

Errata: a revision of pp. 51-54 of the thesis has been attached to the inside front cover page.

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Where MC falls but MD rises, as in graph and chart (c), the perverse case is the one in which the MC curve is steeper than the MD curve. At the intersection the net social product of the firm is at a minimum rather than a maximum. This is likewise the case where both MC and MD decline, a situation which is always perverse. The three single-intersection cases in which an optimum exists, then, are: (1) where both MC and MD rise, (2) where MC rises, MD falls, but the absolute value of the slope of the MC function exceeds that of the MD function, and (3) where MC falls, MD rises, but the absolute value of the slope of the MD function exceeds that of the MC function.

D. THE SHORT-RUN SUPPLY CURVE OF THE OPTIMALLY-REGULATED POLLUTER

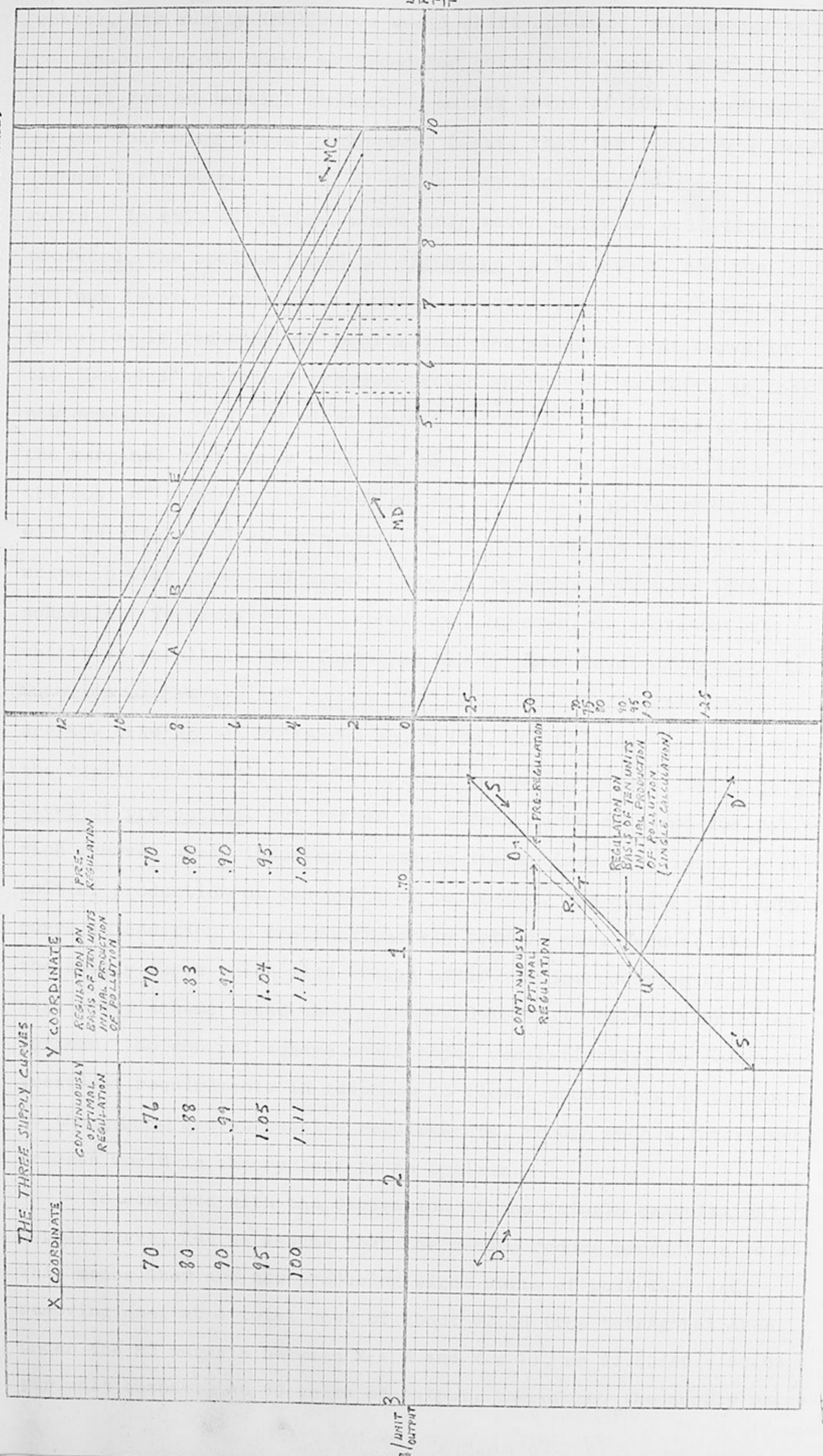
If we assume that marginal pollution removal cost and marginal pollution damage curves rise, we can analyze the tatonnement procedure by which the optimal levels of pollution removal, and product output, are determined. The previous section dealt with the determination of the optimal level of pollution removal, given some output level, associated initial pollution level, and product price. But equilibrium output levels will fall and product price will rise if costs of production rise (assuming that the demand function for the output is not completely inelastic, and is unaffected by the changes in question). So let us return to the "well-behaved" situation depicted in Figure III-4-a, add an output market, and consider the hypothetical data to represent an entire industry facing a declining demand curve for its product. We assume only (1) the fixed technological relationship between output of the good and production of pollution, and (2) rising marginal removal cost and damage curves.

In Figure III-7, Quadrant III depicts the equilibrium in the output market when no pollution removal is undertaken. We have postulated a supply curve of $X = 100Y$ and a demand curve of $X + 50Y = 150$. One hundred units of the good are produced and sold at a price of \$1. Quadrant I shows the optimum level of pollution removal, given that 100 units of the good are produced; seven units pollutant should be discharged, and three removed. The function in Quadrant IV represents the fixed technological relationship between units of output and units pollutant produced.

FIGURE III-7

I MARGINAL EFFLUENT TREATMENT COSTS
AND MARGINAL POLLUTION DAMAGES

2 / UNIT
POLLUTANT



IV FIXED TECHNOLOGICAL RELATIONSHIP BETWEEN
UNITS OUTPUT AND UNITS POLLUTANT PRODUCED

UNITS OUTPUT
TIME

III THE OUTPUT MARKET

If the industry, in equilibrium, were suddenly required to undertake the optimum amount of pollution removal (to remove three units), its supply (MC) curve would shift upwards. We can derive a continuous supply curve adjusted for pollution removal which is optimal for an initial product output level of 100 by reasoning in the following manner. Suppose, first, that the industry's owners reduce their output to 70, at which they incur zero pollution removal costs. In this situation, where only seven units of pollution are produced, the optimum level of discharge is 5.5 units, and the optimum level of removal 1.5 units. That is, when production of pollution is reduced, the position of the marginal cost curve in the "bounded" graphical representation shifts to the left, so that it now commences at 7 and rises upward and to the left. The shift of the marginal cost curve will not be a simple parallel shift, because the cost of removing the first of ten units in a given amount of water will be slightly less than the cost of removing the first of eight units in that amount of water, ceteris paribus, and so on through the schedule. To simplify the exposition, however, we represent the shifts as parallel. The fact that the optimum level of removal is a function of the level of production means that the supply curve we are now drawing, on which the point (70, \$0.70) lies, is still not the supply curve adjusted for optimal pollution removal costs at any level of production, but rather the supply curve adjusted for pollution removal costs incurred to attain the optimum pertaining to an initial production of ten units of pollution. We derive this supply curve in addition to the continuously optimal one, because this is the supply curve which will emerge after the introduction of a regulatory scheme based upon a once-and-for-all calculation of an optimum. No control scheme could hope, realistically, to readjust treatment requirements in response to firms' production adjustments to the initial and successive requirements, though such a tatonnement process would in theory lead to an optimum.

To continue with the derivation of the "single calculation" supply curve, let us assume that the owners reduce production to 80. This means they are now producing eight units of pollutant and removing one, at a total cost of about \$2.50 (the tetragonal area under the MC curve B between $X = 8$ and $X = 7$), or $\$2.50/80 = \0.03 per unit output. At 80 units of output, therefore, the supply price

is \$0.83. If production were at 90 units, the industry would be generating 9 units of pollutant and removing two, at a total cost of about \$6.00, or $\$6.00/90 = \0.07 per unit output. The supply price is therefore \$0.97. At 95 units of output, 2.5 of the 9.5 units pollutant would be removed at a cost of about \$8.13; the supply price would be \$1.04. The intersection of this supply curve with the demand curve (STU and DD', respectively) will occur at a level of output between 95 and 100 units.

Now to derive the supply curve adjusted for optimal pollution removal costs at any level of production. At an output of 70, the optimum level of pollutant discharge is now 5.5, so the industry must remove 1.5 units at a cost of about \$4.13 (the area under MC curve A between $X = 7$ and $X = 5.5$), or \$0.06 per unit output. The first point we derive on this supply curve, then, is (70, \$0.76), which may be compared with (70, \$0.70) on the other. At an output of 80, optimum discharge is 6 units, so 2 units of pollutant must be removed at a cost of \$6.00, or \$0.08 per unit output. The supply price is therefore \$0.88. Similarly, at 90 the supply price is \$0.99, and at 95 the supply price is \$1.05.

The "continuously optimal" supply curve ORU theoretically begins at (0,0) and is at all other points distinct from the other two supply curves, except where it intersects the "single calculation" supply curve STU, at an output of 100 units. The "single calculation" supply curve STU coincides with the "pre-regulation" curve for outputs of 70 and below, but separates for higher outputs, and intersects the "continuously optimal" curve ORU where output is at 100.

The characteristics of the point of intersection between the "continuously optimal" supply curve ORU and the demand curve DD' may be described as optimum conditions.

E. THE OPTIMUM CONDITIONS OF PRODUCTION AND EFFLUENT TREATMENT UNDER COMPETITION

In a 1966 article,⁵ Charles R. Plott derived the optimum conditions of production in the presence of external diseconomies, for the two-firm,

⁵ Charles R. Plott, "Externalities and Corrective Taxes," *Economica*, N.S. Vol. 33, No. 129 (Feb. 1966), 84-87.





OPTIMAL WATER QUALITY
IN THE FRONT RIVER BASIN

by William A. Wright

University College

Oxford

September 1, 1971

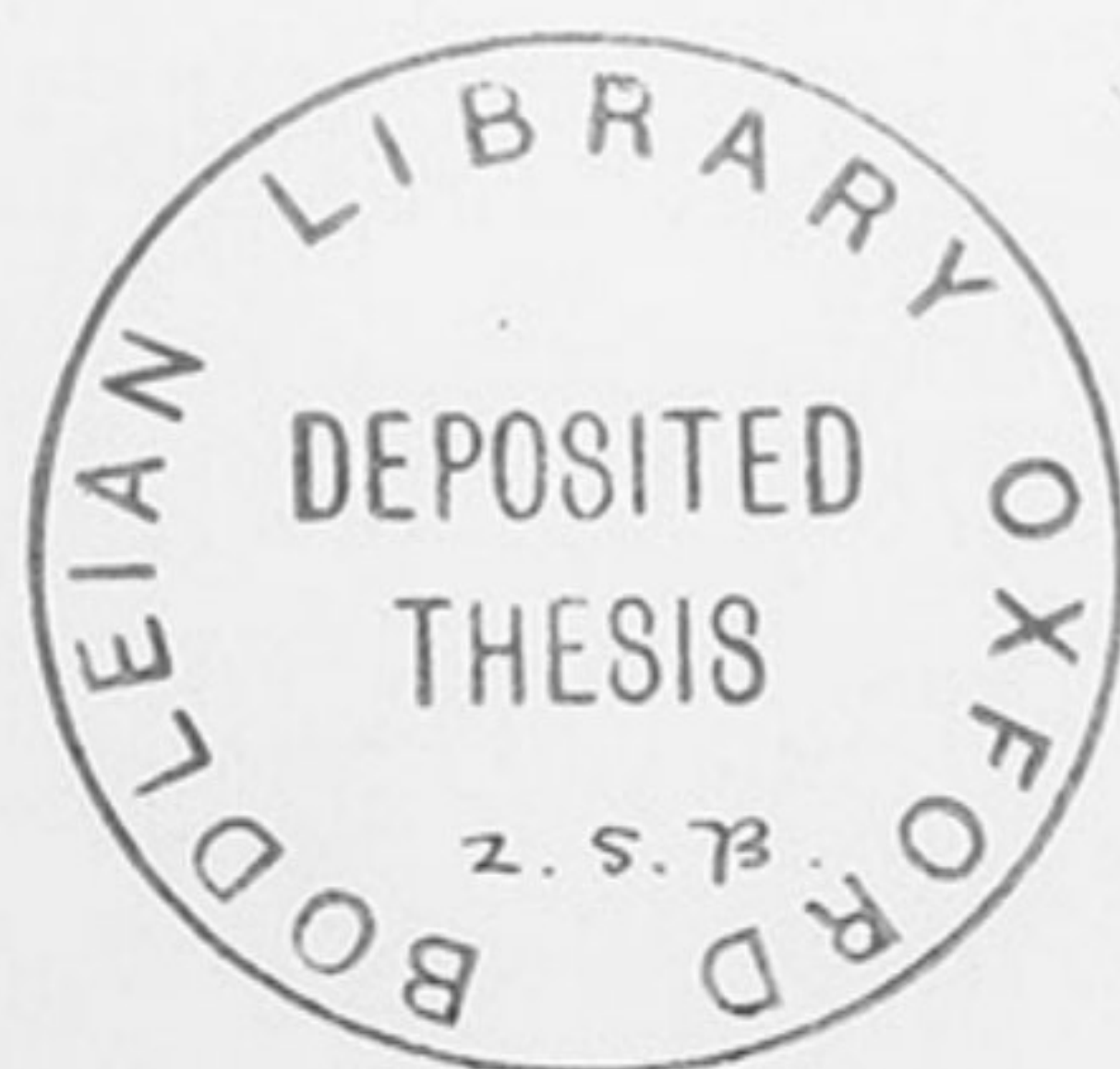


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September 1, 1972 [in 1973] HT



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OPTIMAL WATER QUALITY IN THE TRENT RIVER BASIN

by William A. Wright

ABSTRACT

The thesis examines the theoretical bases for determining optimal pollution levels in the Trent River Basin, demonstrates that neither the organization of a so-called "market in pollution rights" nor the construction of marginal effluent treatment cost and marginal damage functions is a practical means of finding those levels, and proposes ways for using existing data and the Trent Research Programme river model to determine "roughly optimal" pollution levels.

Chapter I describes and criticizes the existing regulatory system in the Trent River Basin. Although water quality has been improving over the past two decades, many costs of the arbitrary, ad hoc system of discharge consents cannot be quantified, nor is it possible to determine whether the present quality of the Trent could have been attained at less cost under a different regulatory scheme. Because both the regulating and regulated institutions, that is, the Trent River Authority and the various local authorities or joint boards thereof, are arms of the government, financed from the same sources, consent terms cannot be enforced effectively, and about two thirds of the outstanding consents are consistently violated. The goals of regulation are to maintain, and, "where possible," to improve the quality of the river, and, although the Trent Research Programme has made impressive strides in cost-benefit analysis, there has as yet been little application of such analysis in setting day-to-day and long-term water quality goals. Therefore, after an initial discussion of programming techniques for attaining arbitrary water quality standards, the thesis addresses itself directly to the question, "What should the water quality goals be?"

One approach to river basin management has been to construct economic models of river basin, based on mathematical representations of the hydrological and biological characteristics of the system, to relate the costs of pollutant removal at any point to the induced physical changes in all downstream river reaches. No such model can derive optimal pollution standards,

but if physical quality goals are provided for various stretches of the river, along with alternative facilities which could be built (each with an associated cost), or alternative charge levels which will induce private construction of treatment facilities, the models can solve either for the least-cost combination of facilities, or for the minimum charges, which will attain the standards. Chapter II discusses in detail two linear programming models (created in the United States) for computing charges. Dynamic programming in the Trent Economic Model is then shown to have several advantages over the linear programming approach, especially with respect to the number of pollutant parameters and treatment alternatives which can be explicitly incorporated, but the disadvantage that it does not suggest an allocation of the costs of optimal facilities among water users.

Chapter III first takes up the question of whether there exists a market mechanism which can determine optimal pollution levels. Objections are raised to a system in which polluters and conservationists bid against each other for a given number of Pollution Rights issued by a River Authority, on the grounds that antipolluters will not bid against each other for Pollution Rights (the free rider problem), nor will they bid against polluters unless it is certain that their successful bids will deprive polluters of an equivalent number of Pollution Rights (the preemption problem). The river authority cannot determine how many Pollution Rights to issue and sell, because antipolluters will not demand any rights at all, unless they first know how many are going to be issued and how many polluters will buy. There can therefore be no centrally-organized market in Pollution Rights.

The next section of Chapter III develops a theory of pollution removal cost and damage curves, under highly restrictive assumptions concerning output of the pollution-based good. These assumptions are then dropped, an output market is introduced into the analysis, and a general short-run model of the polluting firm is presented. First-order optimum conditions, under competitive conditions, are derived, following Charles R. Plott's initial work. A discussion of J. M. Buchanan's point that pollution taxes may reduce social welfare, if there is monopoly in the polluting industry, follows. Differences in the long-run effects of different regulatory schemes are then explained. A model analyzing the optimization problem in a two-basin context is presented, and the chapter concludes with a discussion of the demonstration by W. J. Baumol and D. F. Bradford that sufficiently strong external diseconomies must cause

a non-convexity in the social production set.

