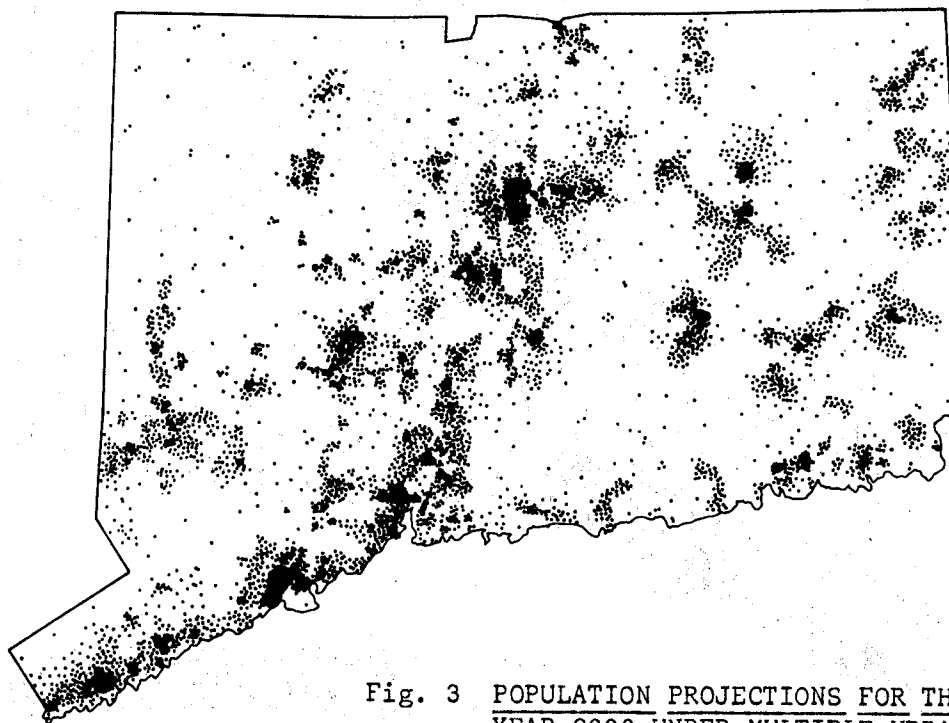


Fig. 3 POPULATION PROJECTIONS FOR THE
YEAR 2000 UNDER MULTIPLE URBAN
CENTERS CONCEPT

Each dot equals 1000 persons

Source: Phase I Report, Figures 1-7 and 1-6, respectively, 1971⁽¹⁷⁾.

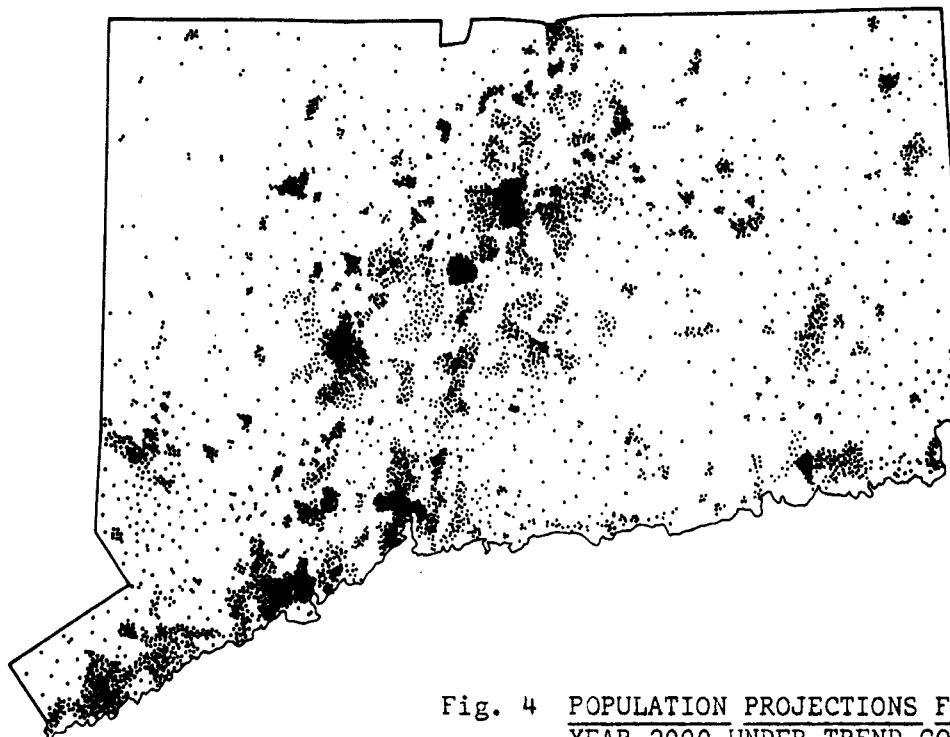


Fig. 4 POPULATION PROJECTIONS FOR THE
YEAR 2000 UNDER TREND CONCEPT

Each dot equals 1000 persons

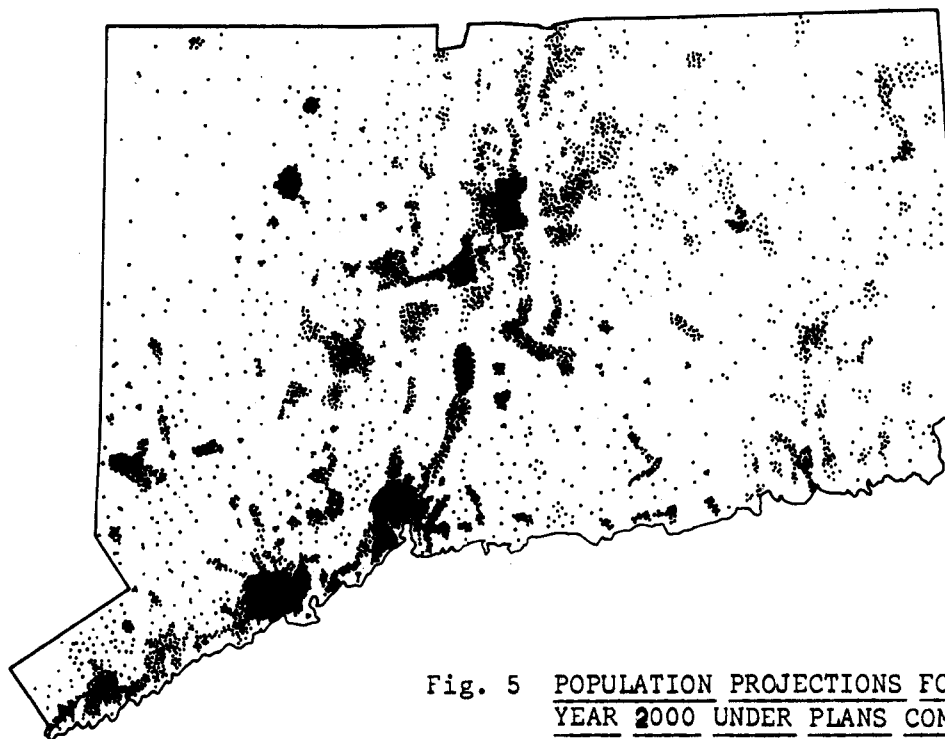


Fig. 5 POPULATION PROJECTIONS FOR THE
YEAR 2000 UNDER PLANS COMPOSITE
CONCEPT

Each dot equals 1000 persons

Source: Phase I Report, Rigures 1-4 and 1-5, respectively, 1971⁽¹⁷⁾.

as the Clean Water Act will never again be needed. The general methodology for the final State plan has been, assuming the future population to be 5.1 million people, to view the future sewer service problem solely from a water quality point of view, i.e., to determine the best location of people based on the optimum location of treatment facilities. The optimum population distribution was determined by "good engineering judgment" to keep the emergence of future problems at a minimum and to reduce overall costs. Criteria used in the final State plan were: maximizing gravity flow for sewers, locating new and expanded facilities consistent with acceptable stream assimilative capacity and sufficient site expansion capabilities, and encouraging growth to take place in areas of large population density, where sewerage service can easily be provided, while encouraging low density growth in areas which can not economically be served.

A basically similar approach will be used for the elements of water supply and recreation, i.e., determining optimal growth based solely on considerations of the one element. When this is accomplished, the three elements — sewer service, water supply, and recreation — will be evaluated in a systematic manner with other planning elements such as highways, urbanization, housing, etc., and a final plan will be developed.

The intent of such an approach is not to dictate where people can or cannot locate, but to serve as a decision tool for the State, regional and local levels of government so that the benefits or consequences of alternative courses of action may be known.

The final recommendation of the plan will be in three forms: land development standards, management recommendations, and site recommendations for the uses of specific water bodies in the State.

GENERALIZED WATER QUALITY MANAGEMENT CONCEPTS

The principal value of water quality management techniques is that they provide a rational basis for analyzing water quality problems rather than solving every specific problem. If a water quality management system is recognized as a problem of optimizing an interdependent system in a region, many alternative control measures open up for consideration⁽¹¹⁾.

A. Economic Concepts

The American economy is based on a free competitive market. Economically, a firm discharging raw waste into a stream in effect is passing a cost on to downstream water users. This downstream user may be required to provide treatment for supply water. There is really nothing in a free market to require this upstream user to internalize this external cost imposed on downstream users. As a result, an institutional framework has been established to supplement the market process in various ways. This has been historically accomplished by appeals to civic responsibility, damaged parties resorting to courts of law for relief, and by the creation of governmental regulatory agencies⁽²¹⁾, the latter being most effective.

One goal of private firms is to produce up to a point where the added cost of a unit of production is equal to the revenue generated by that unit. This is known as the concept of marginality, shown in Figure 6. As production is increased from X' to X'' on the production axis, we see that total costs (TC) in Figure 6(a) increase at an accelerated rate and marginal costs (MC) in Figure 6(b) must increase at a constant rate. This describes increasing unit costs as one expands production with limited resources.

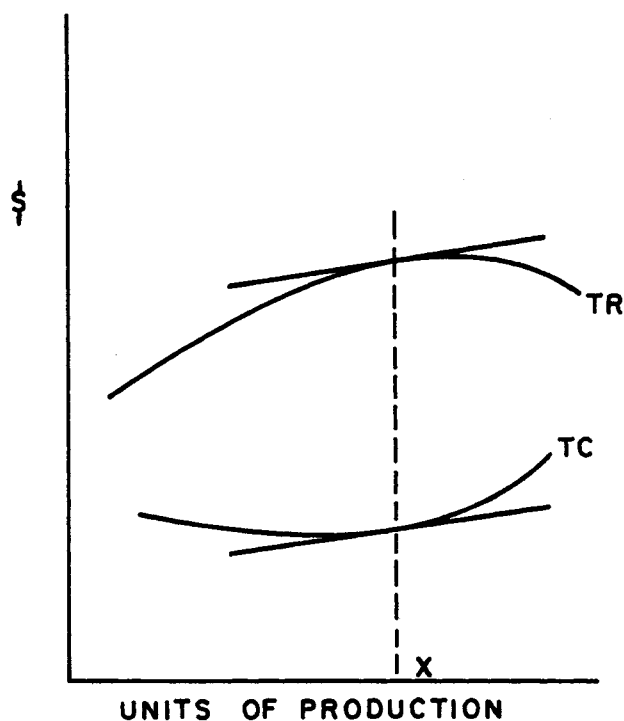


Fig. 6(a) Total Costs (TC) and Total Revenues (TR) vs. Production. TR and TC in this Case are Simple Quadratic Functions.

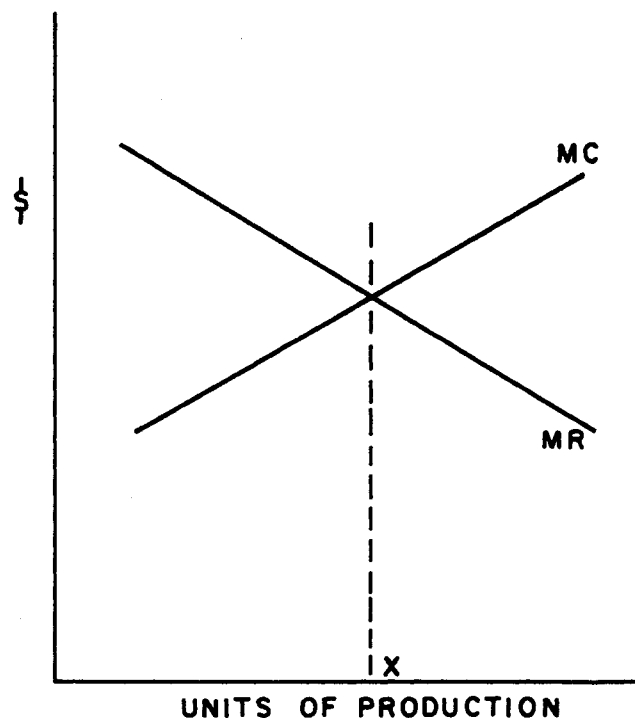


Fig. 6(b) Marginal Costs (MC) and Marginal Revenues (MR) vs. Production. MC and MR are Derivatives of TR and TC in Fig. 6(a).

Simultaneously, however, total revenues (TR) in Figure 6(a) are seen to increase at a decreasing rate, reflected in the negative slope of marginal revenue (MR) in Figure 6(b). This reflects the lower unit price for which the producer must sell a greater quantity of production. If parallels are drawn tangentially to TR and TC in Figure 6(a), the greatest vertical separation of TR and TC is defined. The level of production corresponding to this point is X , termed the point of marginality⁽²¹⁾, where profits are maximized. The equality of the slopes of TC and TR at point X is reflected in Figure 6(b) where MC equals MR. For other economic reasons the firm may choose to operate at a level of production different than X , or at a point of suboptimum

output. Factors such as changes in demand, uncertainty, and practical in-plant considerations are reasons for non-marginal production levels and such factors are discussed in a basic economics text⁽²²⁾.

It is helpful for purposes of economic analysis to regard governmental agencies in water resources as performing similarly to private firms. Public benefits for water resources enhancement might be substituted for total revenues TR in Figure 6(a) and public costs of water resources projects might be substituted for costs of production TC in Figure 6(a). If a goal of private firms is the maximization of profits, a goal of government or institution may be considered to be maximization of the differential of public benefits and costs⁽²³⁾ or net benefits. (Some economists have stated that the concept of maximizing social benefits or satisfaction of whole groups of people as an operational principle is simply a conscious deviation from reality to facilitate explanation of the concepts⁽²⁴⁾. Nonetheless, this report assumes such a concept useful for purposes of analysis.)

Four factors must be considered in the systematic analysis leading to an optimal solution of water quality management problems. Two economic factors are the attainment of water quality for least cost⁽³⁾ and the achievement of cost effectiveness, with two non-economic factors being the attainment of environmental quality and the satisfaction of social well-being⁽¹¹⁾.

If it were proposed that a water quality governmental agency function like the private firm in Figure 6, it would readily be apparent that many factors could contribute to a decision to operate at a point of less-optimum output (i.e., benefits) — such as political considerations, arbitrariness of public health rules and standards, influence by industrial management, and a host of organizational and sociological constructs⁽²⁶⁾. Consideration of

these factors may be desirable but it is important that the decision-makers be made aware of the real cost of such constraints.

In spite of the sub-optimal behavior of those institutions which effect water quality control to a significant degree, it is helpful for purposes of analysis to regard the institutional framework as optimal. In this way, the decision-makers may know the cost of constraints. Research, if not prohibitively expensive in relation to the gains, may be fostered to work towards the elimination of costly, arbitrary standards.

A major feature of the economics of water quality management is the achievement of economies of scale, or the achievement of low unit costs. This is shown in Figure 8. Several waste dischargers along a stream who are not achieving economies on an individual basis can sometimes realize economies by combining into collective facilities discharging at a fewer number of points. This is known as the regional approach when individual dischargers are municipalities. Generally, it is most economical for firms or towns to combine on a river-basin or sub-basin basis. Regional systems involving two or more towns presently exist in several cases in Connecticut.

This approach may have wide future application in Connecticut, for there are local areas discharging relatively large amounts of waste within local basin or sub-basin areas. Examples are the lower Thames Basin (a Housatonic River Sub-Basin), and the Quinebaug River Basin (a Thames River Sub-Basin).

Disadvantages of the regional approach are that low abandonment of facilities which have not been fully depreciated may be a major cost, and the added cost of waste conveyance may be great. Uncertainty of economic projections is greater regionally, which may result in more over-building of facilities⁽²⁶⁾. Another disadvantage of regionalization is that upstream

flows may be lowered considerably because of diversions to the regional facility. Also, the shock loading resulting from a single large discharge could have a detrimental effect on water quality. To maintain desirable levels of quality, flow augmentation or planned distribution of waste loadings may be required in conjunction with regionalization. (Institutional forces may mitigate against implementation of the regional concepts and these are presented in Chapter III, Section C.) The regionalization concept has much utility, provided that these factors are taken into account.

Engineering-economic research indicates that economics of scale can be realized in many ways. They are: joint treatment of individual wastes, low-flow augmentation, stream aeration or treatment, effluent diversion within or out of the basin, and stream specialization.

For purposes of the following analysis, the institutional framework is assumed to be a regional authority which can plan, design, construct, operate, and maintain facilities. The authority has the responsibility of establishing standards to assure the anticipated uses of the stream.

The regional authority, through an extension of the analysis, may be considered as a firm which has as its goal the maximization of profits. To achieve this, it is necessary to minimize costs associated with overall water quality management within a basin area, which is assumed to constitute the boundary of the authority. The concept of minimizing costs entails not only providing least-cost wastewater treatment but also a consideration of minimizing water treatment and opportunity costs, which represent foregone opportunities for water uses as a result of each alternative.

The development of an optimum solution to water quality management may be seen by considering basin plans A and B in Figure 7. A stream runs through