Chapter III thus discusses four conditions under which the derivation of marginal pollution removal cost and marginal damage curves will not reveal optimal pollution levels or optimal charges. Chapter IV compounds the skepticism with which such an exercise would have to be viewed by examining the scanty existing data which relates to removal costs and damages. Costs of effluent treatment at discharge points are compared with costs of water treatment at intake point. Various types of Trent Research Programme cost data are presented to show that since (1) the average Trent river flow dilutes the average effluent discharge by an overwhelming factor, and in addition breaks down a portion of the biodegradable pollutants, and (2) the average water abstraction for purposes of drinking or industrial use amounts to an insignificant proportion of average flow, the marginal cost of effluent treatment at individual outfalls will generally exceed the resultant marginal reduction in damages to municipal water plants. The average abstractor must remove from his intake only a tiny fraction of any unit of pollutant discharged. The conclusion is that pollution control efforts must be justified on grounds of reduced damages to users of the river in situ rather than to downstream municipal and industrial water abstractors.

The basic problem with the consumer's surplus method of constructing marginal damage curves is how to introduce a pollution-variability factor into the Clawson technique for estimating the demand curve for a recreational facility. Four possible ways of solving the problem are analyzed, but only one bears any promise of producing useful results. The chances of deriving marginal cost and damage functions which will be both accurate enough to satisfy the demands of economic theory and plausible enough actually to form the basis of a river quality management policy are thus very slim indeed for the foreseeable future.

Chapter V, therefore, develops a practical economic framework within which water quality goals can be chosen. Proposals are made for using Trent Research Programme data, and in particular the river model, to determine quality goals. Charging schemes are then considered in the context of the Trent Basin as devices for attaining whatever quality goals are chosen. The chapter ends with three recommendations:

- (1) Systematic cost-benefit analysis should be applied to specific improvement proposals for specific reaches. In particular, the costs for the

improvement, as calculated by the river model, should be compared with two estimates of incremental recreational benefits, one the fishing benefits estimate according to the Gibson-Anderson consumer's surplus approach, the other a rougher estimate based on additional "recreational activity days" which will be permitted or induced by the improvement.

(2) Government policy toward water quality improvement in the Basin, which seems at present to be based on a philosophy that the more money spent on effluent treatment the better, should take a more analytical approach to the costs and benefits of its programs.

(3) The current regulatory system in the Basin, involving discharge consent quotas, pretreatment requirements, and charges, should be gradually converted to a system relying much more heavily on charges to constrain pollution levels in the Basin. The latter system would both be more efficient in attaining whatever quality goals are set, and fairer than the ad hoc, unsystematic application of quotas and pretreatment requirements.

OPTIMAL WATER QUALITY IN THE TRENT RIVER BASIN

CHAPTER I

POLLUTION IN THE TRENT RIVER SYSTEM

A. THE EXISTING SYSTEM OF WATER RESOURCES CONTROL¹

The River Trent flows for 171 miles through the Midlands. Its tributaries bring the total length of the river system to 905 miles. Thirty-nine miles from the source of the Trent is its confluence with the River Tame, which drains the Birmingham area, and introduces the greatest single load of pollutants into the Trent. Thus choked while yet a stream, the Trent struggles to Nottingham, where its mean annual flow in 1968-69 was about 1600 million gallons per day (mgd), and dry weather flow (exceeded 95% of the time) 650 mgd. Its waters are alternately augmented by effluent discharges and tributary flows, each bearing loads of organic and chemical matter in greater or lesser concentrations than those present in the main body at the confluence. Eventually the Trent joins the River Ouse for the final journey to the North Sea.

The Trent waste carriage system included, in 1970-1971:

- (1) 646 industrial plants each making a direct discharge of more than 1500 gallons per day (gpd) of process water, for a total of about 70 mgd, the size of the discharges ranging from 1500 gpd to 4,500,000 gpd.
- (2) 101 local authorities operating 605 sewage treatment plants with a total dry weather flow of 337 mgd of sewage. About 20-30% of the volume of sewage treated represents industrial discharges into municipal sewer systems. The sewage works may be classified by size:

a. Large (over a million gpd)	53
b. Medium (100,000 - 1 million gpd)	136
c. Small (10,000 - 100,000 gpd)	229
d. Minor (1,500 - 10,000 gpd)	187
- (3) 89 private sewage works, mostly rural, with negligible discharges.
- (4) many types of pollutants, among them biological oxygen demand (BOD),

¹ Much of the information in this section is taken from the Trent River Authority's Annual Reports for the years ended 31st March, 1969, 1970, and 1971.

suspended solids, ammoniacal nitrogen, oxidised nitrogen, chlorides, and heavy metals. Records of the concentrations of most of these substances at about 200 sampling points in the river system are available for the past twenty years, except for certain metals, which have been monitored only since 1970.

(5) a river basin authority with full regulatory powers.

The Trent River Authority, under the general jurisdiction of the Department of the Environment, is charged by the Water Resources Act 1963, Section 4, to

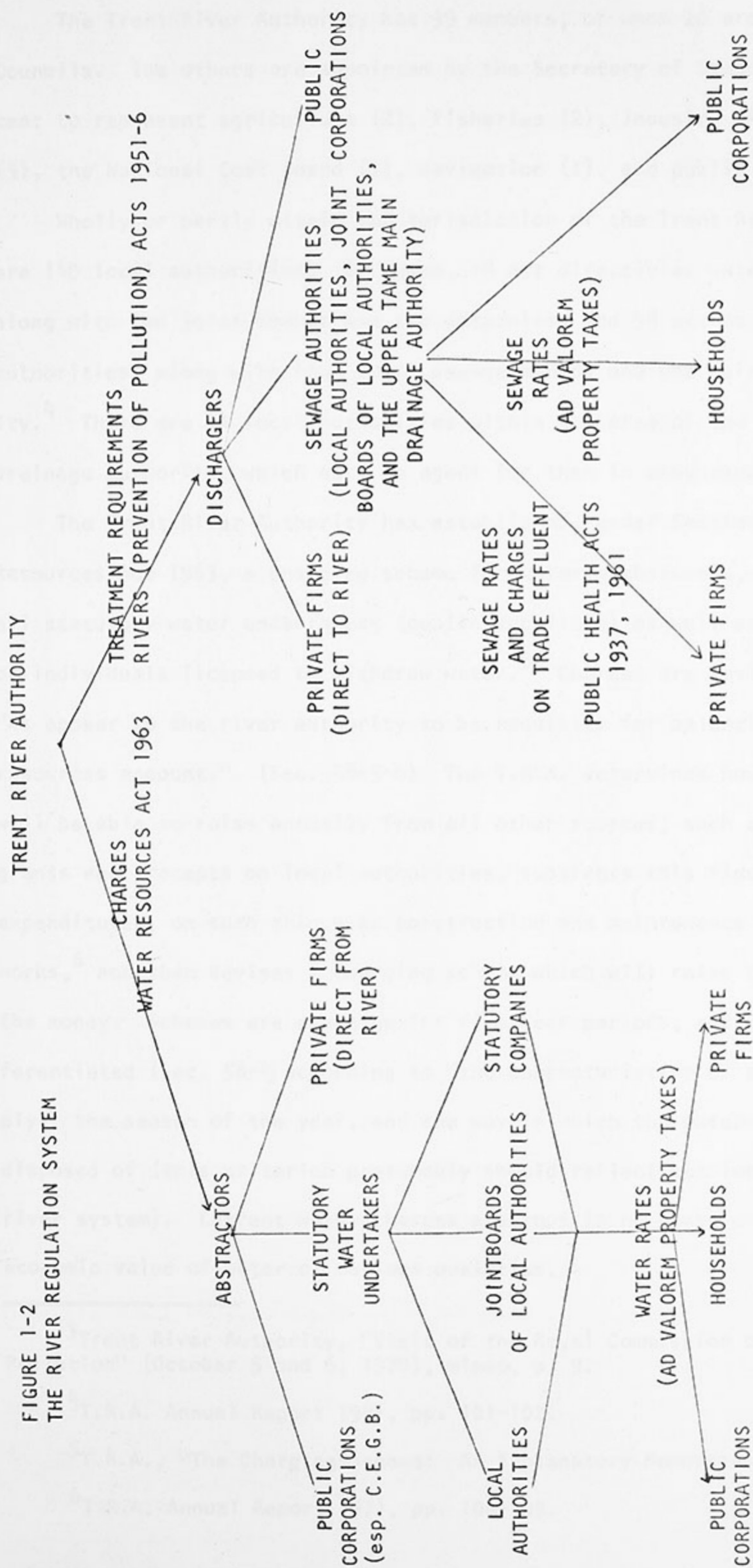
take all such action as they may from time to time consider necessary or expedient, or as they may be directed to take by virtue of this Act, for the purpose of conserving, redistributing, or otherwise augmenting water resources in their area, of securing the proper use of water resources in their area, or of transferring any such resources to the area of another river authority.

The Authority and its predecessor, the Trent River Board, have been working since 1948 to lessen the pollution load in the Trent. Steady and substantial improvement has occurred. Appendix Figure A summarizes the concentrations of various substances at two points in the river, Trent Bridge (Nottingham) and the Colwick testing station, over the past several years.

There are three types of organizations in England and Wales with executive functions affecting water management: statutory water undertakers, of which there are 198, sewerage and sewage disposal authorities (more than 1,300), and river authorities (29). Statutory water undertakers treat and supply 2898 million gallons per day of water for domestic and industrial use. Of this total local authorities supply 763 mgd, joint boards of local authorities 1499 mgd, and statutory companies 636 mgd (1969 figures). Many local authorities and joint boards thereof also act as sewage disposal authorities, operating more than 5,000 works, and serving population groups numbering from fewer than a thousand to 7.7 million.² The river authorities exercise some measure of control over both statutory water undertakers, who must obtain permission for any new abstractions and pay charges for all withdrawals of water, and sewage authorities, whose plants must be issued consents governing the quantity and quality of sewage effluents discharged to the river system. The 1963 Water Resources Act gives authorities general responsibility for water conservation, to which end they prepare hydrometric schemes and water demand forecasts, monitor underground water resources, license abstractions from surface waters, and construct

²Central Advisory Water Committee, The Future Management of Water in England and Wales, London: Her Majesty's Stationery Office, 1971, pp. 5, 7, 13.

FIGURE 1-2
THE RIVER REGULATION SYSTEM



and operate major conservation works. They are also responsible for land drainage, sea defense, pollution control, fisheries, and navigation and recreation.

The Trent River Authority has 39 members, of whom 20 are elected by County Councils. The others are appointed by the Secretary of State for the Environment to represent agriculture (2), fisheries (2), industry (4), land drainage (5), the National Coal Board (1), navigation (1), and public water supply (4).³

Wholly or partly within the jurisdiction of the Trent River Authority are 140 local authorities. Of these, 18 act directly as water undertakers, along with two joint boards and two companies, and 98 act as sewage disposal authorities, along with four joint sewage boards and one main drainage authority.⁴ There are 14 local authorities within the area of the Upper Tame Main Drainage Authority, which acts as agent for them in many regulatory matters.

The Trent River Authority has established, under Section 58 of the Water Resources Act 1963, a charging scheme for water withdrawals, which applies to all statutory water undertakers (public suppliers) as well as any other firms or individuals licensed to withdraw water.⁵ Charges are levied at such rates "as appear to the river authority to be requisite for balancing their water resources account." (Sec. 58-5-b) The T.R.A. determines how much money it will be able to raise annually from all other sources, such as government grants and precepts on local authorities, subtracts this figure from estimated expenditures, on such things as construction and maintenance of hydrometric works,⁶ and then devises a charging scheme which will raise the balance of the money. Schemes are drawn up for five-year periods, and charges are differentiated (Sec. 58-4) according to "the characteristics of the source of supply," the season of the year, and the way in which the water is to be used and disposed of (this criterion presumably should reflect net loss of water to the river system). Current water charges are thus in no sense a measure of the economic value of water of various qualities.

³Trent River Authority, "Visit of the Royal Commission on Environmental Pollution" (October 5 and 6, 1970), mimeo, p. 9.

⁴T.R.A. Annual Report 1971, pp. 101-102.

⁵T.R.A., "The Charging Scheme: An Explanatory Memorandum."

⁶T.R.A. Annual Report 1971, pp. 104-105.

Statutory water undertakers obtain payment from users through the water rates. Metered water is rare; charges vary over England as a whole, from 10p to 25p per thousand gallons where metering exists.⁷

The current pollution regulation system in the Trent River Basin relies on consent quotas, pretreatment requirements, and charges to constrain pollutant discharges. The Trent River Authority controls direct discharges to the river by both industries and municipal sewage plants, by means of consent quotas and pretreatment requirements only; it does not levy effluent charges. Local authorities, and in particular the Upper Tame Main Drainage Authority as legal agent for several constituent local authorities, control discharges to municipal sewers by means of effluent charges as well as consent quotas and pretreatment requirements. Charges thus do not apply to all polluters throughout the basin, nor are they uniform for all polluters in the basin to whom they do apply. The charging scheme of the U.T.M.D.A., however, applies to all the constituent local authorities for which it acts as agent in the control of trade discharges, and serves as a model for the City of Birmingham charging scheme.

The U.T.M.D.A. scheme is based on average costs for the 50 treatment works under its jurisdiction, though plant sizes vary from facilities for 50 people to facilities for 1,500,000 people. Charges are not differentiated according to the efficiency of the particular sewage treatment plant to which the firm must discharge its wastes. Charges are designed to cover the full cost of industrial waste treatment by the municipal plant. The basic cost per unit effluent is calculated by dividing total annual costs of all sewage plants in the U.T.M.D.A. area by total annual sewage flows through those plants. Certain portions of the basic cost are attributed to volume, oxidation, and sludge removal. The strength of any individual industrial waste is compared to that of settled household sewage, with respect to oxidation and sludge removal requirements, and the appropriate modifications of the basic cost are made, including additions for removal of metallic wastes. The bases for charging, classification of wastes, actual charging schemes for 1970-1971 and 1971-1972, and the detailed "Control of Trade Effluents: Progress Report for 1969-71," by Dr. N. Harkness, Chemist for the U.T.M.D.A., are all attached to the Appendix.

⁷C.A.W.C., Future Management, p. 10.

An individual firm in the Trent River Authority area may thus either be paying local authorities to treat its wastes to the T.R.A.-imposed 20:30:20 standards for discharges to the river (perhaps after pretreatment), or treating its own wastes to T.R.A. standards. The figures refer to milligrams per litre of BOD, suspended solids, and ammonia, respectively, and are called "Royal Commission standards." This is because a Royal Commission in 1912 proposed that if these effluent standards were maintained, most streams would not give rise to a nuisance, for they would provide at least an 8:1 ratio of stream to effluent volume. The resultant maximum stream concentration of 4 mg/l BOD was thought to represent "fairly clean" water capable of supporting fish life. Of course, since 1912 effluent volumes have increased enormously relative to streamflows. For example, 80% of the volume of the River Tame in summer consists of sewage effluent. But nearly all sewage plants built since that time have been designed to produce 20:30:20 effluent, regardless of the size and quality of the river to which they discharge. The Royal Commission stream standards have fallen victim to the institutionalization of the effluent standards which were associated with them in 1912. This is why, in February, 1971, the Pollution Control and Fisheries Officer of the T.R.A. felt compelled to submit to the Authority a paper entitled, "The Need for Higher than Royal Commission Standards for Sewage Effluents Discharged to the Upper Tame."⁸

Partly because a majority of the members of the Trent River Authority represent local governments, and partly because it seems futile for one government body to prosecute another, the Authority finds it difficult to enforce the terms of its consents to municipal sewage plants. The average 1970 effluent quality, under dry weather conditions, for discharges to the River Tame was:⁹

BOD	32 mg/l
Suspended solids	48 mg/l

Violations of trade effluent consents are almost as common as violations of municipal consents; however, private firms are more susceptible to pressure from the River Authority.

⁸W. F. Lester, "The Need for Higher than Royal Commission Standards for Sewage Effluents Discharged to the Upper Tame," T.R.A. mimeo, February 1971.

⁹W. F. Lester et al., "The Effect and Cost of River Purification Lakes," in Institute of Water Pollution Control, The Trent Research Programme: Proceedings of Symposium (15-16 April, 1971), Table 3, p. 75.

FIGURE 1-3¹⁰

<u>Local authority treatment works</u>	<u>1970-71</u>	<u>1969-70</u>	<u>1968-69</u>
Satisfactory	270	270	203
Unsatisfactory	365	373	437
<u>Private treatment works</u>			
Satisfactory	36	42	55
Unsatisfactory	53	55	68
<u>Trade effluents</u>			
Satisfactory	294	283	249
Unsatisfactory	352	328	373

B. THE LEGAL STATUS OF DISCHARGERS AND THE RIVER AUTHORITY

The U.T.M.D.A. is in quite a different legal position from other drainage boards in the T.R.A. area and elsewhere. The 1937 Public Health Act gave regulatory authority to local authorities, and to their drainage boards formed thereafter. But the U.T.M.D.A., having been formed in 1877, has no regulatory powers under the 1937 Act. It is, in the terms of the Act, an "interested body" which must be consulted on all drainage issues. The U.T.M.D.A. thus has a de facto, if not de jure, veto power on all regulatory matters. There are 14 local authorities in its area, among them the City of Birmingham, which has an effluent control department which coordinates with the U.T.M.D.A. The Birmingham Corporation has in fact adopted the general control scheme of the U.T.M.D.A. U.T.M.D.A. consents for trade effluent discharges to the public sewers total about 40 mgd, 28 mgd for Birmingham alone. Average emissions are roughly 22 mgd in Birmingham, 12 mgd elsewhere. Any discharger in Birmingham must apply to both the U.T.M.D.A. and the Birmingham Corporation for a consent. This added level of paperwork and coordination could be eliminated if the Authority itself were given direct regulatory powers.¹¹

A local authority has a legal obligation to accept domestic sewage in the public sewers (Sec. 34, Public Health Act 1936). Local authorities in fact generally require that householders dispose to the public sewers, at least for new buildings. Although the authorities have no statutory obligation to accept any given industrial effluent, the policy of the T.R.A. to divert direct industrial discharges to the public sewers in effect pressures local authorities to accept any effluent, subject to whatever pretreatment

¹⁰ T.R.A. Annual Report 1969, p. 57, and 1971, p. 58.