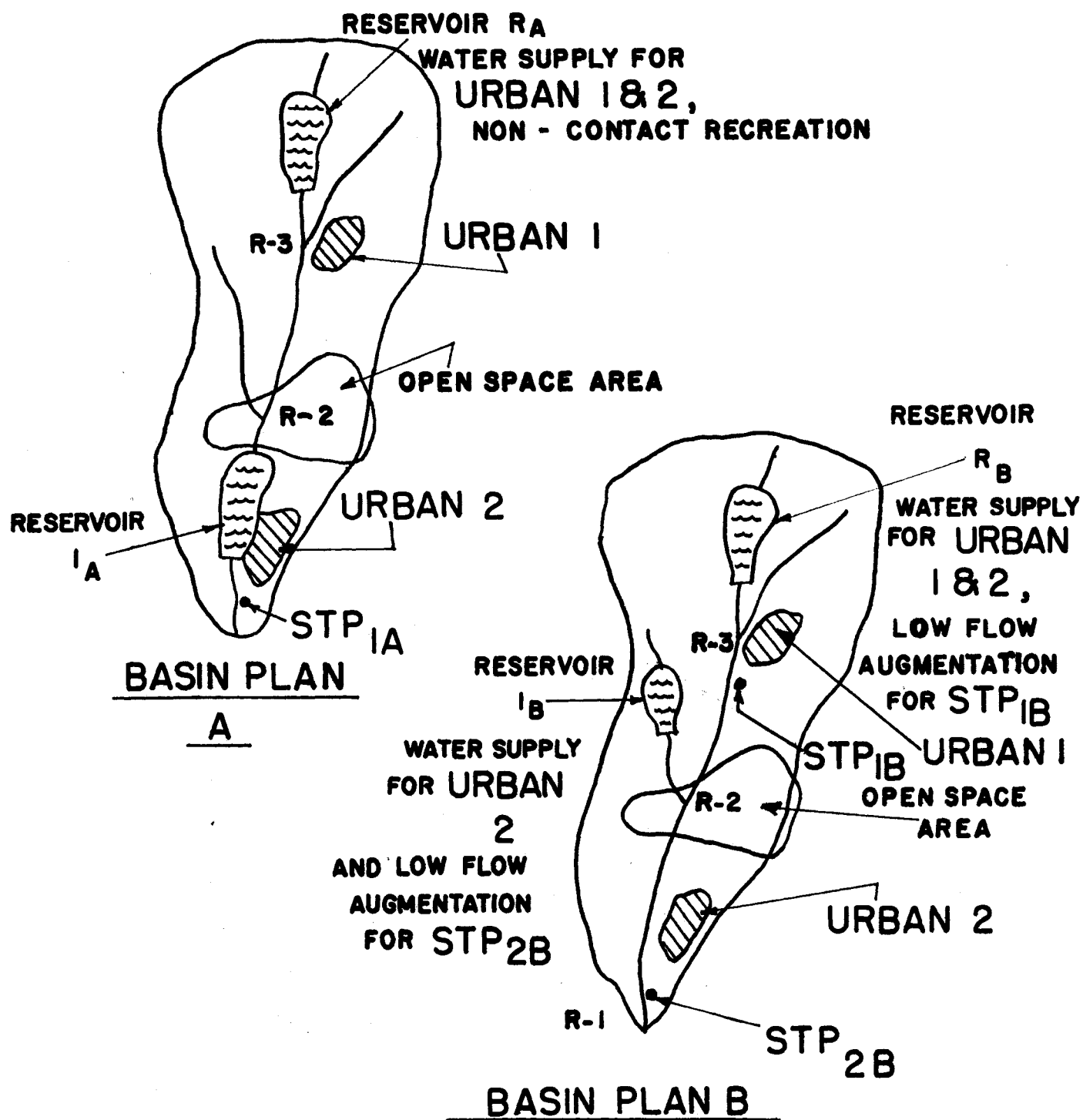


Fig. 7 ALTERNATIVE BASIN PLANS A & B

the basin with two tributaries. There are urban developments $URBAN_1$ and $URBAN_2$ in the north-central, and southern portions of the basin, with sub-urban developments contiguous to the urban areas. The remainder of the land is termed undevelopable and/or open space. In Plan A, one treatment facility is proposed, STP_{1A} , and in Plan B, two treatment plants, STP_{1B} and STP_{2B} , are proposed. The cost of Plan B is the requirement of low-flow augmentation for Point R-3. A further cost of Plan B may be the inability of providing contact recreation downstream of STP_{1B} unless higher treatment is provided at STP_{1B} . This is presently an institutional constraint in Connecticut. A cost of Plan A is the requirement of low-flow augmentation and reservoir I_A because of STP_{1A} downstream.

Many other costs could be presented for these two plans. Some of the costs of a plan may thus be viewed as foregone opportunities of that plan. The costs of providing water quality under Plans A and B may be determined by opportunity costs, the cost of providing treatment (Figure 8), and by damage functions describing damages caused under various flow regimes in Figure 9. Integrating the curves in Figure 9 gives the probability of costs for natural flow regmines, and modified flow regimes FR #1 and FR #2. By comparing the total costs under Plans A and B and choosing the plan with the lower cost value, overall costs have been minimized. (Depending upon the constraints, there could have been more alternatives and attendant opportunity costs considered in this example.)

In some cases the evaluation of alternatives, or "tradeoffs" may be fairly straightforward, but for others an analysis cannot be made without a more demanding mathematical approach^(8,9,10) using an optimization model.

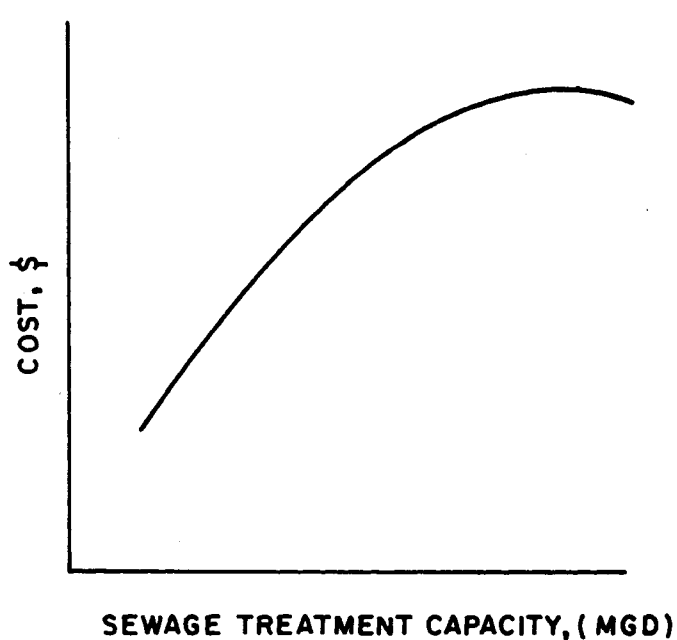
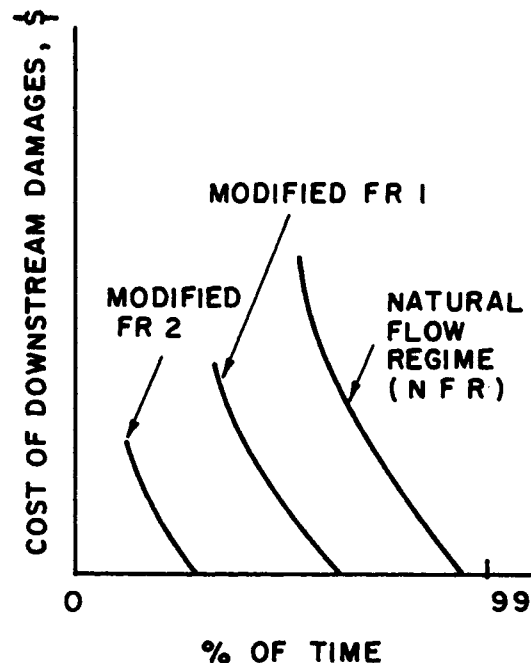


Fig. 8 Treatment Cost Curve

Fig. 9 Damage Functions
For Alternate Stream-flow
Regimes

The general approach for either case is to evaluate the combinations of alternatives to meet water quality standards for least cost, and to consider the appropriate social, environmental, and institutional constraints.

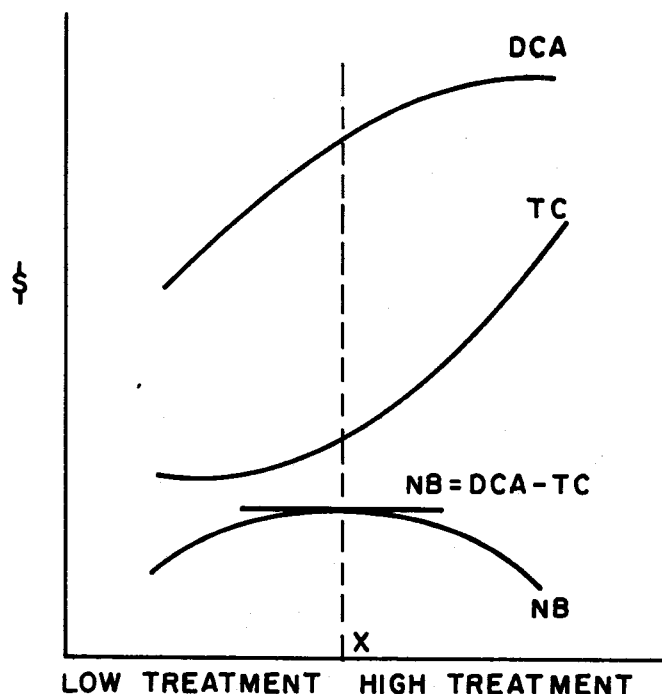
A major problem in applying this approach to Connecticut's problems is that not all costs and benefits have been quantified through cost functions. Examples are recreational benefits and public health standards. Some analyses in the past have chosen to disregard these incommensurables and proceed to calculate the commensurables and take in the incommensurables into account as a last step.

An alternate approach is to view these incommensurables as constraints in the system and to build an optimization around them. The standard is assumed, and a least-cost analysis is then performed. The standard is then

varied to determine the cost sensitivity in terms of other elements. Ultimately the optimum constraint is determined⁽²¹⁾. Independent research may also contribute to a more objective constrain value.

To summarize thus far, a regional authority has been proposed to carry out water quality management in a basin. This authority has been hypothetically considered as a firm attempting to minimize treatment costs to achieve a standard. The firm acts competitively in that it will invest in treatment up to the point where an incremental expenditure in treatment is greater than the additional gain in public benefits. Conceptually this is shown in Figure 10. Point X describes the economically optimal level of treatment. At this point, DCA, damage costs avoided (benefits), exceed treatment costs by a maximum value based on the same reasoning applied to the private firm maximizing profits illustrated in Figure 6. This concept may also be shown by a minimization of total costs (treatment and damage costs) as portrayed in Figure 11, where DC, the damage cost, equals the negative of DCA in Figure 10. Net benefits, in Figure 10 ($DCA - TC$), are maximized while in Figure 11, total costs ($DC + TC$), are minimized. Since $(DC + TC) = (-DCA + TC)$, minimizing $(DC + TC)$ or $(TC - DCA)$ means maximizing $(DAC - TC)$.