¹¹ Interview with Dr. N. Harkness, Chief Chemist, U.T.M.D.A., 10 March 1971.

requirements they wish to impose. Local sewage plants are required to meet the consent standards issued to them by the river authorities (Rivers Acts 1951-61). But while local authorities derive the bulk of their income from the rates, they depend upon the government for grants and loan sanctions for capital expansion of sewage treatment facilities, though exchequer grants bear no necessary relation to expenditures on sewage disposal.¹² Lags in financing such expansion to keep pace with growing effluent volumes are one of the reasons for the poor record of municipal sewage plants in the T.R.A. area in meeting consent standards -- only 203 of 640 municipal discharges (32%) in 1968-69 met consent standards, while 42.5% met the standards in 1970-71. Although the substandard discharges are illegal, the T.R.A. is in no practical position to institute proceedings under Section 2 of the Rivers Act 1951 against most of the local authorities in its area and have fines imposed on them. (No such fine has ever been imposed.) It is quite apparent to all parties that there are no effective legal or economic incentives for local authorities to improve sewage effluents. To close down a local authority sewage plant is thought quite out of the question: what would be done with the sewage it treats (however badly)?¹³

Plenary regulatory power on paper thus does not mean automatically that the T.R.A. can obtain the water quality it desires. Its statutory role as administrative enforcer is hindered by the overwhelming number of consent violations, the lack of incentives for municipal sewage plant managers to fulfil the terms of their consents, and the Authority's unwillingness to engage in futile prosecutions of other public bodies.

Private dischargers are somewhat more susceptible to control -- though only 249 of 622 discharges (40%) were found to be within the terms of the relevant consents in 1968-69, and 46% in 1970-71. The T.R.A. does not wish to put anyone out of business, but the fact that the Authority has the ultimate power to shut down a plant through legal action, subject to appeal to the Secretary of State for the Environment, puts teeth into its demands. Filing of notices that legal proceedings are under consideration is the first formal step taken if discussions with a violator do not result in the improvement of his effluent. If there is still no response, suit is brought -- almost always successfully -- and fines are imposed. Since fines are generally small,

¹²C.A.W.C., Future Management, p. 16.

¹³Interview with Mr. G. M. Woodward, Principal Scientific Officer, T.R.A., 8 January 1971.

some violators find it cheaper to continue their discharges and pay occasional fines, than to improve the effluent. Penalties under the Rivers Act of 1951, whose Section 2 outlaws the discharge of "any poisonous, noxious, or polluting matter," are a maximum £200 fine for first conviction under indictment, and for repeat offenders under indictment, £500 or £50 per day or six months' imprisonment for managers or directors proven guilty of intent. Because monitoring of discharges (by random inspection) is by no means perfect, the T.R.A. is reluctant to engage in wholesale legal proceedings to an extent that would antagonize the majority of dischargers and induce more deliberate evasion. Although it is quite likely that most violations currently occur not because of any intentional act, but simply a lack of continuous plant supervision to ensure proper disposal of wastes, intentional illegal discharges would increase, it is thought, if the Authority were seen to rely more heavily on legal compulsion than on persuasion. Thus private dischargers who violate their consents, whose only legal recourse, on paper, would be an argument before the Secretary of State under Section 6 of the Rivers Act 1961, to the effect that the terms of its consents are arbitrary and unfair, are not as susceptible to control by the T.R.A. as the Rivers Acts 1951-61 intended.¹⁴

Those industrial dischargers who abide by the terms of their consents have certain safeguards of their rights to discharge effluent. They are not subject to prosecution under Section 2(a) of the Rivers Act 1951 (above), or to suit for nuisance, defined in the Public Health Act of 1936, Section 92, Part III as "any dust or effluvia caused by any trade, business, manufacture, or process and being prejudicial to the health of, or a nuisance to, the inhabitants of the neighborhood." A consent cannot be modified for two years after its issue (Section 5, Rivers Act 1961). But thereafter the T.R.A. has power to review and to modify the consent. Appeal to the Secretary of State for the Environment is allowed.

An industrial discharger to the municipal sewers is subject to whatever terms and conditions the local authority imposes, by virtue of powers under the Public Health Acts of 1937 and 1961. The local authority has no more legal obligation to accept trade effluents in its sewers than the T.R.A. has to accept direct discharges, but applications are rarely turned down outright. Costly pretreatment requirements are often imposed. Local sewage authorities

¹⁴Mr. Woodward, 8 January 1971.

are granted specific powers to impose effluent charges by Section 55 of the Public Health Act of 1961. There is no such specific grant of powers to the river authorities in the Rivers Acts 1951-61.

C. CRITICISMS OF THE PRESENT SYSTEM

Two recent government reports have strongly criticized existing institutions in Great Britain for managing water resources. The reports are Taken for Granted: Report of the Working Party on Sewage Disposal (1970), and the Central Advisory Water Committee's The Future Management of Water in England and Wales (1971).

(1) Both reports review the traditional separation of decision-making on water supply and sewage disposal issues, and argue that the interrelationships now require coordination if not unified management. Many members of the C.A.W.C. favor the creation of about ten multi-purpose River Water Authorities for England and Wales, with functions of water supply, sewage disposal, river management, and future planning. A River Water Authority would "act as a public utility, providing or disposing of water and making economic charges for doing so."¹⁵

(2) Both reports argue for a drastic reduction in the number of sewage authorities, and the C.A.W.C. would cut severely the number of statutory water undertakings and river authorities as well,¹⁶ to the end of internalizing some of the externalities which arise from the fact that the residents of existing sewage districts do not bear the costs and reap the benefits solely of their own disposal arrangements. The Working Party believes that larger sewage authorities would be able to attract more qualified personnel.¹⁷ The C.A.W.C. considers another major objective of consolidation into larger bodies to be the spreading of the costs of sewage, effluent, and water treatment. Average costs of treating given units of effluent to given standards vary widely according to plant size and age of facilities, while per capita sewerage costs of course vary with population dispersion.¹⁸

¹⁵C.A.W.C., Future Management, p. 48.

¹⁶Taken for Granted: Report of the Working Party on Sewage Disposal (1970), p. 50; and C.A.W.C., Future Management, pp. 35-36.

¹⁷Taken for Granted, p. 50.

¹⁸C.A.W.C., Future Management, p. 57.

(3) Financial arrangements come under heavy attack in both reports.

The Working Party states: "There is no rational system of allocating costs between the dischargers and users of river water."¹⁹ The basis for this complaint is that neither municipal sewage plants nor direct industrial dischargers pay effluent charges to river authorities, in the way that both public and private abstractors do. It should be remembered, however, that river authorities can and do impose costly pretreatment requirements upon direct industrial dischargers, that industrial firms who discharge to municipal sewers generally pay charges to local authorities, and that both householders and industries pay sewage rates. Both dischargers and "users" (abstractors) thus pay shares of the costs of keeping river water at its present quality level. But the system of cost-sharing has evolved haphazardly and in response to quite different considerations and pressures than economic optimization.

It is noteworthy that the C.A.W.C. believes that effluent charges should be imposed generally.²⁰

(4) The Working Party recommends that Crown properties, which are presently exempt from effluent control, be subjected to trade effluent laws.²¹ Local authority properties other than sewage works, though not legally exempt from controls as Crown properties are, present the same regulation problems to the Trent River Authority as municipal sewage works: the Authority has little enforcement power.

The basic criticism of the existing system, however, is simply that the regulation has made little or no reference to economic criteria. No one knows what river quality should be, or why, or whether current quality could have been attained more cheaply, or better quality at equal cost. No attempt was made, prior to the establishment of the Trent Research Programme, to determine what value the people of the basin placed on improved water quality, or to evaluate the different costs and benefits of different control methods, or to justify, on economic grounds, government action in the field of pollution control in the first place.

¹⁹Taken for Granted, p. 50.

²⁰C.A.W.C., Future Management, pp. 50-51.

²¹Taken for Granted, p. 52.

D. GOVERNMENT PROPOSALS FOR CHANGE

On December 2, 1971, the Department of the Environment published Circular 92/71, entitled, "Reorganisation of Water and Sewage Services: Government Proposals and Arrangements for Consultation."²² The circular deals basically with institutional changes, and does not evince an analytical view of the economic problems of setting water quality goals and choosing means of attaining those goals. The government has adopted the principal recommendation of the Central Advisory Water Committee, for the creation of ten multi-purpose Regional Water Authorities. The new authorities, to come into being on April 1, 1974, will have combined responsibilities for water supply, sewage disposal, and future planning. It is proposed that the Trent and Severn basins be united under one authority, one reason being that the water supply of Birmingham, over 200 mgd, is abstracted from the Severn and discharged to the Trent system. Specific financial arrangements have not yet been proposed, but "the Government agrees in principle that, apart from Exchequer grants for specific purposes, the revenues to enable the new authorities to discharge their main functions should come from charges for the services they provide. ... It is intended that there should be statutory safeguards to ensure that the costs of a Regional Water Authority's operations are distributed equitably between different categories of water user." (paragraphs 35, 39)

E. THE GOALS OF THE TRENT RIVER AUTHORITY

In June, 1968, the Trent River Authority published a "Preliminary study of the resources, demands, and future development of water supplies"²³ in its area. The study implicitly assumed that charges for water would remain at nominal levels, and concluded that the Trent itself would have to be tapped as a potable water supply by the early seventies, to make up the projected residual quantities demanded after the River Dove and Derwent, and ground water resources, had provided their "maximum yield." The Pollution Control branch of the Authority is therefore trying to bring the waters of the Trent to a degree of cleanliness which will permit their treatment to potable

²²Department of the Environment, Circular 92/71, Her Majesty's Stationery Office, 2 December 1971.

²³Trent River Authority, Water Resources Preliminary Study, June 1968.

standards within this decade. Since it is technically possible to treat almost any quality of water to potable standards, at a price,²⁴ this goal is so flexible that it is no goal at all. The working objective of most river authorities is "improvement," and each new Regional Water Authority "will be under a specific statutory obligation to maintain, and where possible improve, the quality of the rivers and canals in its area." (D.O.E. Circular 92/71, paragraph 26) The Trent Research Programme (1969-1972), sponsored by a government grant, has introduced concepts of "optimal quality" into policy-making circles, but the goals of pollution control efforts have not yet been stated systematically.

If the Trent River Authority were to adopt a goal of "optimal water quality," could it find and achieve it?

²⁴The Local Government Operational Research Unit, in its report "Trent Economic Model," December 1970, says of bunter recharge, a water treatment method using naturally-occurring sandstone layers as filters: "...for all practical purposes at the present time, provided the equivalent of a W.T.1 plant is installed at the recharge site, all foreseeable river water qualities can be treated by this method to potable standard." (p. 45) Many rivers in the United States of considerable worse quality than the Trent, including the Delaware, are currently being used as sources for public water supplies.

CHAPTER II

THE USE OF RIVER BASIN MODELS TO ATTAIN ARBITRARY QUALITY STANDARDS

In dealing with water pollution, the state may attempt both (1) to determine optimal pollution levels, and (2) to devise a regulatory scheme which will produce those levels. Most current pollution control programs in Great Britain and the United States ignore the first problem. They are generally based on arbitrary quota schemes, with judgments as to what overall river quality in any particular stretch ought to be left to the basin authorities. In recent years much research has been devoted to the construction of mathematical representations of river systems, and several computer-based river models have been used to reveal how to meet any given set of water quality standards at least total cost to the society of the basin. The existing computer-based river models, whether they attempt to compute optimal charges or not, solve constrained maximization problems in which the constraints are exogenously-determined water quality standards. This procedure, of course, does not find optimum pollution levels; the marginal damages of pollution are not compared with the marginal costs of pollution removal. But a prior discussion of these techniques will facilitate analysis of potential methods for determining optimal water quality standards.

A. LINEAR PROGRAMMING MODELS

Two well-developed linear programming models are those of the Delaware and Miami (Ohio) river basins in the United States. The Delaware Estuary Comprehensive Study¹ includes a comparison of alternative charging schemes according to the total costs of the effluent treatment they will induce at individual outfalls, to attain alternative prescribed quality standards

¹Delaware Estuary Comprehensive Study, Preliminary Report and Findings, Philadelphia: Federal Water Pollution Control Administration, July 1966.

Edwin L. Johnson, "A Study in the Economics of Water Quality Management," Water Resources Research, Vol. 3, No. 2 (2nd Qtr. 1967), 291-305.

(dissolved oxygen levels) in different reaches of the river.² These schemes are a single effluent charge (SECH) per unit of pollutant, standardized throughout the basin; a zoned effluent charge (ZECH), standardized within each of several zones, the charges being generally higher in zones where water quality is poorer; and the least cost system (LC), which minimizes the total costs of attaining the given standards. The latter is not really a charging scheme in the sense of SECH or ZECH, for it prescribes a different charge per unit pollutant for each polluter. The charge is simply the product of the appropriate dual evaluator, or "shadow price," associated with the optimum solution, and a physical constant relating BOD removals in any reach to increased DO levels in any other reach. These are the only charges for which Jerome Hass solves in his model of the Miami River Basin,³ which is an extension of the work of several earlier researchers.

A SECH is the least costly method of attaining those standards which its imposition produces. This is because each firm and municipal sewage plant will adjust its discharges until the marginal cost of further reductions equals the charge. But for some arbitrary set of standards, the least cost system will be SECH only if polluters' responses to the charge just meet, but do not overreach, each quality goal in each reach. SECH will generally induce overfulfillment of goals in some reaches in order to fulfill goals in other reaches. ZECH will be more efficient (abstracting from costs of administration) because a uniform charge applies within zonal subdivisions rather than over the whole system. There will be fewer reaches, each with its own quality goal, within a zone than in the whole river system, so the expected degree of overfulfillment of quality goals in some reaches in order to meet goals in critical reaches is smaller than under a SECH system.

The LC system, still more efficient than ZECH, takes explicit account of both (1) marginal treatment cost functions, and (2) location, the latter to a greater degree than ZECH. Individual polluters with relatively small marginal effluent treatment costs are presented with tax bills (charges) which will cause them to reduce their pollution in such a way that quality goals in each

² Another regulatory method investigated is a uniform treatment requirement, that each polluter remove a given percentage of his current waste loads.

³ Jerome E. Hass, "Optimal Taxing for the Abatement of Water Pollution," Water Resources Research, Vol. 6, No. 2 (April, 1970), 353-365.

reach are just met. LC in effect substitutes the use of the assimilative capacity of the river in non-critical reaches, for the extra treatment which SECH would require to meet the same set of goals. But whereas every polluter would have to pay the SECH, the LC system may not impose any burden upon those polluters with high marginal treatment costs, even if they are heavy polluters, if they are located, for example, downstream of reaches with high DO goals, or sufficiently far upstream that the river can reaerate itself before the pollution load causes damage.

If we abstract from administrative and information costs, the total cost for attaining a given goal vector is smallest for LC, next smallest for ZECH, and highest for SECH. The Delaware Study estimates the relative magnitudes of these total costs, for several goal vectors. The total cost for SECH is always considerably lower than the total cost for a fourth, non-charge, regulatory variant, the imposition of a requirement that all polluters reduce their current discharges by a uniform percentage.

TABLE 1. Typical Economic Costs of Treatment To Achieve Specified DO Goals

Cost of Treatment*				
DO	UT	SECH	ZECH	LC
2	5.0	2.4	2.4	1.6
2-3	8.4	7.7	6.3	5.8
3	11.2	7.7	7.4	6.9
3-4	20.0	12.0	8.6	7.0
4	23.0	23.0	23.0	16.0

*Cost in $\$10^6$ per year for treatment.

Source: Edwin L. Johnson, "A Study in the Economics of Water Quality Management," Water Resources Research, Vol. 3, No. 2 (2nd Qtr. 1967), p. 297.

Figure 11-1 is a simplified version of the Delaware Estuary model, for three reaches only. The objective function of the primal problem is the total cost of attaining the quality standards for dissolved oxygen in each reach, m_1 , m_2 , and m_3 . The constraints require that the amount of dissolved oxygen in any reach be greater than or equal to the amount necessary to bring the waters to the prescribed standard. The matrix of a_{ij} represent the pounds of oxygen "saved" in reach j by the removal of a unit of BOD at waste source i . They are derived with the Streeter-Phelps equation, which describes the effect of the decomposition of a unit of BOD on the dissolved

oxygen deficit (difference between current and saturation levels of dissolved oxygen), as a function of time in the stream.⁴ Saturation levels are a function of several physical variables, for example temperature. Data on rate of flow are used to convert the time function to a geographical function. The a_{ij} are thus not actually constants, but are assumed to be so for the programming problem. This assumption could be even more realistic if the method were applied to non-degradable (conservative) pollutants; but the application of linear models has thus far been restricted to one pollutant, BOD. The f_i are the additional pounds of BOD removed at source i . Thus the product $a_{ij}f_i$ represents "pounds of oxygen saved" (in reach j , by waste removals at i); the sum of these products must be greater than the minimum additional pounds of oxygen required to attain the standard.

The LC model simply solves this program subject to the basic constraints, to determine the optimal vector of f_i . The SECH and ZECH models make BOD removals (the f_i), functions of the charge p . Another set of relationships must be established from treatment cost, federal and local tax, and profit data to show the responses of each discharger to the nominal charge. The nominal charge p is converted to an *effective* charge taking account of taxes; this gives a measure of cost in terms of reduced profits, presumably assuming no change in production, output price, or sales. This measure can only be rough because output of waste is assumed constant, though it is recognized that increased costs caused by the charge will induce not only increased waste treatment but almost certainly a decrease in waste production. The waste treatment costs, the c_i , are also effective costs, after taxes and subsidies. Edwin L. Johnson describes the operation of the program as follows:⁵

[T]he strategy in SECH is to select an arbitrary nominal charge for the estuary and to convert this to an effective charge for each discharger, which, in turn, maps into an induced increase in removal. The estimated additional removal for all dischargers determines a quality improvement vector q , which is compared with the desired vector q^* . If $q \geq q^*$ element by element and if $0 \leq q_j - q_j^* \leq E$ (E being some allowable error) for at least one j , then the charge P is the lowest charge that will result in the specified quality improvements; if $q_j < q_j^*$ for any j , then p is incremented by some positive amount, and the process is repeated.

ZECH performs exactly as SECH, except that a different charge may obtain in each zone of the water body, and conceivably more than one set of such charges will induce sufficient removals to satisfy the quality improvement constraint. Therefore, an additional condition is specified that selects from along all feasible sets of charges that set that induces the least total expenditure on waste reduction.

⁴ H. W. Streeter and E. B. Phelps, "A Study of the Pollution and Natural Purification of the Ohio River," Public Health Bulletin 146, U. S. Public Health Service, Washington, D. C., 1925.

⁵ Johnson, "Study," p. 296.

SECH then selects a charge p such that the induced waste reduction $f(p)$ satisfies the three basic constraints. ZECH selects a set of p 's, say p_k^* , for each zone, such that the induced waste reductions $f(p_k^*)$ satisfy the three basic constraints and also

$$\sum_i C_{ik} f_{ik}(p_k^*) \leq \sum_i C_{ik} f_{ik}(p_k)$$

for all other p_k which satisfy the three basic constraints.

The principle of operation for Hass's Miami River basin model is exactly the same as for the Delaware Estuary least cost model. The problem, however, is formulated slightly differently; and Hass introduces a new alternative to waste treatment at individual outfalls. The new element is low-flow augmentation, through the regulation of reservoirs. Optimality requires the equation of marginal costs of further waste load reductions by individual and centralized treatment. In Figure III-2, y represents units of flow ($y = 1$ if there is no augmentation), and ϕ_0 is a constant marginal cost per unit of flow augmentation. As is evident from the figure, the products $w_i x_i$ correspond to the f_i in the Delaware model.

Although Hass simulates individual treatment cost functions in order to solve his model, his simulated runs suggest that a Dantzig-Wolfe decomposition procedure⁶ may be used by the central authority to determine optimal taxes without knowing firms' individual treatment cost functions. This iterative procedure requires the authority to submit a set of taxes to polluters who indicate how much waste they will discharge under this regime. The authority uses the responses to derive a new set of taxes which are then submitted to polluters in the same manner. Hass suggests that the optimal set of taxes will be reached by a tatonnement process, after relatively few iterations. He assumes throughout his analysis that polluters' responses will be accurate.

The optimal charges or taxes which are derived by a least cost model are the shadow prices associated with the dual formulation of the problem. These shadow prices are the λ_i in Figures II-1 and II-2. The λ_i represent the marginal value of an additional pound of oxygen in reach i . The dual problem maximizes the total value of oxygen in all reaches saved by waste

⁶For comprehensive descriptions of the procedure, see George Dantzig and Philip Wolfe, "The Decomposition Algorithm for Linear Programs," *Econometrica*, Vol. 29, No. 4 (1961), 767-778; and

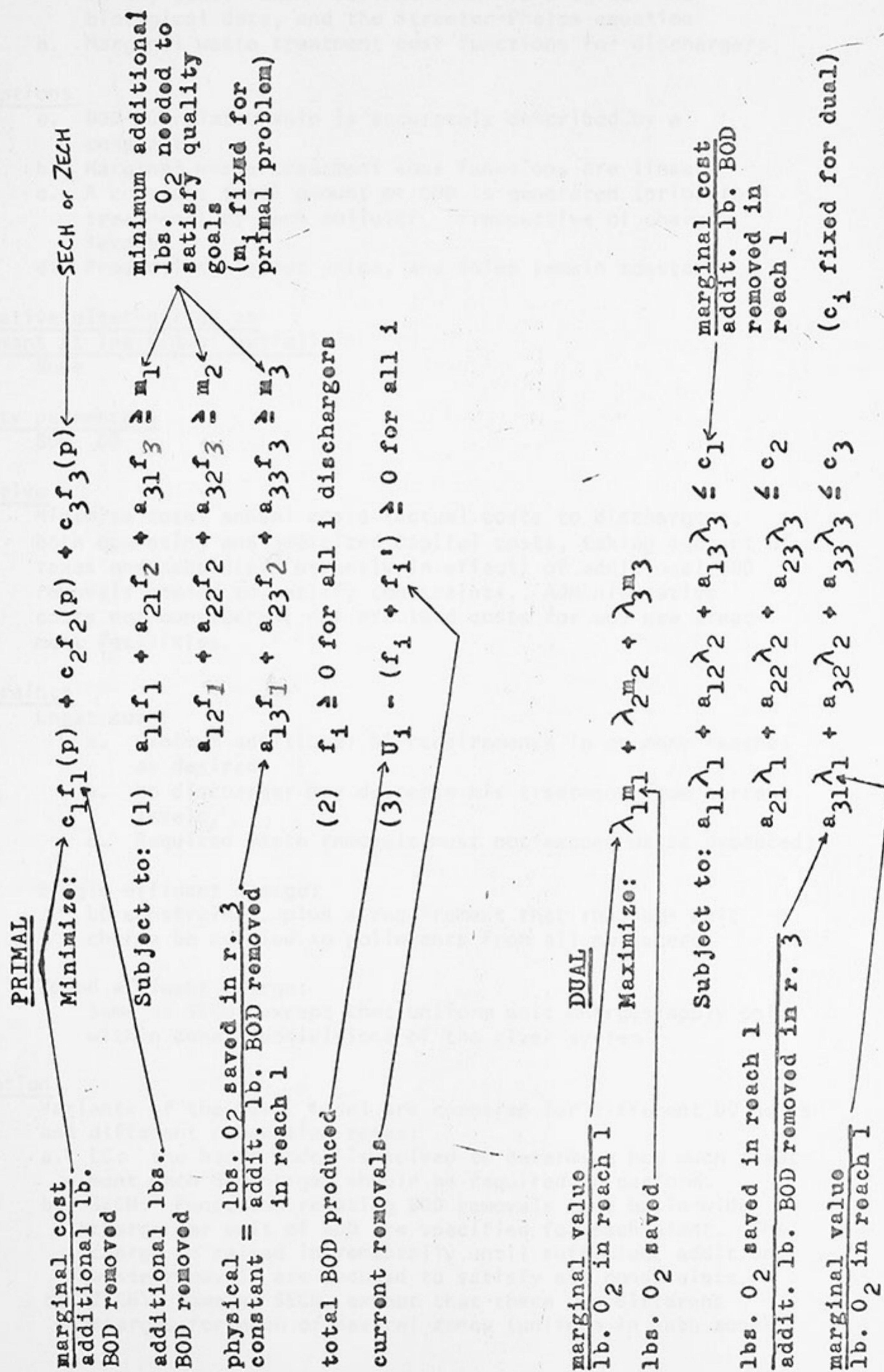
William J. Baumol and Tibor Fabian, "Decomposition, Pricing for Decentralization and External Economies," *Management Science*, Vol. 2, No. 1 (Sept. 1964), 1-32.

treatment in all other reaches, subject to the constraints that the aggregate marginal value of the oxygen (in reach i) saved by additional BOD removals in all other reaches is less than or equal to the aggregate marginal cost of the BOD removals. That is, the value of the oxygen "saved" or "produced" in all other reaches cannot exceed the cost of producing it (by removing BOD in reach i). The inequalities are in this form because the dual is a maximization problem.

The shadow price λ_j associated with the j th constraint (of the primal) m_j , measures the marginal value of supplying an extra unit of oxygen to reach j , when oxygen levels are optimal. Since a_{ij} measures the pounds of oxygen required in reach j by the discharge of a pound of BOD in reach i , $\lambda_j a_{ij}$ is the marginal cost to society of polluter i 's failure to treat his wastes further, when oxygen (and therefore pollution) levels are optimal. The sum of these products, $\sum_j \lambda_j a_{ij}$, is therefore the optimal tax on polluter i , to which polluter i will equate his marginal cost of further BOD removals.

Linear programming models can thus reveal the least-cost configuration of waste removals to attain a given array of quality standards in various reaches. If waste removals are made a function of a SECH, then the linear programming technique can be adapted to reveal the lowest SECH which will induce the attainment of given standards. But linear programming models cannot derive economically optimal standards themselves.

FIGURE II-4: SIMPLIFIED MODEL OF DELAWARE ESTUARY



DELAWARE ESTUARY STUDY - FEDERAL WATER POLLUTION CONTROL ADMINISTRATION -
LINEAR PROGRAMMING MODEL

1. Data requirements

- a. Matrix relating BOD removed in any reach to DO levels in any other reach--derived from hydrological and biological data, and the Streeter-Phelps equation
- b. Marginal waste treatment cost functions for dischargers

2. Assumptions

- a. BOD-DO relationship is accurately described by a constant.
- b. Marginal waste treatment cost functions are linear.
- c. A constant total amount of BOD is generated (prior to treatment) by each polluter, irrespective of charge levels.
- d. Production, output price, and sales remain constant.

3. Collective alternatives to treatment at individual outfalls

None

4. Quality parameters

BOD, DO

5. Objective

Minimize total annual costs (actual costs to dischargers, both operating and amortized capital costs, taking account of taxes and subsidies currently in effect) of additional BOD removals needed to satisfy constraints. Administrative costs not considered; nor are land costs for any new treatment facilities.

6. Constraints

Least cost:

- a. Minimum additional DO requirements in as many reaches as desired
- b. No discharger may decrease his treatment from current levels.
- c. Required waste removals must not exceed waste produced.

Single effluent charge:

LC constraints, plus a requirement that the same unit charge be applied to pollutants from all polluters

Zoned effluent charge:

Same as SECH, except that uniform unit charges apply only within zonal subdivisions of the river system

7. Operation

Variants of the basic model are compared for different DO goals and different reaeration rates:

- a. LC: the basic model is solved to determine how much treatment each discharger should be required to perform.
- b. SECH: Functions relating BOD removals to a basin-wide charge per unit of BOD are specified for each plant. The charge is raised incrementally until sufficient additional waste removals are induced to satisfy all constraints.
- c. ZECH: Same as SECH, except that there are different charges for each of several zones (uniform in each zone)

MIAMI RIVER SIMULATION - JEROME HASS - LINEAR PROGRAMMING MODEL - DECOMPOSITION ALGORITHM

1. Data requirements

- a. Matrix relating BOD removed in any reach to DO levels in any other reach--derived from hydrological and biological data, and the Streeter-Phelps equation
- b. Marginal cost function for flow augmentation
- c. Marginal waste treatment cost functions for dischargers are simulated for computer run; but knowledge of these would be unnecessary if the decomposition algorithm were proven to converge upon optimal tax structure after few iterations, in all cases.

2. Assumptions

- a. BOD-DO relationship is accurately described by a constant.
- b. Marginal cost function for flow augmentation is linear.
- c. A constant total amount of BOD is generated (prior to treatment) by each polluter, irrespective of charge levels.

3. Collective alternatives to treatment at individual outfalls Low-flow augmentation

4. Quality parameters BOD, DO

5. Objective

Minimize total daily costs of additional BOD removals and flow augmentation needed to satisfy constraints. Administrative costs not considered.

6. Constraints

- a. Minimum additional DO requirements in as many reaches as desired
- b. No discharger may decrease his treatment from current levels.
- c. Flow augmentation must be positive or zero (units are normalized).

7. Operation

The basic model is solved to determine how much treatment each discharger should be required to perform. Treatment levels may be thought of as functions of an optimal charge per unit BOD, individualized for each discharger. These charges, however, are not independent variables, but shadow prices associated with the constraints, in the optimal allocation model. Hass demonstrates an adaptation of the Dantzig-Wolfe decomposition procedure whereby the central authority may derive optimal treatment configurations and charges without knowing individual effluent treatment cost functions.

B. DYNAMIC PROGRAMMING IN THE TRENT ECONOMIC MODEL

The Trent Economic Model⁷ is based on a very different conceptual framework and computer program than the linear programming models. The Trent model views effluent treatment at point of discharge and water treatment at point of intake as substitutable processes for attaining given amounts of water of predetermined quality in any particular reach of the river system. Dischargers choose among a limited array of effluent treatment plants, with associated costs per unit of effluent treated to the level which defines the plant type. For example, a primary treatment plant, which removes about 40% of the effluent's BOD load, of a certain size has a certain present cost, composed of all operating and capital costs, discounted over a thirty-year period. The computer program presents each discharger with several effluent treatment options. These options are specific to the individual firm in the case of industrial effluent treatment. There are four types of municipal sewage plant.

The options of river water abstractors are more limited, because of the way in which quality states are defined. The quality state of the river is defined by the type of plant (one of ten types) required to treat any amount of river water at intake point, up to the capacity of the plant, to potable standards. Municipal users must choose that plant which treats the required amount of water to the common potable standard. Industrial users have the option of taking potable water from municipal water treatment plants, or installing the most elementary type of treatment plant, irrespective of the quality of intake water.

If it is cheaper to provide, say, 50,000 gallons per day of potable water at abstraction point Y by building a large water treatment plant (with a cost of \$100,000) at Y and a small effluent treatment plant at

⁷ Local Government Operational Research Unit, Royal Institute of Public Administration, Trent Economic Model, December, 1970.

FIGURE II-3
The River Trent Recreation Study Location Map
 Source: The Trent Research Programme



FIGURE II-4

(page 2)

TRENT RESEARCH PROGRAMMEKEY TO ROUTINE OBSERVATION POINTS AND REACHESRoutine Observation Points

R.O.P. 2	Hanley	33	Perry Barr	64	Keyworth
4	Hanford	34A	Water Orton	75	Confluence
6	Great Haywood	35	Lea Marston	89	Ambergate
8	Yoxall	37	Chetwynd Bridge	91	Tamworth
11	Burton	41	Rocester Dove	96	Bridgend Lock
14	Shardlow	44	Monk's Bridge	104	Rocester Churnet
17	Trent Bridge	48	Matlook Bath	215	Shirland
19	Kelham	51	St. Mary's Bridge	216	Bullbridge
20	Dunham	56	Wilne Tollbridge	298	Weddington
23	Keadby	59	Birstall	352	Stanford
32	Tame Bridge				

Reaches

T = Trent

UTA	}	= Tame
UTB		
MT		
LT		

ANK = Anker

CH = Churnet

D = Dove

DT = Derwent

AM = Amber

E = Erewash

S = Soar

discharge point X (costing \$25,000), than by building a large plant at X (\$100,000) and a small plant at Y (\$50,000), the model will choose the former combination as the least-cost method of achieving the goal. Quantity requirements are exogenous data fed into the program as constraints. Quality requirements for the abstracted water are fixed at potable standards. But it is possible to feed in constraints on the quality of the whole river at any point, in terms of sixteen different pollution parameters. Thus the model can reveal the least-cost combination of effluent treatment and water treatment plants which will give either (1) a fixed amount of potable water at any point in the system, or (2) a certain quality for the entire river at any point in the system.

The model operates in the following manner. The first upstream user, say a discharger, will have the choice of, say, three treatment plants. Thus any one of three possible quality states (in terms of the sixteen parameters) may confront the second user; if the latter is also a discharger with the choice of three treatment plants, one of as many as nine states will confront the third user. Associated with each of these nine states is a cost composed of the costs of the particular treatment installations chosen by the upper two users. The model recognizes only 30 different possible states; if there are two or more combinations of installations which will give a certain state at a particular point, the model chooses the cheaper combination and "forgets" the more expensive alternative. Thus, as the model proceeds downstream, it keeps a running record of all possible quality states at any point, together with the cheapest method of attaining that state.

The model is flexible with respect to ways of incorporating the self-purification of the river. At any point where water or effluent enters or leaves the river system, the new concentration of the various pollutants is calculated according to a simple arithmetic "mass balance" equation. Between such points, almost any mathematical representation of the effects of self-purification on pollutant concentrations can be incorporated into the model. Such representations need not be generalized; the operation of the model can accommodate different representations for different stages or reaches.⁸

There are several methods of improving water quality besides individual treatment of effluents or intake waters. These include river purification

⁸ L.G.O.R.U., Trent Economic Model, pp. 15, 37, 83-84.

lakes, flow regulation, and mechanical reaeration, among others. The model can consider any such alternative. Experiments are being conducted with a pilot river purification lake for the River Tame, which drains Birmingham.