Figure 10 and 11 were drawn as smooth curves and the axes were not quantified to illustrate their conceptual nature. Applying values to these curves has been accomplished for TC, but not for DC or DCA. Deterministic examples of DC are increased water treatment costs or added cost of recreation at an alternate location. Less deterministic values of DC are esthetic damages to water and related land uses. DC is variable and probabilistic due



NB-Net Benefits; DCA-Damage Costs
Avoided; TC-Total Treatment Costs

Fig. 10 Point of Optimum Treatment,
Maximization of Net Benefits

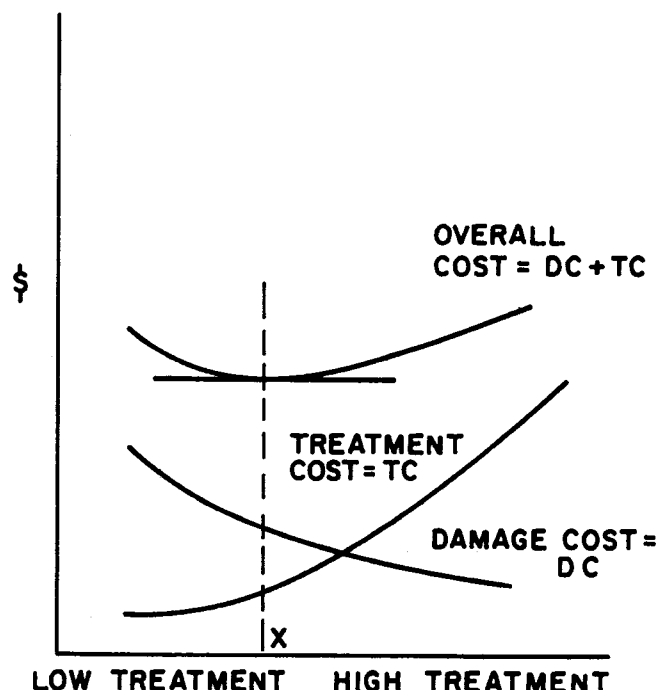


Fig. 11 Point of Optimum Treatment,
Minimization of Total Costs

to varied flow regimes as shown in Figure 9. The quantification of the benefits of water quality enhancement is an important current research area and many studies have been carried out⁽¹⁰⁾.

It is appropriate for institutions carrying out water quality management planning to evaluate water quality and water-oriented standards on an economic basis. One reasonable purpose of substantial investments of public funds in water quality improvement is the achievement of cost-effective solutions to water quality problems⁽³⁾. An example of cost effectiveness is the achievement of a maximum degree of water quality improvement for every expenditure

of funds. It is recognized that such an approach is rarely undertaken by institutions for a number of reasons, the most frequently cited reason being "lack of data." But sufficient data exist and the water environment is understood to such a degree^(27,28,29) that a case can be made for the application of cost-effectiveness techniques. The following cost-effectiveness example will be presented through the use of two models, a water quality model and maximization of net benefits model as illustrated in Figure 10.

The basic physical description of the example is shown in Figure 12. The Streeter-Phelps water quality model⁽³⁰⁾ will be used, which relates C (dissolved oxygen) responses to BOD (biochemical oxygen demand) inputs. This relationship predicts the dissolved oxygen response to streams which have a slow velocity, large depth, and waste inputs which lie within the first-stage (carbonaceous) range of biochemical oxygen demand⁽³⁰⁾. The ratio of dissolved oxygen present to the saturation value (C/C_s) as measured at a point in the stream corresponding to the location of the critical oxygen deficit is proposed as a measure of water quality. The loading to the stream is assumed to be a standard strength, point source municipal waste, free from toxic materials, average flow $Q_p = 7.0$ MGD, with $k = 0.39$ days⁻¹ (biochemical oxygen demand constant)⁽³¹⁾ and BOD = 200 mg/l. The stream is assumed to conform to the assumptions of Streeter-Phelps with a seven-day, ten-year recurrent low flow $Q_s = 3.0$ MGD (the design basis) and r , the reaeration rate, equal to seven days⁻¹⁽³¹⁾. The value of C in the river at the point of introduction of sewage is assumed to be within Class B criteria, 9.0 mg/l (full saturation) at 20°C and the biochemical oxygen demand of the stream above the point of waste discharge is assumed to be 30 mg/l. The rather large assumption of complete mixing of sewage and river water is made for the purpose of this

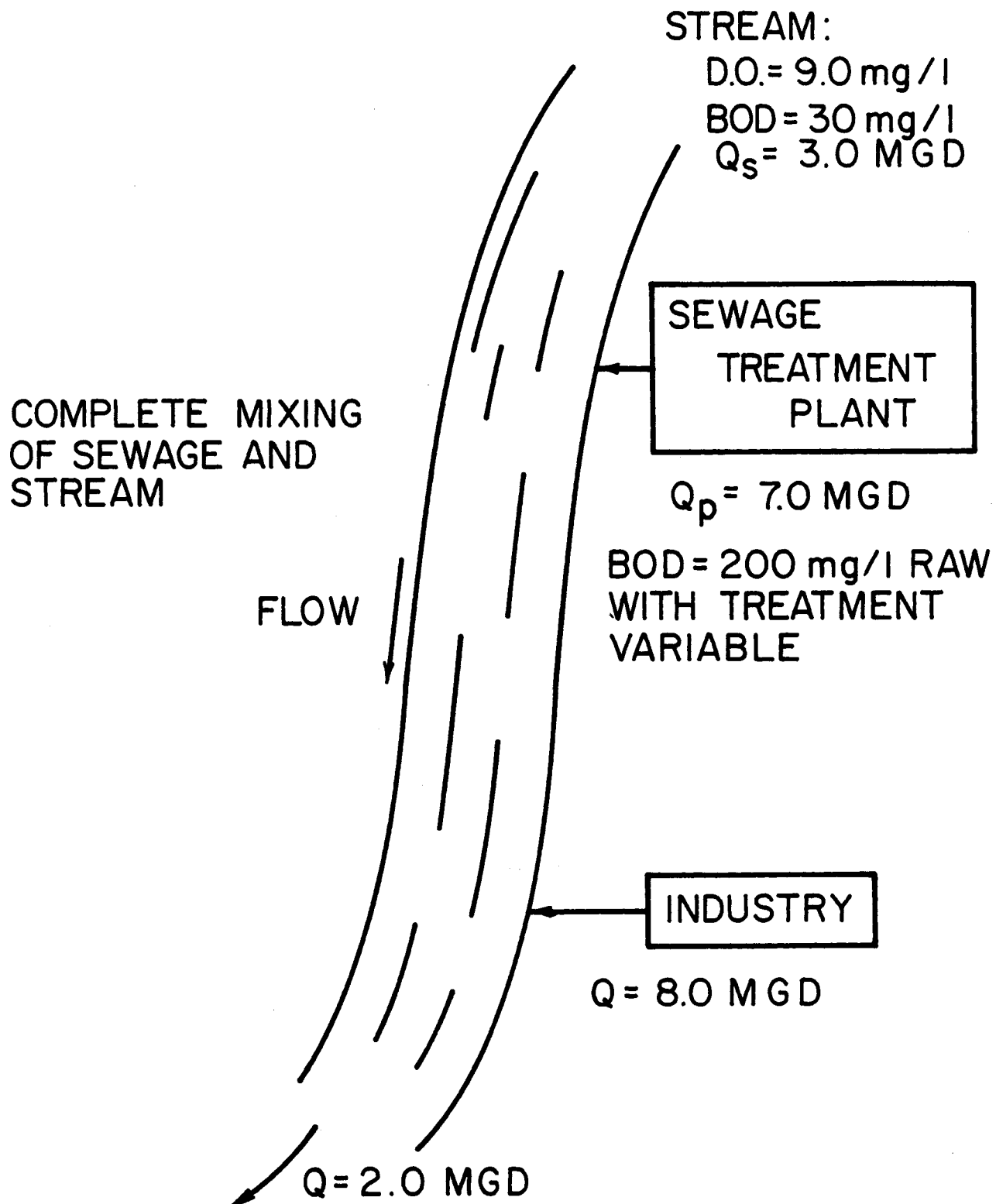


Fig. 12 PHYSICAL DESCRIPTION OF EXAMPLE USED FOR COST-EFFECTIVENESS APPROACH

analysis. The results are shown on Figure 13, Curve A. Under these conditions, the critical oxygen deficit $D_c = C_s - C_{\text{critical}}$ may be calculated by the following simplification of Streeter-Phelps:

$$D_c = \frac{L}{f e^{k t_c}}$$

where

D_c = critical oxygen deficit, mg/l

L = biochemical oxygen demand of stream mg/l

$f = r/k$ - stream purification rate, days⁻¹ / biochemical oxygen demand constant, days⁻¹

k = biochemical oxygen demand constant, days⁻¹

t_c = time of occurrence of D_c , days

A point on Curve A corresponding to 30 per cent biochemical oxygen demand removal is calculated:

Biochemical Oxygen Demand = 200 mg/l,

At 30 per cent removal biochemical oxygen demand = $200 - .30 \times 200 = 200 - 60 = 140$ mg/l.