An important problem with which the Trent Research Programme has yet to deal is the allocation of the costs of building the required "least-cost" facilities among the various river users. The linear programming models solve for the set of charges which will reduce total pollution loads to target levels, and the charges may be imposed without directing that each firm build the specific installations whose cost functions were previously incorporated into the model in order to solve for the charges. (The firm will build the installation if it remains the cheapest way to reduce its discharges by the required amount; but the charging scheme does not limit the firm to this alternative, and indeed induces research to find cheaper ways of reducing pollution.) The Trent Economic Model, on the other hand, solves only for a discrete set of effluent and water treatment plants with associated (minimized) total costs. The model-builders were not assigned the task of showing how the least cost configuration of treatment plants is to be financed. Therefore little consideration was given in the model to pollution charges as a source of revenue or as a continuous financial incentive to reduce discharges.

TRENT ECONOMIC MODEL - LOCAL GOVERNMENT OPERATIONAL RESEARCH UNIT - DYNAMIC PROGRAMMING

1. Data requirements

- a. Annual costs (operating and discounted capital costs, 30-year horizon) for building an array of installations chosen from among:
 - (1) ten types of water treatment plant
 - (2) four types of sewage works
 - (3) individual industrial effluent treatment plants (for all private dischargers)
- b. Marginal cost functions (per unit pollutant removed) for river purification lake, bunter recharge

2. Assumptions

- a. Effects of pollutants are independent of the levels of other pollutants, except for ammoniacal and oxidised nitrogen.
- b. A constant total amount of each pollutant is generated (prior to treatment) by each polluter.

3. Collective alternatives to treatment at individual outfalls River purification lake

4. Quality parameters

Biological oxygen demand, ammoniacal nitrogen, oxidised nitrogen, dissolved oxygen, suspended solids, temperature, total dissolved solids, monohydric phenols, chromium, copper, nickel, zinc, lead, cadmium, total organic carbon, chloride

5. Objective

Minimize total annual costs of either:

- (1) providing fixed amounts of potable water at various points in the system, or
- (2) meeting quality constraints imposed on various reaches; or both.

6. Constraints

Either:

- (1) required amounts of potable water at various locations, or
- (2) minimum quality constraints (for the whole river in any reach) in terms of any or all of the sixteen parameters; or both.

7. Operation

The first upstream user, for example a discharger, will have the choice of, say, three treatment plants. Thus any one of three possible quality states may confront the second user. If the latter is also a discharger with the choice of three treatment plants, one of as many as nine states will confront the third user. Associated with each of these nine states is a cost composed of the costs of the particular treatment installations chosen by the upper two users. The model recognizes a maximum of 30 different possible states; if there are two or more combinations of installations which will give a certain state at a particular point, the model chooses the cheaper combination and "forgets" the more expensive alternative. Thus, as the model proceeds downstream, it keeps a running record of all possible quality states at any point, together with the cheapest method of attaining that state.

CHAPTER III

THE THEORY OF THE RIVER-POLLUTING FIRM

A. DEFINITIONS

(1) EXTERNALITY OF PRODUCTION.¹ Let X and Y be two goods; $x_1, \dots, x_n$ and $y_1, \dots, y_n$ be factors of production; and w_x and w_y be river water used (as either process water or effluent carrier or both) in the production of X and Y , respectively. Let the utility function of any person i be

$$U_i = U_i(X, Y)$$

Let the production functions of two firms be

$$X = f(x_1, \dots, x_n, w_x)$$

$$Y = g(y_1, \dots, y_n, w_y)$$

An externality arises from Y 's activity when either

$$U_i = U_i(X_i, Y_i, w_y) \quad , \quad \text{or}$$

$$X = f(x_1, \dots, x_n, w_x, w_y) \quad , \quad \text{or both.}^2$$

External diseconomies, with which we are exclusively concerned, are distinguished by the further conditions that $\partial U_i / \partial w_y < 0$, and $\partial X / \partial w_y < 0$, respectively.

(2) POLLUTION. This is the generic name for a host of individual pollutants (or pollution parameters, as they are called in the Trent Research Programme), such as biological oxygen demand and ammonia, whose presence in the river, in concentrations above certain threshold levels, imposes damages upon downstream users of the water. Effluent is a suspension or

¹The classic definitional article is James M. Buchanan and W. Craig Stubblebine, "Externality," *Economica*, N.S. Vol. 29, No. 116 (Nov, 1962), 371-384. We do not deal in this paper with externalities of consumption.

An excellent discussion of externalities in the context of water resources management is given in Allen V. Kneese and Blair T. Bower, *Managing Water Quality: Economics, Institutions, Technology*, Baltimore: Johns Hopkins, for Resources for the Future, Inc., 1968, chapter 5.

²E. J. Mishan includes in his definition of an externality that it arises unintentionally. E. J. Mishan, "Joint Products, Collective Goods and External Effects," *Journal of Political Economy*, Vol. 77 (1969), pp. 342-343.

solution of pollutants arising from industrial production or sewage treatment processes. Effluent treatment and water treatment are essentially the same process: the removal of these pollutants from water. Waste refers to pollutants or effluents arising from any human activity.

(3) NET VALUE OF SOCIAL PRODUCT. One way to conceive of the stock or flow of economic welfare in an externality-ridden society is to reduce an aggregate value of product index, such as real Gross National Product, by the monetary value of aggregate damage to individuals from the external diseconomies of production in the economic system. (External diseconomies to firms, as well as all external economies, of production, are already accounted for in the GNP index.) We are more interested, however, in analyzing changes in the aggregate, than in defining the aggregate itself. These changes are best conceived of, on a micro level, in terms of consumer's and producer's surplus. Now, GNP does not measure these surpluses, but instead sums total revenues (transactions prices times traded quantities) for productive enterprises over the economy. Nonetheless, our exposition will be clearest if we use the term "net value of social product", on those occasions when we must refer to aggregate levels of economic welfare, without discussing the problems and mechanics of aggregation, and use the concept of consumer's surplus to analyze changes in those levels.

(4) OPTIMALITY. Optimal pollution is that level at which the net value of social product is maximized. If competitive conditions hold throughout the economy, then one of the conditions of optimality is that marginal costs of further removals of pollution at any discharge point exceed the marginal reduction in damage at all other points. We shall use the term "optimal" to refer to the level of pollution at which this condition obtains, both before and after we introduce an output market into the analysis and state the other conditions for optimality in a competitive situation. We shall then discuss problems revealed by the theory of the second-best, for example, how the existence of monopolistic elements in polluting industries may render these conditions meaningless.

B. THE INABILITY OF MARKETS TO PRODUCE

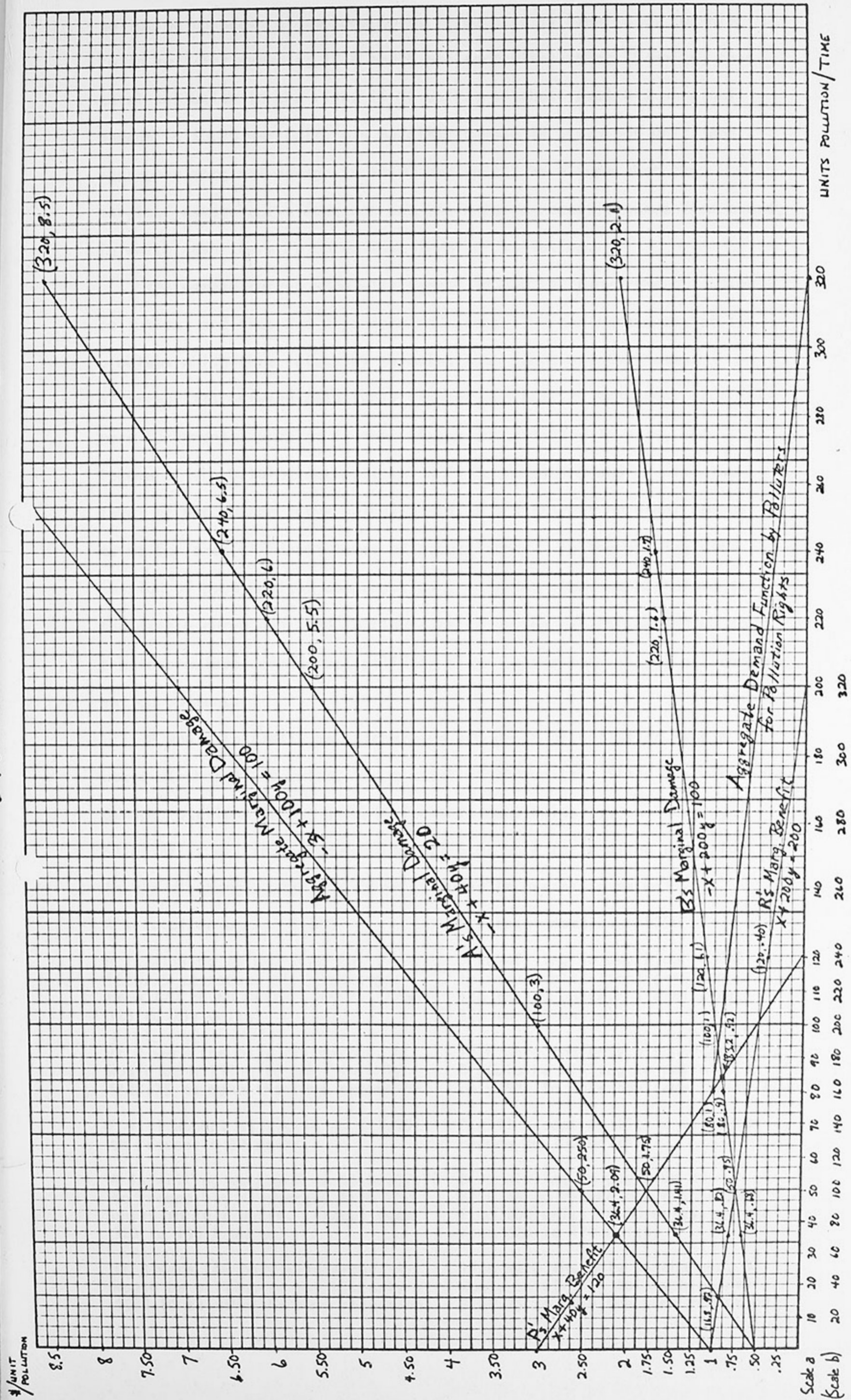
OPTIMAL POLLUTION LEVELS

The unregulated discharge into a river of wastes which affect consumption and production by other users of the river waters will produce a situation in which the net value of social product can be increased by state intervention, provided (1) that marginal costs of information and negotiation among the affected parties are greater than the marginal increase in net product which could be effected by a bargain, and (2) that marginal costs of state action are smaller than that potential increase. But few existing regulatory programs in Great Britain or the United States attempt either to evaluate pollution damages or to reduce pollution to that level at which the marginal cost of further reductions exceeds the marginal reduction in damages. Having discussed the most advanced, computer-based methods available for attaining arbitrary quality goals at least cost, we take up the question which ended Chapter I: can the Trent River Authority both (1) derive optimal pollution levels, and (2) devise a practical system of attaining those goals, all the while keeping administrative costs below the expected increase in the value of social product? Minimizing administrative costs means, practically, minimizing the amount of information required to accomplish the two tasks, since gathering accurate cost damage data is the major administrative task. The question therefore naturally arises whether a market can be set up in such a way that the individual polluters and damagees, acting in their own interests, will set pollution at optimal levels, without the need for some river basin authority to gather detailed information on costs and damages.

1. Potential Private Bargaining

Before we discuss the difficulties in establishing a market in PR's, we abstract from bargaining costs and examine incentives for individual damagees to compensate individual polluters, in a system in which there is a legal right to pollute. Figure III-1 depicts hypothetical marginal benefit functions of two polluters, P and R, and marginal damage functions for two antipolluters, A and B. Scale a was used to construct the curves. Scale b merely indicates the total levels of pollution in the river if each of the two polluters is discharging the corresponding number of units of

FIGURE III 1



pollution on scale a, so long as it is marginally beneficial for him to do so. For example, if P and R are each discharging 25 units, then total pollution in the river is 50 units; at that level B's marginal damage is \$0.75 per unit, A's marginal damage is \$1.75 per unit, and aggregate marginal damage is \$2.50 per unit. We assume that the marginal damage curve does not cut the marginal benefit curve from above, in which case there is no optimum level of pollution.

The damage curves show willingness to pay to remove the offending pollution, and thus are dependent on income. We can remove one of the problems which this raises by assuming that there are no income differentials between relatively lighter and heavier damagees. But the more fundamental problem is that if any compensation is paid, the income of the bribing antipolluter will be reduced — and so will the level of his damage curve. Thus there is a different marginal damage curve for each different level of compensation. In the ensuing discussion of hypothetical compensation processes, then, we postulate that the damage curve depicted in Figure III-1 is the one corresponding to the income level of the antipolluter after he has made all of his compensation payments.

P would initially be discharging 120 units of pollution, and R would discharge 200 units, for a total of 320 units. Since the marginal damage functions in our example increase monotonically, each damagee (A or B) is willing to pay either polluter more for a given reduction in his discharges when the other polluter is operating as well.

A's total damages = \$1440

B's total damages = \$256

A is willing to pay P up to \$533.75 to reduce his discharges from 120 to 50 units. (total from 320 to 250 units)

B is willing to pay P up to \$41 to reduce his discharges from 120 to 100 units. (total from 320 to 300 units)

If P were the only discharger, A would be willing to pay him only \$183.75 to make the same reduction.

If P were the only discharger, B would be willing to pay him only \$21 to make the same reduction.

P will accept as little as \$61.25 to reduce to 50 units.

P will accept as little as \$5 to reduce to 100 units.

A is willing to pay R up to \$1137.70 to reduce his discharges from 200 units to 16.8 units. (total from 320 to 136.8 units)

B is willing to pay R up to \$296.25 to reduce his discharges from 200 units to 50 units. (total from 320 to 170 units)

If R were the only discharger, A would be willing to pay him only \$588.10 to make the same reduction.

If R were the only discharger, B would be willing to pay him only \$168.75 to make the same reduction.

R will accept as little as \$84.27 to reduce to 16.8 units. R will accept as little as \$56.25 to reduce to 50 units.

Any change in the initial situation--any bargain actually achieved--will alter the nature of remaining potential bargains. For example, if A actually pays R some amount between \$84.27 and \$1137.70 to reduce his discharges to 16.8 units, he will no longer be willing to pay P up to \$533.75--but instead only \$213.15 to reduce his discharges from 120 units to 50 units. Likewise, if A pays P first, he will be willing to pay R only \$817, no longer \$1137.70, to reduce his discharges from 200 to 16.8 units. And once A has paid either P or R, there is no longer any scope for a bargain between B (alone) and the compensated polluter.

Observed that B (in general, those for whom marginal pollution damages are relatively low) will have an incentive to pay to have pollution reduced, even if he believes that there are others such as A whose relatively higher marginal damages will cause them to pay. B would benefit from paying on his own to have pollution reduced from 320 to 83.2 units (by paying R to remove all his pollution and P to reduce from 120 to 83.2 units). Though he would be providing a public benefit(to A), B would still benefit privately by more than his private costs--because the public good of "freedom from pollution" is divisible, though not excludable. A fortiori, A (in general, those for whom marginal pollution damages are relatively high) would not refrain indefinitely from making private compensation arrangements with individual polluters. A would benefit from paying on his own to have pollution reduced to 50 units. The mechanics of compensation would be something like the following:

Figure III-2

Payment is made to:	Reduction in pollution (units)	Min. Pay. Required	Max. will. of A to pay	Max. will. of B to pay
(1) R	By R: 200 to 120 Total: 320 to 240	16	600	152
(2) P	By P: 120 to 100 Total: 240 to 220	5	125	33
(3) R	By R: 120 to 0 Total: 220 to 100	84	540	156
(4) P	By P: 100 to 80 Total: 100 to 80	15	55	19

(5) P	By P: 80 to 50	41.25	63.75	(24.75)
	Total: 80 to 50			
TOTAL: 320 to 50		161.25	1383.75	(384.75)

Steps (2), (3), and (4) are only approximations of the order in which the discrete payments would be likely to be made. For example, in step (3), just before R has completely eliminated his pollution, it would become slightly cheaper to begin paying P again. But regardless of whether further refinements are made in the compensation process, the position at the end of step (4) will be the same, and A will go on to pay P to reduce to 50 units.

Fifty units, however, is not the optimum level of pollution, because discharging the 50th unit provides fewer benefits to P than aggregate damages to A and B. B would be willing to pay \$9.72 for the additional reduction to 36.4 units, and A would be willing to pay \$19.42 for the same reduction. Together the antipolluters would pay \$29.14, and P would accept as little as \$26.11, to reduce from 50 to 36.4 units. Thus, when individual bargaining has run its course without attaining optimal pollution levels, it will still be in the interest of all antipolluters to pay polluters to move to the optimum position by organizing a bribe fund (to which everyone contributes up to his marginal damage), sooner or later. In this situation involving a divisible public good, and only two polluters and two antipolluters, it is unlikely that the strategic free rider problem ("If only I hold out long enough, the other man will pay") would prove an insuperable hurdle to the attainment of an optimum. The lure of the possibility of improving one's own position by one's own payments would eventually overcome the strategic objections to paying now. Relatively heavier damagees would stand to gain more by bribing, and would be under greater pressure to give in first. This phenomenon, and differences in bargaining power, would affect income distribution among antipolluters, but would not preclude the attainment of optimal pollution levels, in theory.

We have been abstracting, however, from the costs of organizing antipolluters, as well as transactions costs, and these are likely to be greater in practice than the potential benefits from bribing, when the number of antipolluters and polluters is large. It is because these costs of organizing and transacting in the real world are relatively

great, that there is a potential economic case for state action in the first place. There are no doubt a great many nominal damagees for whom the costs of transacting exceed the potential benefits, even though in the absence of such costs they might make individual bargains with polluters. The problems of strategic holdouts may be accentuated where there are a large number of other antipolluters, any one of whom may break down and pay compensation first. And there is the additional possibility that for some antipolluters, marginal damage at current pollution levels not only falls, but equals zero. Such an antipolluter would have no incentive to bribe polluters while the river was very dirty, but if it were cleaned up to such a degree that trout fishing or perhaps swimming would be possible if an additional polluter or two were bribed, he might undertake these payments on his own.

2. The Dilemma of the Basin Authority

A "market in Pollution Rights" would have the regulatory body issue a number of Pollution Rights to discharge unit amounts of certain pollutants, and then, having legislated that all discharges not represented by a PR are illegal, sell the Rights on an organized exchange to anyone who wishes to purchase them, be he a private corporation, a municipality, an anglers' association, or an individual Crusader for a Clean Environment. The idea is that if polluters and antipolluters are bidding against each other for PR's, quality standards will be set by the market. We shall show that the idea cannot be put into practice.

A Pollution Right would have different excludability properties depending upon who held it. The right to discharge effluents is a private good in the hands of a polluter. What one polluter has cannot be used by others without his consent. But the right to be free of the effect of others' discharges is a public good. One person's possession of the right benefits all. Thus an antipolluter has no incentive to bid against a fellow antipolluter.

An additional peculiarity of this hypothetical market is that the commodity traded, the PR, does not appear in the antipolluter's utility function, unless it reduces pollution. Pollution appears there, as a negative term. But to the antipolluter, the PR is a good only insofar as it reduces pollution. The fact that an antipolluter buys and holds

a PR does not necessarily mean that pollution levels will be below what they otherwise would have been by an amount corresponding precisely to the units represented by the PR. Only if it can be ensured that an antipolluter's purchase denies that PR to a polluter, will the PR appear in the antipolluter's utility function. This difficulty may be termed the "preemption" problem, and is a quite different phenomenon from the "free rider" problem. The latter has to do with disincentives for private individuals to contribute to the cost of goods whose claim to "publicness" arises from their indivisibility as well as non-excludability. It is a problem which afflicts the efforts of like-minded persons to combine to purchase a public good, the consumption of which by one of those persons does not reduce the amount available for consumption by the others, and the purchase of which by one individual in fact makes the good available in equal amounts to all the others. On a strategic plane, the problem may be either (1) the suspicion that one's own contribution will go for nothing unless all contribute and may not in fact be necessary if all others contribute (in the case of a non-excludable and indivisible good), or (2) the unwillingness that others should benefit from one's own payments without paying themselves, mixed with one's own desire to benefit freely from others' payments (in the case of a non-excludable but divisible good). The free rider problem would apply, then, to an extent described below, only to the antipolluters' side of a market in Pollution Rights.

By contrast, the preemption problem would arise from the presence in the market of two opposite-minded groups, one of which would bid not because they want to exercise Pollution Rights, but because they wish to keep the other group from exercising them. We shall show that the dependence of antipolluters' demand for PR's upon both the quantity issued and the polluters' demand functions for PR's would destroy the possibility of simultaneous bidding to determine the optimal quantity in the first place.

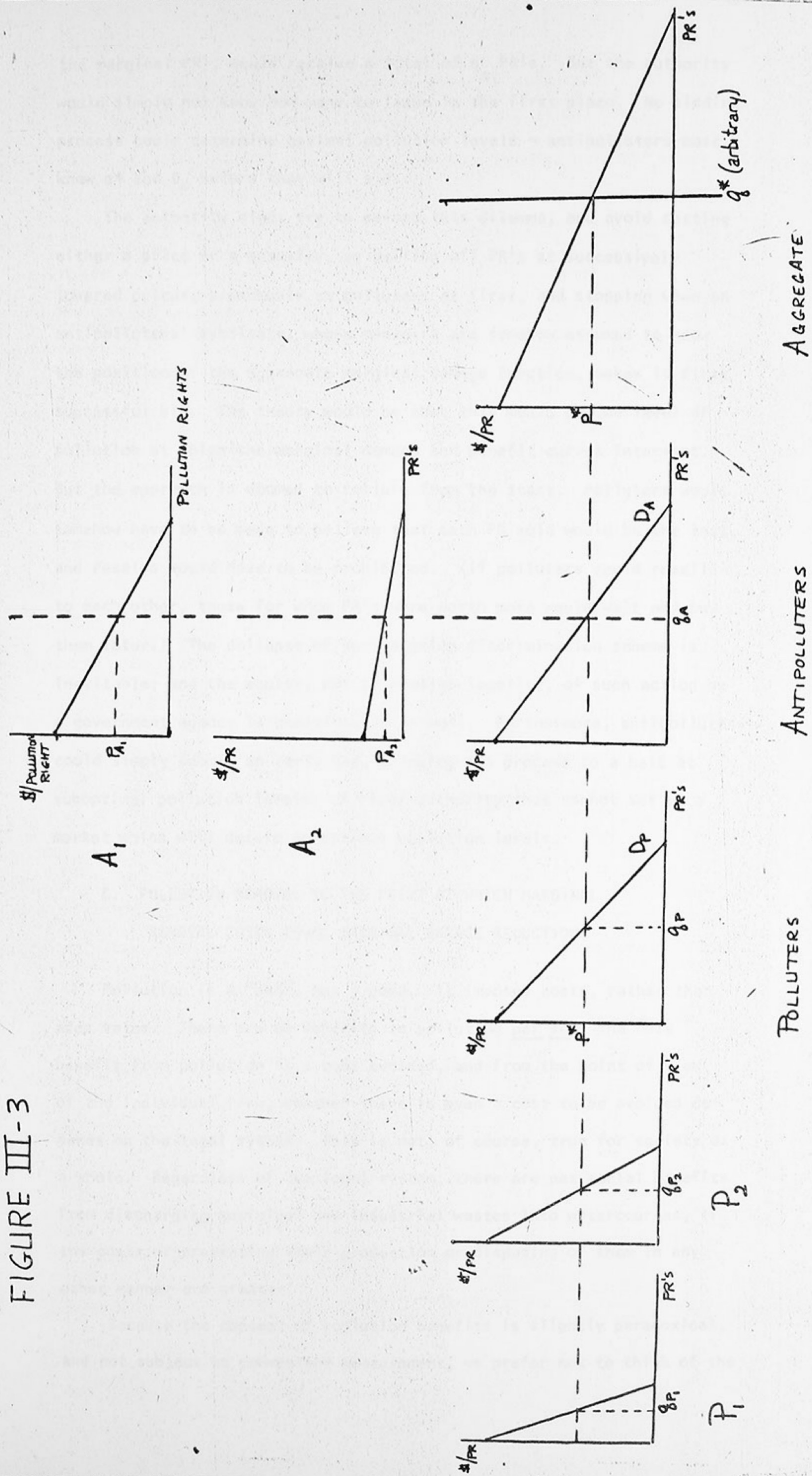
Suppose that the river authority issued a number of Pollution Rights, each entitling the holder to discharge one unit of pollution, but each of which is infinitely divisible. The authority can set the price, or the quantity to be issued, but not both, if it wishes to clear the market. A price of \$2.09 would not clear the market; it would sell

only 36.4 PR's, if that many were issued, to P. A would not be motivated to buy any. At a price of \$1.50, P would buy 60 PR's. A would be willing to pay an amount up to the area under his marginal damage function between 50 and 60 on the X axis, that is, \$18.75, to keep ten PR's out of P's hands. These last ten are only worth \$16.25 to P. But A's use of the \$18.75 to purchase 12.5 PR's would not prevent P from purchasing his 60 PR's. This is the preemption problem. Only if A paid P directly some amount between \$16.25 and \$18.75 would all parties be satisfied, at the stipulated \$1.50 price for PR's.

In general, if the authority sets an arbitrary price and stands willing to issue whatever quantity of PR's is demanded at that price, antipolluters, organized or not, will simply not bid for PR's, since polluters will buy the same number of PR's whether or not antipolluters bid. This procedure would establish, not a market, but a charging scheme, and resultant pollution levels would in no sense be optimal.

The only other alternative for a river basin manager who does not know the positions of the marginal damage and marginal benefit curves is to issue an arbitrary quantity and ask for bids. But the quantity would not be optimal, nor would the price which emerged. The quantity of PR's which antipolluters will demand at any price is a function not only of that price — the sole determinant of the quantity which a polluter demands — but also of the probability that their purchases will in fact deprive polluters of those PR's. This probability is in turn a function of the number of PR's issued by the authority, and antipolluters' knowledge of the polluters' aggregate demand function for PR's. In Figure III-3, then, we show what is really an impossible equilibrium situation, because not only the shape but the very existence of the antipolluters' demand functions for PR's depend upon antipolluters' knowledge of q^* and D_p . If they could be drawn, the hypothetical demand curves for antipolluters A_1 and A_2 would be summed vertically to give a function which is in turn aggregated horizontally with the polluters' demand function to give the aggregate demand function for PR's which faces the river authority. The arbitrary quantity issued by the authority would be allocated in the manner shown: polluters, all paying the same price p^* , would receive a total of q_p PR's, and antipolluters, contributing different amounts p_{A1} and p_{A2} to the antipollution fund (for

FIGURE III-3



the marginal PR), would receive a total of q_a PR's. But the authority would simply not know how many to issue in the first place. No bidding process could determine optimal pollution levels — antipolluters must know q^* and D_p before they will bid.

The authority might try to escape this dilemma, and avoid setting either a price or a quantity, by selling off PR's at successively lowered prices, presumably to polluters at first, and stopping when an antipolluters' syndicate, whose managers are somehow assumed to know the position of the aggregate marginal damage function, makes its first successful bid. The theory would be that this would be the level of pollution at which the marginal damage and benefit curves intersect. But the approach is doomed to failure from the start. Polluters would somehow have to be made to believe that each PR sold would be the last, and resales would have to be prohibited. (If polluters could resell to each other, those for whom PR's were worth more would wait and buy them later.) The collapse of such a price discrimination scheme is inevitable; and the equity, not to mention legality, of such action by a government agency is questionable as well. Furthermore, antipolluters could simply submit an early bid, bringing the process to a halt at suboptimal pollution levels. A river authority thus cannot set up a market which will determine optimal pollution levels.

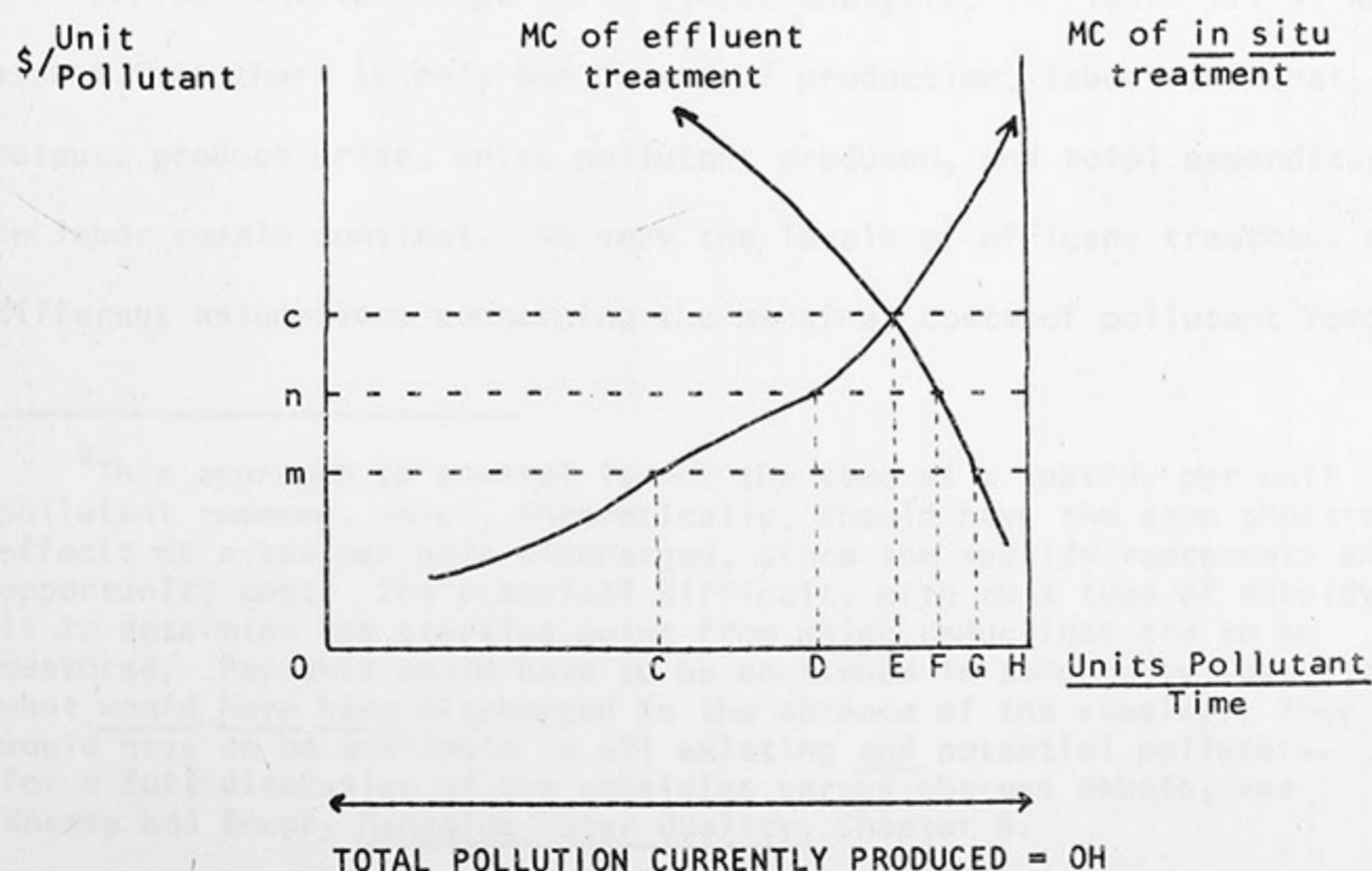
C. POLLUTION REMOVAL TO THE POINT AT WHICH MARGINAL REMOVAL COSTS EQUAL MARGINAL DAMAGE REDUCTIONS

Pollution is a "bad", not a good. It imposes costs, rather than adds value. There are no benefits in polluting per se. The only benefit from pollution is a cost avoided, and from the point of view of the individual firm, whether there is even a cost to be avoided depends on the legal system. This is not, of course, true for society as a whole. Regardless of the legal system, there are net social benefits from discharging municipal and industrial wastes into watercourses, if the costs of preventing their production or disposing of them in any other manner are greater.

Because the concept of pollution benefits is slightly paradoxical, and not subject to convenient measurement, we prefer not to think of the

optimization problem in terms of equating marginal damages and benefits. Instead, we shall compare marginal damage with marginal costs to polluters of removing or avoiding that damage. The marginal cost curve should represent the least-cost combination of pollution-removal processes. It must be assumed that if polluters by pooling resources, or by paying existing municipal or other waste treaters, can get their wastes treated more cheaply than they can do it themselves within the plant or at the individual outfall, they will demand and obtain the necessary collective facilities. If it were assumed that polluters were limited to effluent treatment, and damagees to collective river treatment, one could equate the marginal costs of the two means of removing pollutants, given that a certain quantity of pollution is to be removed--but this would not reveal how much pollution should be removed, for these marginal costs are not in addition equated to independently-derived marginal damages.³

³Equating the marginal costs of two alternative means of pollution removal is one of the tasks of Jerome Hass's linear programming exercise. Hass assumes that quality standards are given--a completely inelastic damage function--and treats individual effluent treatment and in situ treatment (low flow augmentation) as alternative methods of attaining the standards. If he solved for single effluent charges instead of "least cost" shadow prices, his approach could be illustrated graphically as in the figure below. If the arbitrary quality goal is that DF units of pollutant should be in the river, then a SECH of n would induce removal of OD units by in situ treatment, and FH units of effluent treatment. If the quality goal is zero pollution, a charge of c would cause OE units to be removed by in situ treatment, and EH units by effluent treatment. The intersection of the two curves, of course, does not define an optimum level of pollution. A marginal damage function must be added to the analysis.



Since pollution is a "bad", pollution removal is a good. The latter has sometimes been referred to loosely as a factor of production. But pollution removal is fundamentally different from the types of things we normally call factors of production, for it has no positive marginal physical product to the firm. The use of more effluent treatment does not increase output, except insofar as materials are recovered. This is why offers of partial subsidization of effluent treatment facilities will not by themselves cause pollution to be reduced. If the government pays anything less than 100% of the cost of such facilities, there remains a positive cost of effluent treatment which no profit-maximizing producer will absorb in the absence of legal sanctions, pressures of public opinion, or some other external force.⁴

On the other hand, pollution removal may be said to have a social value of marginal product. The net value of social product will rise with an increase in pollution removal, so long as the value of damage reductions exceeds the opportunity cost of resources devoted to pollution removal. The social value of marginal product of pollution removal may become negative, just as the marginal physical product and value of marginal product of any conventional factor can become negative for a firm if the factor is used too heavily. But the social value of marginal product of pollution removal is not the demand price for this productive service (quantities of other productive services constant). Pollution removal is valuable to the firm only if and insofar as the law makes it cheaper than not removing pollution.

For our initial comparative static analysis, in Figure III-4, we assume that there is only one factor of production, labor, and that output, product price, units pollutant produced, and total expenditure on labor remain constant. We vary the levels of effluent treatment under different assumptions concerning the marginal costs of pollutant removal.