Stream biochemical oxygen demand, L , is:

$$L = \frac{L_p Q_p + L_s Q_s}{Q_p + Q_s}$$

where

L_p = treatment plant effluent BOD, mg/l

Q_p = treatment plant flow, MGD

L_s = upstream BOD, mg/l

Q_s = stream flow, MGD

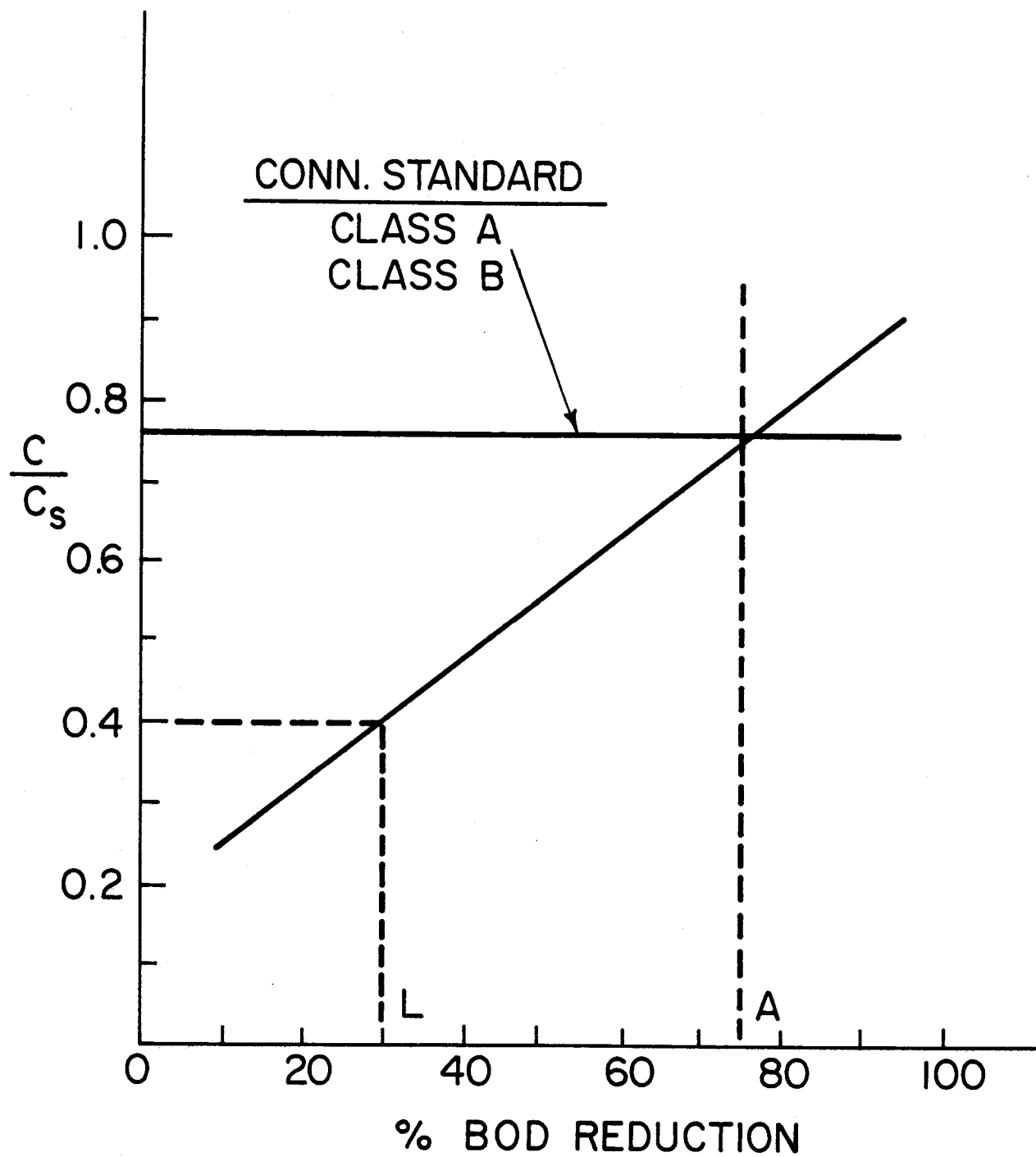


Fig. 13 WATER QUALITY RESPONSE TO BOD REMOVALS
IN WASTE TREATMENT

$$L = \frac{140(7.0) + 30(3.0)}{7.0 + 3.0} = 107 \text{ mg/l}$$

$$t_c = \frac{\ln f}{k(f-1)} = \frac{\ln \left(\frac{7.0}{0.39} \right)}{.39(18.0-1.0)} = 0.44 \text{ days}$$

$$D_c = \frac{L}{f e^{kt_c}} = \frac{107}{18.0 e^{.39 \times .44}} = 5.55 \text{ mg/l}$$

$$C = C_s - D_c = 9.00 - 5.55 = 3.45 \text{ mg/l at } 20^\circ\text{C}$$

$$C/C_s = 3.45/9.00 = 0.40$$

Curve B in Figure 13 describes a condition where the treatment plant flow is smaller relative to the flow of the stream. The stream is the same as in Curve A but the treatment plant has a flow of 2.0 MGD. In that case, water quality is not as sensitive to treatment plant removal efficiencies. For purposes of comparison, a Connecticut Water Quality criterion of 75 per cent saturation is also indicated⁽²⁰⁾ corresponding to point Y, where BOD removal = 75 percent.

It is assumed that the three MGD stream (ten MGD below the treatment plant) downstream is used only for industrial water supply which requires water free from turbidity and solids. As BOD removals in sewage treatment are decreased, effluent BOD increases, stream oxygen is lowered and septicity, growth of saprophytic bacteria causing turbidity and undesirable growths, will occur⁽²⁰⁾. For the purposes of the economic analysis it is assumed that granular carbon is used to accomplish water treatment at C levels less than 3.80 mg/l ($C/C_s \leq 0.40$ corresponding to less than 30 percent BOD removals in Figure 13 along line 1).

This process would cost the industry about \$1,500,500 to construct, assuming that the industry uses eight MGD⁽³²⁾ of water. This is shown in Figure 14 as damage costs avoided curve DCA (IND). Treatment cost for the seven MGD sewage treatment plant is also shown in Figure 14⁽³²⁾. Assume that the industry presently uses groundwater for its pure supplies (quality requirements are DO \geq 4.0 mg/l) and the more oxygen in the water, the more value it holds to their operation (e.g., a fish hatchery), shown in Figure 14 as DCA (OXY). The total curve is drawn by superimposing DCA (IND) and DCA (OXY).

It is possible also to draw DCA curves corresponding to public water uses such as fishing and recreation, based on a determination of the economic values of such recreation⁽³³⁾. BOD exerts an effect on fish life and on swimming only through dissolved oxygen in a narrow range and only at low levels⁽²⁸⁾. In Figure 14 the curve NB (net benefits) may be drawn using the procedures described for Figure 11. BOD removals from 70 to 85 percent may be termed the maximization of net benefits (along curve NB) where benefits are: (1) a maximum and (2) relatively insensitive to costs.

A desirable goal of water quality management is the attainment of cost-effectiveness. This defines a range of treatment levels for which maximum net benefits accrue for an incremental improvement in water quality⁽³⁾. It may be found by dividing curve NB in Figure 14 by curve A in Figure 13, shown in Figure 15. This indicates that if treatment is provided to yield BOD removals in the range of 50 percent to 78 percent, that cost effectiveness is attained or, maximum net benefit results from water quality improvement. In Figure 13, curve A intersects the Connecticut water quality standard and line A indicates that this corresponds to approximately 75 percent BOD removal. In the cost

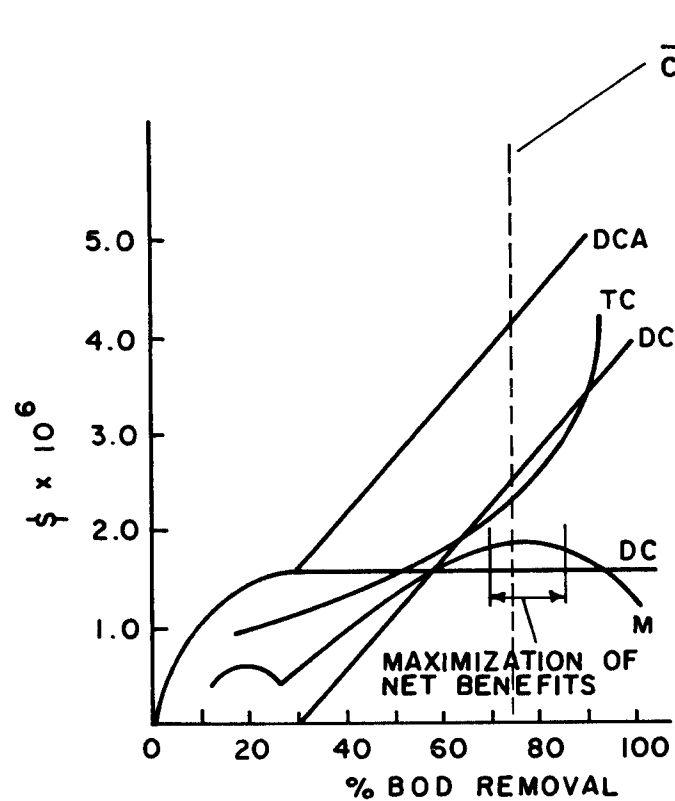


Fig. 14 DETERMINATION OF NET BENEFITS

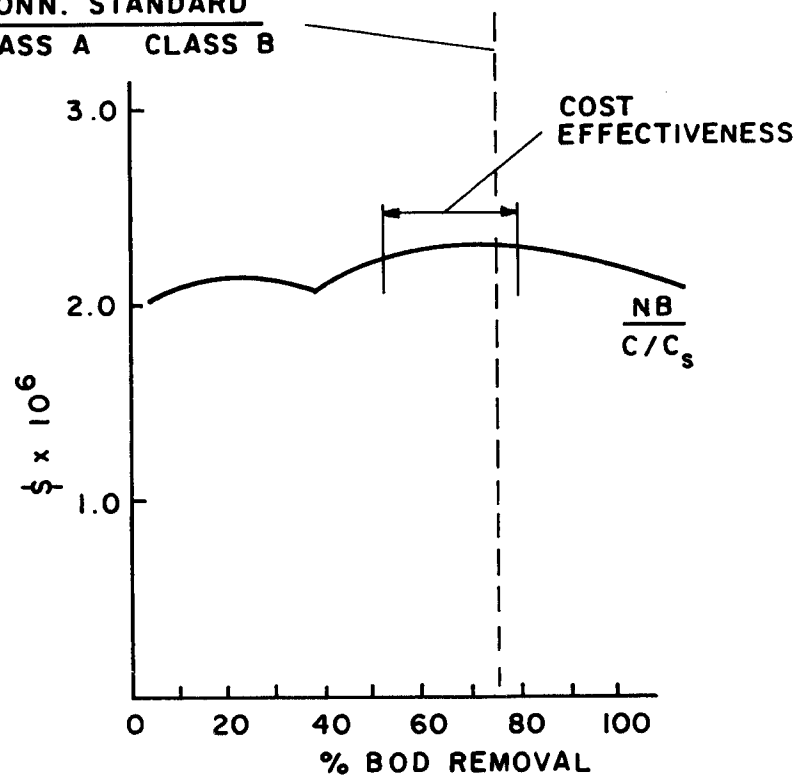


Fig. 15 RANGE OF COST EFFECTIVENESS

cost-effectiveness analysis, 75 percent BOD removal lies within the cost-effective region.

This example shows that the optimum treatment range in the cost analysis in Figure 14 overlaps the optimum treatment range in the cost-effectiveness analysis. If treatment is provided within the overlapping range (70 to 78 percent removal), the net benefits of water use will be maximized and the benefits associated with water quality improvement will also be maximized. In this case, the standard is justified, based on the cost analysis and on the cost-effectiveness analysis. In many cases, it will be found that the standard will fall outside this range and for such cases the excess cost of reaching such a standard can be determined and an evaluation made pertaining to the continuance of secondary waste treatment or a standard of Class B water quality when Class C is indicated by the analysis.

It is recognized that it could be time-consuming and difficult to analyze all streams on a statewide basis. It is possible, however, to identify streams where potential benefits from a quality improvement would appear to be either very abundant or very remote, and to run an analysis similar to the above to establish cost-effective standards.

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B. Technological Concepts

1. Introduction

The evaluation of alternatives for meeting projected water quality deficiencies must necessarily be partly technological. Effective water quality management planning cannot be achieved without an understanding of the relationships between waste loadings and stream responses. In some cases, this relationship is comparatively easy to understand and to simulate, as was

the case in the preceding example which assumed stream behavior in accordance with the Streeter-Phelps model, but in other cases, the relationship may be exceedingly complex, requiring careful application of sophisticated stream input-response mathematical models.

Future treatment facilities in Connecticut will impose a greater strain on the water resources of the State. This strain will vary in extent and intensity dependent upon two major factors: the anticipated local development, and the local availability of the stream's waste assimilative capacity. Data reflecting anticipated development on a State-wide basis is available from the identification of deficiencies, presented in the Phase 1 report⁽¹⁷⁾ and described in Chapter 2, Section C of this report. Future waste loadings may thus be calculated.

Waste loadings take many different forms, and EPA has divided them into broad classifications: point sources and non-point sources⁽³⁾. Point sources are considered to be those wastes normally conveyed to a point, treated, and subsequently discharged. Municipal and industrial wastes conforming to this description are examples. Non-point sources are wastes which cannot feasibly be collected, treated, and discharged. Examples are storm water runoff in many cases and agricultural runoff. The water quality impact of non-point wastes can be ameliorated only through non-treatment alternatives, such as the institution of land use measures or flow augmentation. Where both point and non-point sources exist, the significance of non-point sources can bear heavily on the choice of alternative pollution abatement measures. For example, if the limiting factor for excessive algal blooms in the basin is phosphorous, advanced waste treatment at a point source in the form of phosphate extraction

would not be effective if there were significant phosphate fertilizer runoff in the basin. This form of advanced waste treatment would be effective only if algae growth were limited by the amount of phosphate present in the point source.

Combined wastes are another form of waste loading which must be considered. These problems are restricted to the urban areas of the States. It was not uncommon in the past to construct one sewer line for the conveyance of both storm and sanitary wastes to a watercourse. At present, combined sewerage systems may cause water quality problems in many different ways. Raw sewage overflows take place at various points in the sewerage system during storm periods, discharges exist at combined sewer outlet points, and interference with the operation of secondary treatment plants may occur during storms due to excessive hydraulic loadings to the treatment plant. The problem of combined wastes is of long-range significance because correction will take many years and require substantial investments. Alternatives for correction are sewer separation and, second, conveyance of the combined wastes to a combined waste treatment facility, treatment, and disposal at a suitable point.

Technological gaps exist with respect to the behavior of many materials discharged into the aquatic environment. Wastes are basically heterogeneous in nature, consisting of many unknown materials. These materials may interact synergistically in the receiving stream⁽⁵⁾, and have sometimes unknown short-range and long-range effects. Hence, the establishment of models such as chemical equilibrium models is a research area⁽³⁴⁾.

The proper choice of pollution abatement measures requires a careful consideration of stream characteristics. The water quality impact of a waste may be calculated based on some removal efficiency in the treatment plant.

Mathematical models exist which predict the stream response. When these models are applied, decisions can be made regarding the adequacy of secondary treatment, which is Connecticut's minimum requirement. If secondary treatment is adequate and engineering judgment indicates that the stream's assimilative capacity may be exhausted with future expansions, the model can predict the maximum allowable waste loading at a point to meet water quality standards. The secondary treatment plant must not exceed the design loading. This may be achieved, for example, by encouraging lower density population development to discourage extension of the sewer service area.

If the assimilative capacity does not permit a secondary treatment plant expansion alternative pollution abatement measures may have to be examined. Secondary expansions may be allowed if stream flow augmentation is available or, in the case of estuaries, outfall extensions are provided. Other alternative pollution abatement measures in water quality management planning are: advanced waste treatment, in-stream aeration or some other direct treatment of the stream, stream specialization, relocation of discharge points, effluent flow regulation; effluent diversions from the basin, and control of waste quantities through zoning and/or land use changes, and combinations of the above⁽³⁾. These alternatives will be described in some technical detail later in this section.

These approaches are evaluated in technological terms to produce a water quality management program which will meet the specified water quality objectives at least cost under the social and environmental constraints. For example, assume a stream is accepting a conventionally treated secondary effluent. If this stream is high in fecal coliforms and low in oxygen, super-chlorination and effluent aeration could be provided as one alternative or

low-flow augmentation could be provided by an upstream reservoir, with possible addition of in-stream aeration. Technical and cost-effectiveness analyses using stream models would determine the required facilities.

One principal area of application of technological concepts of water quality management planning involves the resolution of problems of competitive use of the water bodies. Competitive uses considered in this report consist of waste disposal, water supply, and recreation. Technological questions involve a determination of the water quality requirements for each use, as well as the impact of each use on water quality. Considerable information has been set forth and summarized in several texts^(27,28) relative to the water quality criteria for specific water uses. These texts also point out the limitations of present knowledge relative to the hundreds of parameters suspected of having some sanitary significance.

The impact which waste discharges have on water quality varies depending upon the waste loading condition and the other resource use being considered. For instance, the significant parameter relative to the impact of recreation upon water supply is bacteriological. As only one example of the considerations involved in a discussion of the interaction of competitive uses, the significance of one of the more common parameters involved in all three uses will be discussed: pathogenic indicators.

Pathogenic indicators are measured in water to determine the presence of disease-causing organisms originating from fecal pollution, such as enteric viruses and bacteria. Indicators, such as total coliforms, fecal coliforms, and fecal streptococcus are used because it is prohibitively expensive to test for the viruses themselves on a routine basis⁽²⁷⁾. Sources of such indicators may be sewage treatment plant outfalls, failing subsurface

sewage disposal systems, storm runoff, and to an extent, contact recreation, e.g. swimming. Although reports on the relationships of pathogenic indicators to pathogens conflict^(31,35), the measurement of pathogenic indicators and subsequent interpretation based on a sanitary survey normally indicates the specific nature of bacterial contaminants.

The technology of water treatment is such that virtually all pathogens are removable, as evidenced by their present lack of sanitary significance⁽³⁵⁾. There is presently little data on the relationship of polluted recreational water to waterborne disease⁽²⁷⁾. One study has indicated a detectable health effect at 400 FC/100 ml⁽²⁷⁾, but the provision of secondary treatment and chlorination can generally produce an effluent with fecal coliforms in the order of only 200 FC/100 ml⁽⁴¹⁾. Dilution would also result in waters with fecal coliforms significantly less than 400 FC/100 ml. Technologically, it would appear that both contact and non-contact recreation and probably disposal of wastes with at least secondary treatment is consistent with use of a body of water as a potable water supply reservoir, with respect to pathogenic indicators, which represent probably the most restrictive parameter for allowable waste disposal and recreational uses.

The alternative water quality management measures which have been identified to date^(3,21) will now be presented. The techniques are applicable to Connecticut's long-range water quality management programs if current institutional constraints are disregarded.

2. Alternative Pollution Abatement Measures

a. Waste Treatment

Mathematical models for the prediction of stream quality under various waste loadings have existed for about 25 years⁽³⁰⁾. Most of these models have

experienced restricted application because they predict the stream response only to a restricted number of discharges in a stream conforming to certain characteristics. Such a formulation would have limited applicability in Connecticut because streams have diverse characteristics with respect to both location and time. Waste loadings are numerous, diverse, and time-variant.

Mathematical models were introduced about ten years ago which considered the waste-input and stream-response characteristics for uniform sections of a stream. These first models considered only biochemical oxygen demand-dissolved oxygen relationships. A mass balance equation was written for each segment for both biochemical oxygen demand and dissolved oxygen. These differential equations were converted to linear finite difference equations and arranged into a matrix and solved by computer. The number of segments of the stream was limited by the capacity of the computer. The Delaware River Basin Commission⁽³⁶⁾ used these techniques to determine allowable loadings for each waste discharger. Longer reaches were used for lesser-developed reaches of the stream and shorter reaches were used for more highly industrialized portions.