⁴This approach to control is not the same as a subsidy per unit pollutant removed, which, theoretically, should have the same short-run effects as a tax per unit discharged, since the subsidy represents an opportunity cost. The practical difficulty with this type of subsidy is to determine the starting point from which reductions are to be measured. Payments would have to be continued in perpetuity, based on what would have been discharged in the absence of the subsidy. They would have to be available to all existing and potential polluters. For a full discussion of the subsidies versus charges debate, see Kneese and Bower, Managing Water Quality, Chapter 6.

(page 1)

FIGURE III-4 (TABLES)

a. MC rising
MD rising

PRODUCTION COSTS

UNITS OUTPUT	PRODUCT PRICE	VALUE OF OUTPUT	UNITS POLLUTANT PRODUCED	UNITS POLLUTANT REMOVED	UNITS POLLUTANT DISCHARGED	DAMAGE TOTAL	MARGINAL COST*	TOTAL SOCIAL COST*	SOCIAL MARGINAL VALUE OF EFFLUENT TREATMENT THE FIRM	PROFIT AND ENTREPRE- NEURIAL RENT
100	\$1	\$100	10	0	10	\$40	--	\$90	---	\$50
100	1	100	10	1	9	33	\$7	86	+\$4	47
100	1	100	10	2	8	27	6	84	+2	43
100	1	100	10	3	7	22	5	82	+2	38
100	1	100	10	4	6	18	4	86	-4	32
100	1	100	10	5	5	15	3	90	-4	25
100	1	100	10	6	4	13	2	96	-6	17

b. MC rising
MD falling

100	\$1	\$100	10	0	10	\$44	0	\$94	---	\$50
100	1	100	10	1	9	42	\$2	96	-\$2	47
100	1	100	10	2	8	38	4	95	+1	43
100	1	100	10	3	7	32	6	94	+1	38
100	1	100	10	4	6	24	8	92	+2	32
100	1	100	10	5	5	14	10	89	+3	25
100	1	100	10	6	4	2	12	85	+4	17

* PRODUCTION COSTS PLUS DAMAGE

c. MC falling
MD rising

FIGURE III-4 (TABLES) (page 2)

PRODUCTION COSTS

UNITS OUTPUT	PRODUCT PRICE	VALUE OF OUTPUT	UNITS POLLUTANT PRODUCED	UNITS POLLUTANT REMOVED	UNITS POLLUTANT DISCHARGED	DAMAGE	TOTAL SOCIAL COST*	SOCIAL MARGINAL VALUE OF EFFLUENT TREATMENT	NET SOCIAL PRODUCT OF THE FIRM	PROFIT AND ENTREPRE- NEURIAL RENT
100	\$1	\$100	10	0	10	\$40	\$90	---	\$10	\$50
100	1	100	10	1	9	33	93	-\$3	7	40
100	1	100	10	2	8	27	95	-2	5	32
100	1	100	10	3	7	22	96	-1	4	26
100	1	100	10	4	6	18	96	0	4	22
100	1	100	10	5	5	15	95	+1	5	20
100	1	100	10	6	4	13	93	+2	7	20

d. MC falling
MD falling

100	\$1	\$100	10	0	10	\$44	\$94	---	\$6	\$50
100	1	100	10	1	9	42	102	-\$8	-2	40
100	1	100	10	2	8	38	106	-4	-6	32
100	1	100	10	3	7	32	106	0	-6	26
100	1	100	10	4	6	24	102	+4	-2	22
100	1	100	10	5	5	14	94	+8	6	20
100	1	100	10	6	4	2	82	+12	18	20

* PRODUCTION COSTS PLUS DAMAGE

FIGURE III-4
(Graphs)

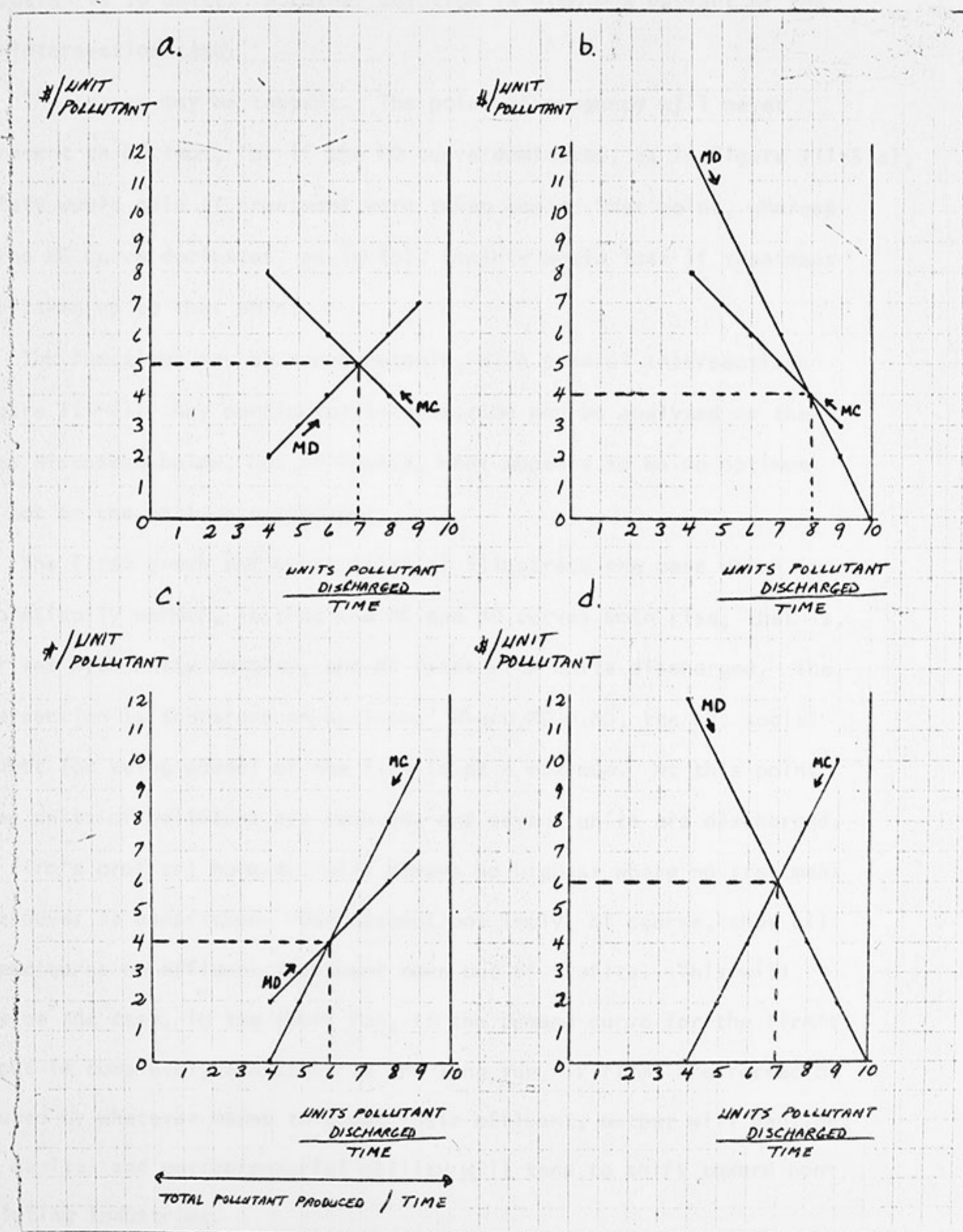


Figure III-4 does not illustrate all possible cases, but only selected examples of single intersection. Other possibilities are as follows:

- (1) The curves may not intersect. If marginal damage (MD) everywhere exceeds MC, then optimal pollution is zero; in the reverse case, optimal pollution is 10 units. A corner solution is simply a variant of the non-intersection case.
- (2) The curves may be tangent. The point of tangency will never represent an optimum, for if the MD curve dominates, as in Figure III-5(a), society would gain if treatment were taken beyond that point, whereas if the MC curve dominates, as in (b), society would lose if treatment were taken up to that point.
- (3) The functions may be non-monotonic, with several intersections (Figure III-6). Any particular intersection may be analyzed on the bases discussed below, but of course, what appears to be an optimum may not be the optimum optimum.

The first graph and chart III-4(a) illustrate the case which is theoretically normal, in that the MC and MD curves both rise, that is, MC rises with units removed, and MD rises with units discharged. The intersection is therefore an optimum. Where $MC = MD$, the net social product (or value added) of the firm is at a maximum. At this point three units of pollutant are removed, and seven units are discharged. The firm's profits, however, will always be highest where no treatment whatsoever is undertaken. Our assumptions imply, of course, that all expenditures on effluent treatment come out of profits. This will only be the case, in the short run, if the demand curve for the firm's output is completely elastic. In the long run, if firms are forced or induced by whatever means to treat their effluent, output will decline, and capital and entrepreneurial ability will tend to shift toward non-polluting industries.

Graph and chart (b) show MC to rise, and MD to fall. If the MC curve is steeper than the MD curve, the intersection is an optimum. But we have depicted the perverse case in which the absolute value of the slope of the MD function (measured from left to right in the conventional manner for both curves) exceeds that of the MC function. In this case the intersection is not an optimum, as the chart clearly shows.

FIGURE III-5

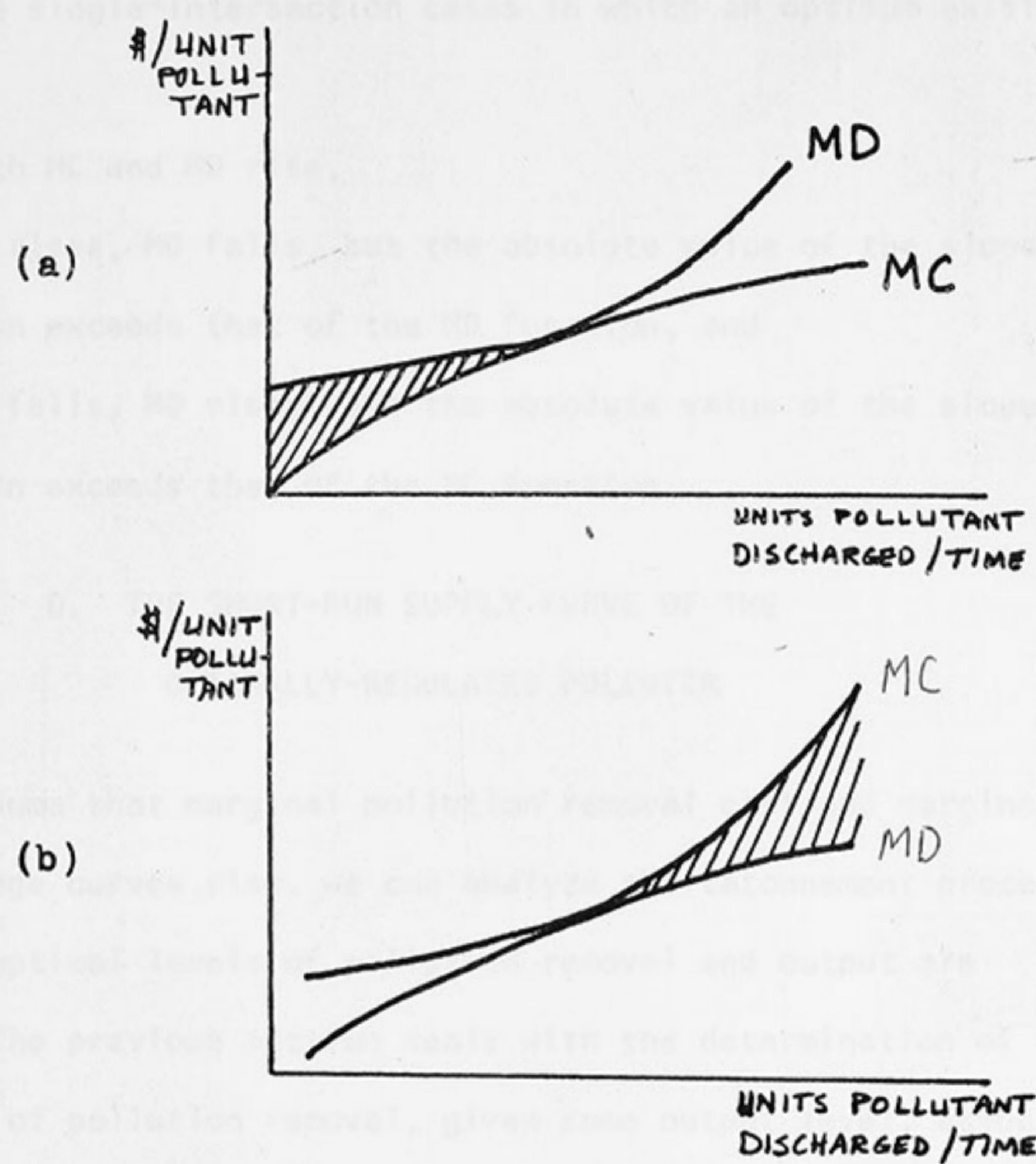
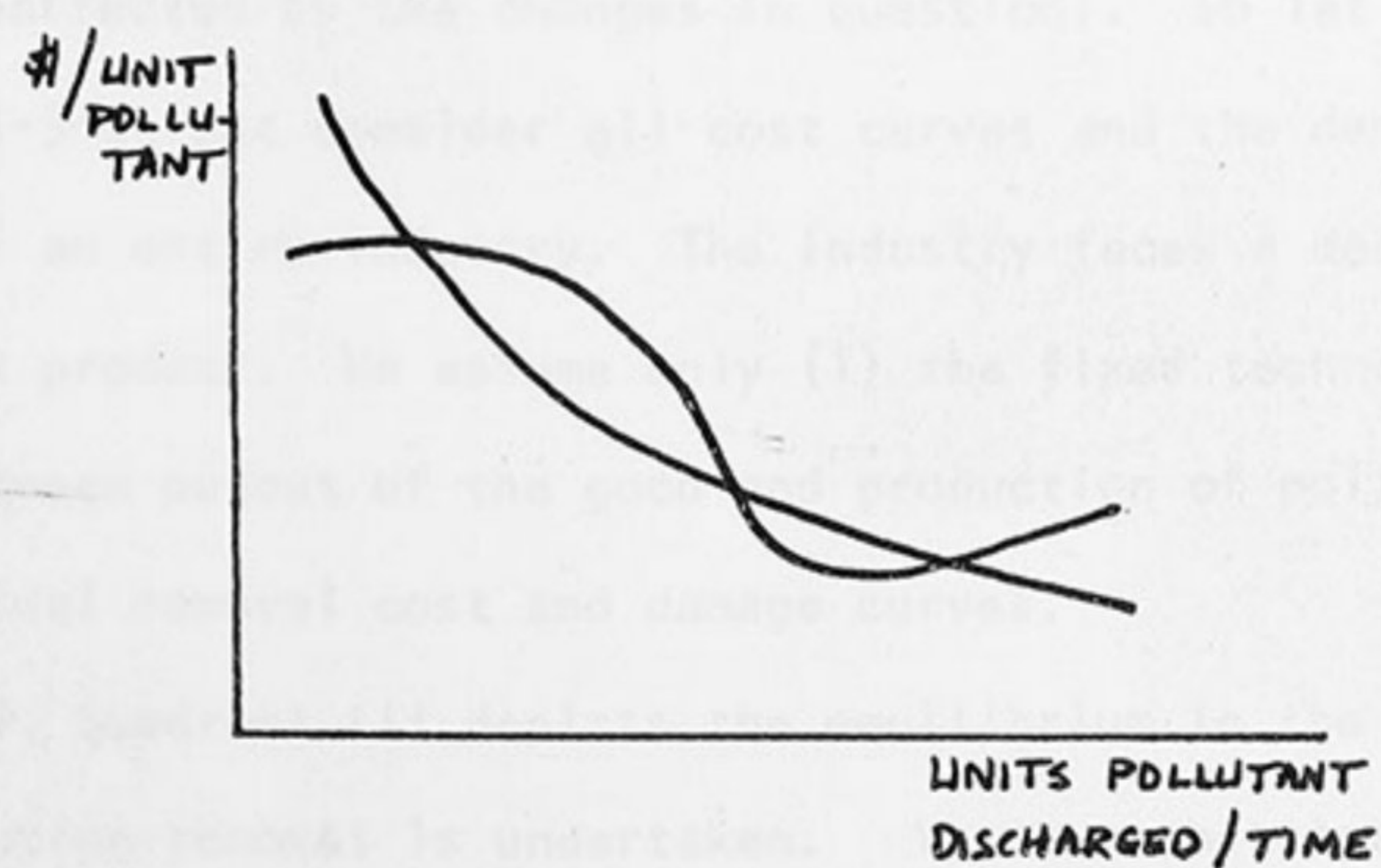


FIGURE III-6



Where MC falls but MD rises, as in graph and chart (c), the perverse case is the one in which the MC curve is steeper than the MD curve. At the intersection the net social product of the firm is at a minimum rather than a maximum. This is likewise the case where both MC and MD decline, a situation which is always perverse.

The three single-intersection cases in which an optimum exists, then, are:

- (1) where both MC and MD rise,
- (2) where MC rises, MD falls, but the absolute value of the slope of the MC function exceeds that of the MD function, and
- (3) where MC falls, MD rises, but the absolute value of the slope of the MD function exceeds that of the MC function.