The biochemical oxygen demand-dissolved oxygen model is an attempt to duplicate one of the processes that regulates water quality. An oxygen balance is made considering oxygen added in the form of reaeration and photosynthesis, and oxygen depleted by the uptake by aquatic organisms.

The model's results are no better than the validity of input data. It is necessary to provide as an input for each reach, the biochemical oxygen demand loadings (pounds per day), stream flow critical conditions (for Connecticut Water Quality Standards that is the seven-day, ten-year recurrent low flow), average stream depth within the reach, measured dissolved oxygen, and temperature values. The reaches must be carefully chosen in that uniform conditions

are assumed throughout. Complete mixing is assumed within the reach so that a single, one dimensional model can be used. The differential equation for the biochemical oxygen demand balance is as follows⁽⁴⁾:

$$\frac{dL}{dt} = E \frac{\partial^2 L}{\partial x^2} - U \frac{\partial L}{\partial x} - (d)L + J \quad \text{Eq. 1}$$

Where L is biochemical oxygen demand concentration, E is the diffusion coefficient found from field measurements, U the stream velocity within the reach, x the distance, t the time, d the biochemical oxygen demand decay coefficient due to bacterial oxidation, and J the increase in biochemical oxygen from external sources. The oxygen balance is mathematically formulated by:

$$\frac{dC}{dt} = E \frac{\partial^2 C}{\partial x^2} - U \frac{\partial C}{\partial x} + r(C_s - C) + P - (d)L \quad \text{Eq. 2}$$

where all terms are as used in Equation 1 and C is the dissolved oxygen concentration, r the reaeration coefficient, C_s the dissolved oxygen concentration at saturation for the measured temperature, and P is the increase in dissolved oxygen for photosynthesis. It is necessary that r and d be corrected for temperature.

It is necessary to determine the time-variant characteristics or the "temporal" characteristics⁽³⁾ of the receiving stream to compute the desired standard. For example, Connecticut's standard for dissolved oxygen for Class C streams requires the values to be greater than five milligrams per liter for no less than sixteen hours of the day⁽²⁰⁾. Some parameters have weekly or seasonal variations which must be detailed as an input to the model. "Spatial" characteristics are also established which detail the water quality objectives with respect to location. This is considered in the establishment of stream reaches by assuming uniform water quality objectives for each reach⁽³⁾.

Data evaluation and screening are necessary, requiring verification of the hypothetical model to existing stream conditions. The amount of data required depends on the relative complexity of the stream characteristics being duplicated. The model must take account of all significant trends in the stream. For example, biochemical oxygen demand and dissolved oxygen data are taken from field investigations and the model is allowed to calculate dissolved oxygen outputs for the biochemical oxygen demand inputs. Field dissolved oxygen values are compared with model output dissolved oxygen values and refinements to the model are made. The model is then rerun until it is established that all significant trends and factors have been considered, including the desirable diurnal variations in dissolved oxygen. Other demands on dissolved oxygen must be considered, such as the nitrogenous demand.

The characteristics of waste materials must be understood to be appropriately considered in the model. Generally waste materials fall into three categories in terms of reaction in water⁽³⁾. Conservative non-reacting materials are inert and tend to be accumulative. Examples are salinity and total dissolved solids. Non-conservative first-order materials are exemplified in biochemical oxygen demand and total coliforms. Sequentially reacting materials with reaction kinetics higher than first-order are exemplified by biochemical oxygen demand-dissolved oxygen relationships and the nutrient cycle.

These varying classes of materials are described to demonstrate that reaction kinetics must be taken into account to construct a viable model. The behavior of a single material in solution may be found in a deterministic manner, but the behavior of a heterogeneous mixture can be found most easily by a probabilistic approach⁽²⁶⁾. It is necessary that constant coefficients

in the mathematical formulation, such as reaeration and deoxygenation, be examined under different stream conditions to determine any variability.

When the above steps have been accomplished, the model is said to be verified for that reach, and performing this process for all of the reaches in the stream will verify the model for the stream. Under any condition of biochemical oxygen demand loading, temperature, and stream flow, the model can predict the resulting dissolved oxygen. For example, the Connecticut River Study⁽⁴⁾ predicted the effect on Connecticut River water quality of: lowering all existing biochemical oxygen demand inputs by 80 percent, instituting in-stream aeration at Hartford, and raising temperature ten Centigrade degrees. Results generated from that study were questionable, however, because the data used for the model were inconsistent and incomplete.

Models cannot be used effectively, however, unless their limitations are well understood. First, it is important that reliable data be used as an input to the model. Second, the model does not account for disturbances in the rate of oxygenation and deoxygenation by variations in concentrations of certain pollutants. Third, reaches must be chosen so that the assumption of uniformity of stream behavior does not conflict with actual field data. Fourth, uniform depth is assumed, and reaches may possess both longitudinal and lateral depth non-uniformity. Fifth, the effect of salinity variations in estuaries is not taken into account. Sixth, tidal fluctuations are not considered. Lastly, unpredicted stream flow regulations may affect the model output. The large amounts of data required by the models may generate administrative problems. Also, many values are difficult to quantify, such as natural oxygen uptake by plants and organisms and the carbonaceous loading added by runoff.

One of the principal reasons water quality models have experienced restricted use is due to the lack of essential data. In view of this, it is important to identify which parameters are important and what level of accuracy of recording those important parameters is required. This process is known as a sensitivity analysis. The general approach used is to plot some measure of water quality against the parameter over a range. In water quality management, desired water quality is a function of the intended use, so each use has its own measure. Examples are number of fish, number of swimmers, number of industrial water users of various quality requirements, and number of sightseers. Examples of parameters are dissolved oxygen, turbidity, pH, temperature, and many toxic materials and synergistic effects arising from combinations of many different materials.

To illustrate this approach, a sensitivity analysis follows on fish production vs. turbidity, shown in Figure 15, based on summarized data from the National Technical Advisory Committee Report⁽²⁷⁾.

Fish density is sensitive to turbidity at values greater than ten JTU and insensitive at values less than ten JTU, as shown in Figure 16. It is important to measure turbidity accurately greater than ten because the cost, in terms of density of fish, changes rapidly. However, it is not important to measure turbidity for values less than ten, because the impact of changed values within this range is insignificant. In a basin where it is rare to encounter turbidity values greater than ten JTU, and fish production is the only use, turbidity would not be important to monitor. Another example is provided in examining the net benefits curve NB in Figure 14 between the ranges of 70 percent and 85 percent. In this range, relative insensitivity to cost is seen.

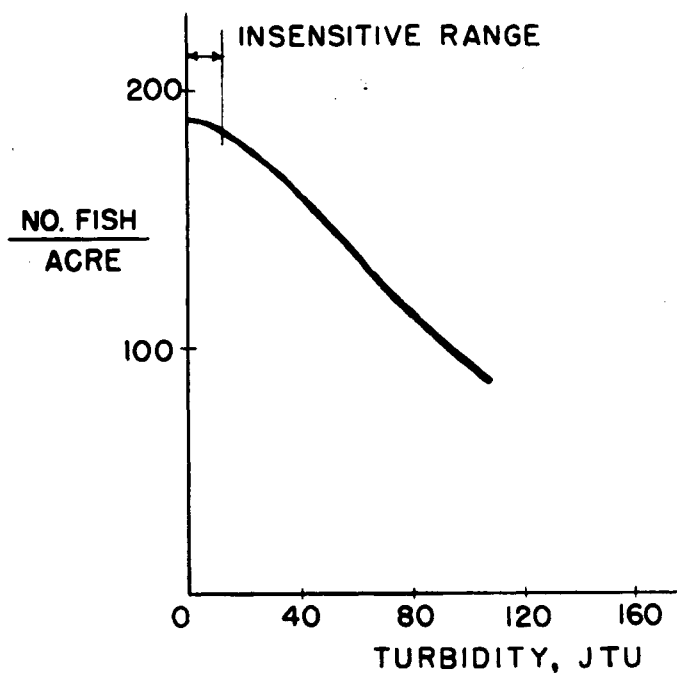


Fig. 16 Sensitivity Analysis of Fish Density (no. of fish per acre) vs. Turbidity

In terms of net benefits to users of the stream, the difference between achieving 70 percent removal and 85 percent removal is essentially insignificant. Relative to the cost-effectiveness curve in Figure 15, the same can be said about biochemical oxygen demand removals of the range 50 percent to 78 percent. Additionally, in Figure 13, curve A is considerably less sensitive to water quality than curve B. For a plant with $Q_s/Q_p = 3/1$, water quality would be so insensitive to biochemical oxygen demand removals over the range of 0 to 100 percent that an argument might be made to dispense with treatment entirely.

However, it is not possible to measure biochemical oxygen demand to a high degree of precision⁽³⁸⁾ and the potential use of sensitivity, cost, and cost-effectiveness analyses could provide a concrete basis for improving the precision of the biochemical oxygen demand test.

The approach used in the preceding example can be applied to include all major water uses as well as all cost-sensitive parameters associated with these uses. For example, fifteen significant parameters associated with twenty major uses would require 300 such curves. Due to relative insensitivity within commonly encountered ranges of the parameters, many curves probably could be quickly eliminated from consideration⁽²⁹⁾. Research may be fostered to identify more parameters and synergistic effects of greater than one parameter and more curves would be generated. The planning process would normally incorporate these new findings as a matter of course.

The heterogeneous nature of stream quality increases as the industrial development of a basin area increases. Presuming that secondary treatment of existing and future waste discharges is achieved in the near future in Connecticut, the possibility of extremely toxic substances discharging to streams may be unlikely. The principal concern of the future will be the effect of increased treated loadings and non-point sources on stream quality. If it can be assumed that the presence of interacting pollutants is negligible, models should be used to predict the maximum assimilative capacity of streams. Parameters of principal interest will be biochemical oxygen demand-dissolved oxygen relationships, total solids, phosphates, and nitrates.

b. Low-Flow Augmentation

Stream flow augmentation is another alternative in water quality management. Under this concept, additional flow is provided to the stream during

critical low-flow periods to maintain water quality. Conceptually, flow augmentation could be provided to maintain water quality for normal stream flows as an alternative to higher degrees of treatment.

The feasibility of flow augmentation depends critically on the availability of water, particularly during low-flow periods. Water taken from an upstream impoundment for flow augmentation has an opportunity cost. This opportunity cost will vary between basins. This cost may not be easily quantified and is derived from recreational, water supply, and flood control considerations. If opportunity costs are low, the likelihood of providing flow augmentation is enhanced. If the opportunity cost is high, the management approach may recommend conditions for multiple use.

Low-flow augmentation can be achieved presently by re-regulation of existing stream retention structures or in the future by providing for excess capacity in proposed reservoir sites⁽¹⁹⁾.

Flow augmentation has several advantages over treatment for the achievement of water quality control. Additional dilution is provided for reducing the effect of materials discharged from secondary treatment plants and from urban and agricultural runoff. The higher river stages resulting from flow augmentation may be desirable from a recreational and esthetic viewpoint. Finally, the higher velocity achieved tends to retard undesirable growths⁽¹⁹⁾ within the stream. A disadvantage is that flow augmentation benefits are seasonal. This fact must be considered in the analysis.

The technological input to a decision related to the use of flow augmentation may take the form of an analysis of benefits. In general, if downstream benefits (within the augmented flow area) are greater than upstream

benefits foregone (upstream of the impoundment dam), flow augmentation is justified.

c. In-Stream Modification

In some cases, despite the provision of adequate treatment of all point sources, anticipated water quality does not result. Deficiencies take the form of problems such as oxygen depletion and nutrient enrichment. Problems of this nature may be due to the non-point sources such as urban and agricultural runoff, siltation, materials passing through treatment plants resistant to treatment, as well as deficiencies attributable directly to the stream.

In-stream modification may provide an alternative for the attainment of water quality. Examples of in-stream modification are in-stream aeration, control of algal blooms by the addition of copper sulfate, and the establishment of siltation controls.

In-stream modification may be accomplished by surface aerators, diffused air, or post-aeration of the effluent.

The quantity of air that can be taken up by water depends on⁽¹⁹⁾:

- (1.) Efficiency of the transfer device.
- (2.) Temperature of water.
- (3.) Dissolved oxygen deficit of the stream.
- (4.) Concentration of waste materials in the water.
- (5.) The desired dissolved oxygen level of the stream.

The feasibility of aeration is currently an active research area. A study done in New Jersey supported by FWQA found aeration to be feasible⁽³⁹⁾.

Aeration as an alternative pollution abatement measure does not compare favorably with advanced waste treatment or low-flow augmentation in that it

does not reduce other pollutants. Also, the installation of surface aerators would be inconsistent with an esthetically desirable area.

An interesting form of in-stream modification is treatment of the stream under the stream specialization approach. This approach has been used in Germany, through cooperative river basin authorities, called Genossenschaften. The Ruhr district, one of the most heavily industrialized areas of the world, is comprised of several sub-basins which flow to the relatively large Rhine River. The Emscher River basin lies within the Ruhr district and the Emscher River flows directly to the Rhine. The Emscher is used solely for waste disposal purposes with a quality objective of the avoidance of esthetic nuisances. Waste dischargers are required to provide primary treatment and the river is concrete lined. Through the use of plantings and attractive bridge design, attempts are made to provide the stream with a pleasing appearance. Primary treatment of the entire stream flow of 1,000 CFS is provided at the mouth of the stream and an upgrading to secondary treatment is being planned⁽²³⁾. Other streams within the Ruhr district are reserved for water supply and recreation.

d. Relocation of Discharge Points

A discharge point may be relocated if water quality requirements cannot be met by the discharge remaining at that given point. An advantage is that economies of scale may be achieved by the resultant regionalization. Disadvantages are that shock loads may be encountered at the point of combined discharge, and that the withdrawn water has been preempted to downstream uses⁽¹⁹⁾.

e. Flow Equalization

The discharge loadings from some outfalls vary with time. Under this concept, peak loadings are directed to a holding tank where the discharge is

bled out at a uniform rate. Also, wastes may be held during critical low streamflow periods, and released during higher streamflow periods. Lagoons may be excavations, diked areas, or inflatable devices⁽¹⁹⁾.

f. Diversion from Basin

This alternative is similar to "relocation of discharge points" except that the discharge is completely removed from the basin. The impact of the diversion on minimum stream flows must be thoroughly examined before this approach is implemented, as water quality could be jeopardized.

g. Greater Water Reuse

Stream loadings may sometimes be reduced through more water recycling. Increased water and wastewater treatment costs, reflected in higher unit water costs, may induce larger water users to use recycling to a large degree. This may be more efficient for the industry and waste loads may also be reduced. The latter may be the case because, if water is only slightly contaminated in one cycle, it may be more effectively treated after several cycles as the contaminants become more concentrated.

h. Control of Waste Quantities Through Zoning and/or Land Use Changes

This approach is specifically concerned with future quantities of wastewater. If it can be determined that any further expansion of a treatment facility will be undesirable, additional population growth of a density requiring sewer service should be discouraged. Reasons for undesirable expansions may be difficulty in expanding the treatment plant due to site restrictions and/or the inability of the stream to accept any further waste loadings without very expensive treatment measures.

The impact of non-point sources on water quality can be ameliorated through many land use measures such as the provision of vegetation to avoid large quantities of urban runoff, which as been established to be polluttional⁽⁴⁰⁾.

C. Institutional Concepts

Historically, institutions responsible for carrying out water quality control have been referred to as "regulatory agencies." The connotation is that of an agency which gives prescriptions on how to comply with standards and functions as a regulator or prohibitor. In order to implement the economic and engineering concepts set forth in this report, a flexible institutional structure is required whose function is continuous water quality management, not regulation.

As mentioned in the introduction, the concept or planning of water quality management means setting forth a systematic identification and evaluation of alternatives, whereas, the practice is the application of facilities that gets the desired results at the lowest cost^(3,21). To date, regulatory agencies have considered as alternatives variations in one approach - the provision of treatment. A State and federal policy presently exists which specifies that non-treatment alternatives (e.g., flow augmentation) are not acceptable where treatment can be provided. These variations usually include alternate treatment plant locations and occasionally changes in level of treatment, with secondary treatment the minimum requirement in Connecticut.

The responsibilities of water resource agencies on the state and federal levels of government at present are too diffused and their authority too constrained. As a result, regulatory agencies as presently constituted do not

have the ability to implement the technological tools and management techniques which have been put forth in this report.

It is entirely possible to use a purely regulatory approach if few sources of pollution exist, if the cause-effect relationship of streams is fully known, and if economy and equity are of secondary significance. Clearly, this is not the case in Connecticut. Therefore, it is necessary to replace the regulatory enforcement approach with a management approach. The institutional arrangements must be such that a sophisticated assessment of engineering-economic options can be achieved, as well as the unimpeded implementation of the selected alternatives.

It has been indicated that in a private competitive market a firm will continue to produce until the marginal cost exceeds the marginal revenue. This aspect of competitive markets does not necessarily carry over to water resources facilities for many reasons. The sizing and pricing of water quality management facilities (collection systems and treatment, etc.) is determined by institutions. Factors normally considered are population growth, waste projections, engineering design standards, and local aspirations, to name a few⁽²⁶⁾. Even though institutions are not structured toward achieving technically optimum systems as their over-riding goal, it is important that technical optimization not be ignored (Chapter III, Section A).

Local governments cannot be ignored in the water quality management process, as in Connecticut they carry projects from conception to completion, including operation and maintenance, subject to regulation by the State and federal governments. Within this context, it is necessary to understand their behavior.

Although the behavior of local governments is not always predictable, the Environmental Protection Agency has made some preliminary conclusions based on limited research⁽²⁶⁾. This research has indicated that optimal solutions for a water quality management problem may be found, but their implementation may be blocked by political forces. This is manifest in: (1) local governmental agencies constantly attempting to justify their existence and maintain their power, and (2) personal decisions in the process conflicting with the optimum solution.

To illustrate, if a town is presented with a choice of providing its own treatment of wastes or combining with another municipality, the decision will frequently be in favor of the former. Local interests usually prevail. More generally, when maintenance or promotion of political gain conflicts with environmental quality or a least-cost/cost-effectiveness solution to a problem, political power may prevail. Political interests may frequently dictate the continuance of low taxes rather than the construction of a sewage treatment plant. Some of the reasons proposed for suboptimal local decisions are as follows⁽²⁶⁾:

- (1.) political forces
- (2.) rigid health rules
- (3.) arbitrary establishment of user charges
- (4.) influence of industrial management
- (5.) host of organizational and sociological constructs.

If these factors must be considered in a water quality management decision, their cost, in terms of deviation from optimality, should clearly be known.

CONCLUSIONS

(1.) The integrated management approach described provides a method for managing water quality efficiently and effectively.

(2.) Present state and federal standards have been established with little regard given to significant economic-engineering concepts.

(3.) A least-cost analysis of one example of a water quality standard showed that the standard was justified by the analysis. The minimum secondary treatment standard was not justified by the analysis.

(4.) A cost-effectiveness analysis of a water quality standard for the same example showed that the standard was consistent with cost-effectiveness. The minimum secondary treatment standard was not justified by the analysis.

(5.) Decisions relating to water quality which are not made on the basis of the management approach may entail a cost which should be made known, in terms of deviation from optimality.

(6.) Sufficient technological data exist to apply the approach. Present data gaps may be incorporated into the ongoing planning process.

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