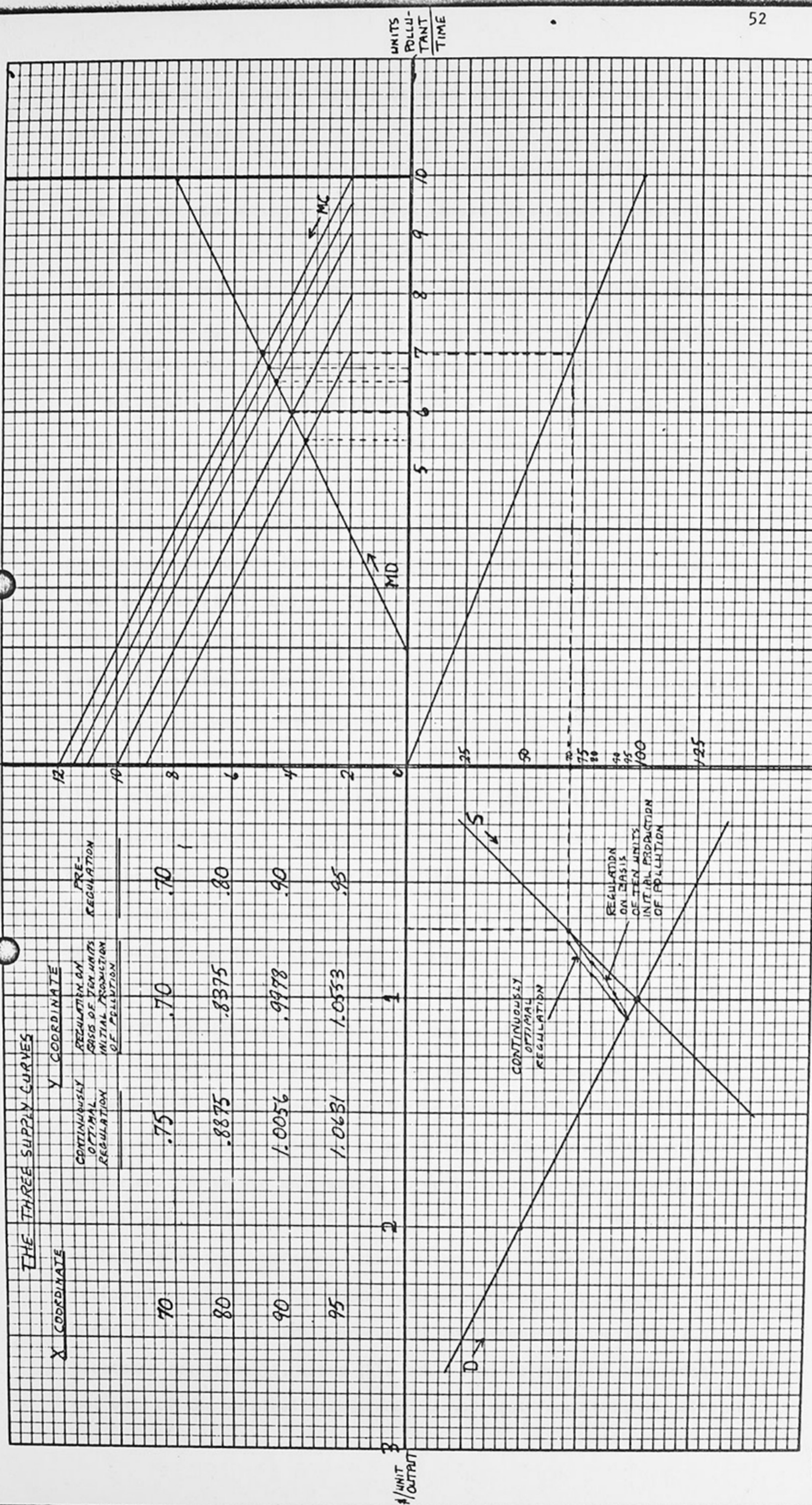
D. THE SHORT-RUN SUPPLY CURVE OF THE OPTIMALLY-REGULATED POLLUTER

If we assume that marginal pollution removal cost and marginal pollution damage curves rise, we can analyze the tatonnement procedure by which the optimal levels of pollution removal and output are determined. The previous section dealt with the determination of the optimal level of pollution removal, given some output level, associated initial pollution level, and product price. But of course equilibrium output levels will fall and product price will rise if costs of production rise (assuming that demand for the output is not completely inelastic, and is unaffected by the changes in question). So let us reexamine Figure 111-5-a, but consider all cost curves and the demand curve to be those of an entire industry. The industry faces a declining demand curve for its product. We assume only (1) the fixed technological relationship between output of the good and production of pollution, and (2) rising marginal removal cost and damage curves.

In Figure 111-7, Quadrant III depicts the equilibrium in the output market when no pollution removal is undertaken. We have postulated a supply curve of $X = 100Y$ and a demand curve of $X \neq 50Y = 150$. One hundred units of the good are produced and sold at a price of \$1. Quadrant I shows the optimum level of pollution removal, given that 100 units of the good are produced; seven units pollutant should be discharged, and three removed. The function in Quadrant IV represents the

FIGURE III-7

I MARGINAL EFFLUENT TREATMENT COSTS AND MARGINAL POLLUTION DAMAGES



III THE OUTPUT MARKET

UNITS OUTPUT
TIME

IV FIXED TECHNOLOGICAL RELATIONSHIP BETWEEN
UNITS OUTPUT AND UNITS POLLUTANT PRODUCED

fixed technological relationship between units of output and units pollutant produced.

If the industry, in equilibrium, were suddenly required to undertake the optimum amount of pollution removal (to remove three units), its supply curve would shift upwards. We can derive a continuous supply curve adjusted for optimal pollution removal costs by reasoning in the following manner. If the industry's owners greatly overestimated the elasticity of demand for their product, and reduced their output to 70, they would incur zero pollution removal costs. There would be an unsatisfied demand for 45 ($= 115 - 70$) additional units at their supply price of \$0.70.

Note, however, that when only seven units of pollution are produced, the optimum level of discharge is 5.5 units, and the optimum level of removal 1.5 units. That is, when production of pollution is reduced, the position of the marginal cost curve in the "bounded" graphical representation shifts to the left, so that it now commences at 7 and rises upward and to the left. The shift of the marginal cost curve will not be a simple parallel shift, because the cost of removing the first of ten units in a given amount of water will be slightly less than the cost of removing the first of eight units in that amount of water, ceteris paribus, and so on through the schedule. To simplify the exposition, however, we represent the shifts as parallel. The fact that the optimum level of removal is a function of the level of production means that the supply curve we are now drawing, on which the point (70, \$0.70) lies, is still not the supply curve adjusted for optimal pollution removal costs at any level of production, but rather the supply curve adjusted for pollution removal costs incurred to attain the optimum pertaining to an initial production of ten units of pollution. We derive this supply curve in addition to the continuously optimal one, because this is the supply curve which will be produced or induced by any regulatory scheme based upon a once-and-for-all calculation of an optimum. No control scheme could hope to readjust requirements in response to firms' production adjustments to the initial treatment requirements, since this would require complete knowledge not only of the marginal damage and removal cost functions, but also of

the demand functions for the firms' products.

To continue with the derivation of the "imperfect" supply curve, let us assume that the owners make slightly better estimates and reduce production to 80. This means they are now producing 8 units of pollutant and removing one, at a cost of about \$3, or $\$3.00/80 = \0.0375 per unit output. At 80 units of output, therefore, the supply price is \$0.8375, and at that price there is unsatisfied demand for an additional 28.125 units. The owners could obtain as much as \$1.40 per unit. They will clearly raise production.

If production were at 90 units, the industry would be producing 9 units of pollutant and removing two, at a cost of about \$7, or $\$7.00/90 = \0.0778 per unit output. The supply price is therefore \$0.9778. At 95 units of output, 2.5 of the 9.5 units pollutant would be removed at a cost of about \$10; the supply price would be \$1.0553. The intersection of this supply curve with the demand curve will occur at a level of output slightly above 95 units.

Now to derive the supply curve adjusted for optimal pollution removal costs at any level of production. At an output of 70, the optimum level of pollutant discharge is now 5.5, so the industry must remove 1.5 units at a cost of about \$3.50, or \$0.05 per unit output. The first point we derive on this supply curve, then, is (70, \$0.75), which may be compared with (70, \$0.70) on the other. At an output of 80, optimum discharge is 6 units, so two units of pollutant must be removed at a cost of \$7, or \$0.0875 per unit output. The supply price is therefore \$0.8875. Similarly, at 90 the supply price is \$1.0056, and at 95 the supply price is \$1.0631. The characteristics of the point of intersection between the "continuously-optimal" supply curve and the demand curve may be described as optimum conditions.

E. THE OPTIMUM CONDITIONS OF PRODUCTION AND EFFLUENT TREATMENT UNDER COMPETITION

In a 1966 article,⁵ Charles R. Plott derived the optimum conditions of production in the presence of external diseconomies, for the two-firm,

⁵Charles R. Plott, "Externalities and Corrective Taxes," Economica, N.S. Vol. 33, No. 129 (Feb. 1966), 84-87.

two-good, two-factor case. He considered the externality problem as one of joint supply. The derivation, with the terminology changed to fit the river pollution model, proceeds as follows:

For the polluter, let

X = output of a good

S = output of suspended solids to be discharged to the river

g = input of gravel-washing (the activity which produces the damaging effluent)

a = input of all other factors of production

P_i = market price of $i = X, S, g, a$

For the damagee, let

L = output of a good

l = input of the factors of production

P_i = market price of $i = L, l$

The polluter maximizes his profits

$$\pi_X = P_X X(a, g) - P_S S(g) - P_a a - P_g g$$

The damagee maximizes his profits

$$\pi_L = P_L L[l, S(g)] - P_l l - P_S S(g)$$

In the absence of bribes, taxes, or subsidies, $P_S = 0$.

Social optimality requires the maximization of

$$\pi_X + \pi_L = P_X X(a, g) + P_L L[l, S(g)] - P_a a - P_g g - P_l l$$

Setting the partial derivatives with respect to a , l , and g equal to zero gives the optimal conditions:

$$(1) \quad P_X \frac{\partial X(a, g)}{\partial a} = P_a$$

$$(2) \quad P_L \frac{\partial L[l, S(g)]}{\partial l} = P_l$$

$$(3) \quad P_X \frac{\partial X(a, g)}{\partial g} + P_L \frac{\partial L[l, S(g)]}{\partial S(g)} \frac{\partial S(g)}{\partial g} = P_g$$

Conditions (1) and (2) are that the value of marginal product of each of the factors must equal the price of the factor. Condition (3)

indicates that the price of the externality-producing factor must equal the sum of the value of its marginal product in the production of the two goods X and L . Since $\partial L / \partial g$ is by hypothesis negative, the pre-regulation factor price P_g must be augmented by a tax on the use of g ⁶

⁶Plott's main point is that the tax must be placed on g or S rather than on X . There is no tax which can be placed on X to fulfil condition (3) without violating condition (1).

equal to the (negative) value of marginal product of g in the production of L . In other words, the tax must equal marginal damage.

A tax on S , the pollutant itself, would be preferable, however, to a tax on g , the pollutant-producing input, whenever the technological relationship between use of the input and production of pollution (the function $S = S(g)$) is not fixed.⁷ To see this, note that the function $S = S(g)$, relating the output of pollutant to the level of usage of the pollutant-producing input, implicitly includes the pollution removal cost function, as well as a technological relationship. Before the imposition of any tax, of course, the pollution removal cost function is irrelevant to the decisions of the firm's manager. A tax on either S or g , however, will induce him to remove pollution up to the point at which the marginal cost of further reductions equals the charge. In the presence of a charge, therefore, optimum conditions (2) and (3) implicitly include the condition that the profit-maximizing polluter has made these reductions. A tax on S is preferable to a tax on g because it would encourage adjustments (perhaps involving research and development outlays, whose present value is less than the present value of expected cost savings) in both the pollution removal cost function and the technological function. However, with a tax on g , the input activity which produces the pollutant, it would never benefit the firm to try to reduce the technological ratio between units pollutant produced and units of the input activity employed.

F. THE EFFECTS OF MONOPOLY

Whether movement from the existing production configuration to the point at which the "continuously optimal" supply curve intersects the demand curve will increase the net value of social product depends upon the current market structure. As Professor J. M. Buchanan has shown,⁸ polluters with some degree on monopoly power impose, in effect, two sorts of external diseconomy on various other members of society,

⁷Plott recognizes but does not develop this point.

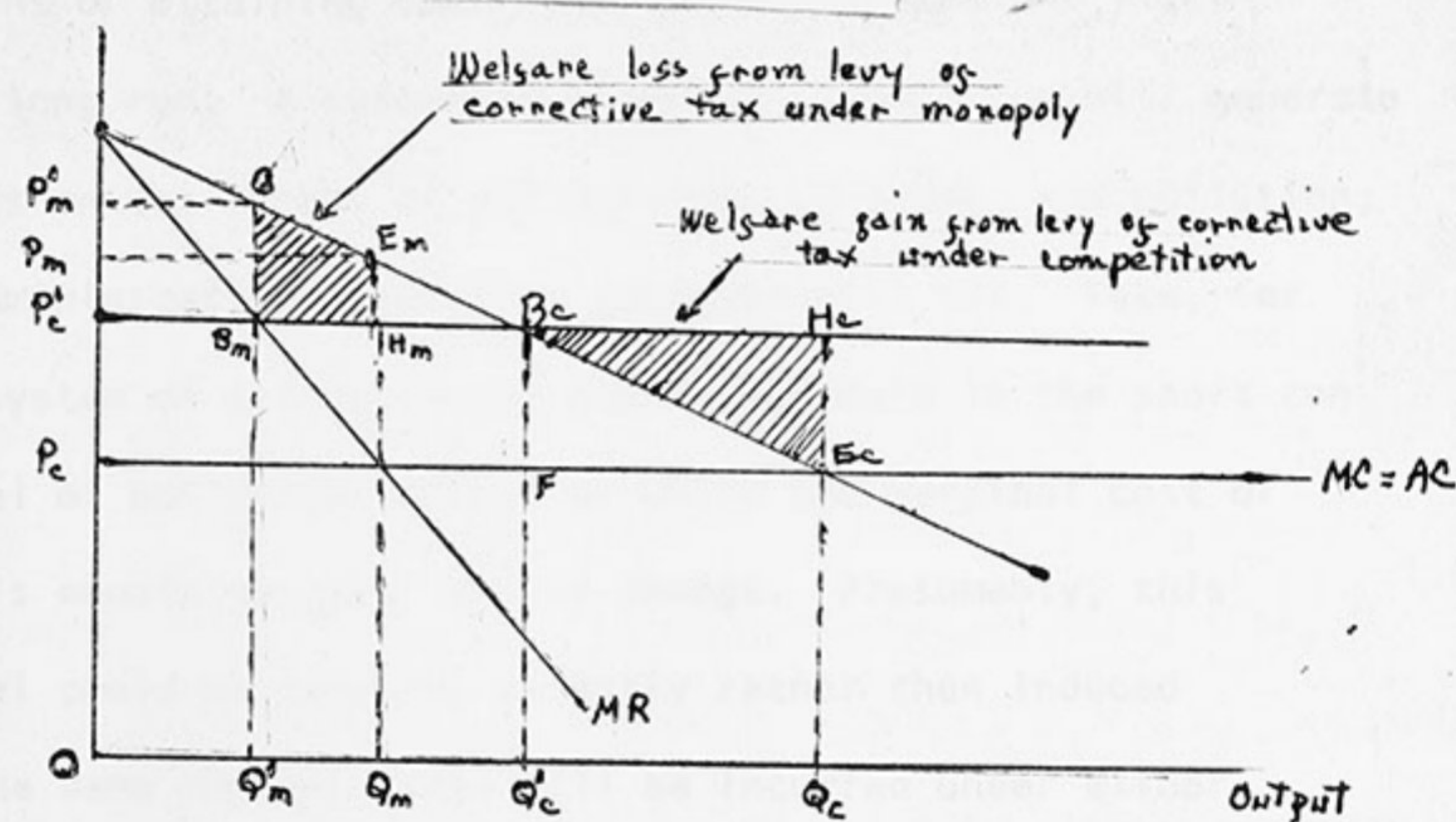
⁸J. M. Buchanan, "External Diseconomies, Corrective Taxes, and Market Structure," American Economic Review, Vol. 59, No. 1, (March 1969), pp. 174-177.

pollution damage, and restriction of output below levels at which marginal cost equals price. If a "corrective tax" (be it an effluent charge or a costly quota requirement) is imposed on the monopolistic polluter, inducing further output restrictions, the net value of social product may well decrease, depending upon whether the loss of consumer satisfaction from the output cuts exceeds the reduction in pollution damage. Dr. Buchanan illustrates this point with the diagram in Figure III-8. The marginal cost curve is assumed horizontal so that the analysis may be entirely in terms of consumer's surplus without considering producer's surplus.

When the industry produces Q_c units of output, as it will under competition, the true social cost of its activity is shown by the area $P_c' H_c Q_c 0$. The imposition of a tax $P_c P_c'$, equal to the external diseconomy per unit, causes production to fall to Q_c' . Assuming (1) that the factors released from the production of Q gain alternative employment in marginal units of other goods, so that factor prices and consumer's surplus elsewhere in the economy are unaffected by this change, and (2) that the money collected as taxes is as socially beneficial as it would have been as part of the total revenue of the industry, we may analyze graphically the social costs and gains of the imposition of the tax. The reduction in social costs is represented by the area $B_c H_c Q_c Q_c'$, whereas the reduction in consumer satisfaction is represented by the area $B_c E_c Q_c Q_c'$. The net welfare gain is thus $B_c H_c E_c$.

If the industry were monopolistic, however, it would initially be producing Q_m units and receiving a price of P_m . The imposition of the tax would cause production to fall to Q_m' and the price to rise to P_m' . The reduction in social costs, $B_m H_m Q_m Q_m'$, is here smaller than the loss of consumer satisfaction, $G E_m Q_m Q_m'$, by the area $G E_m H_m B_m$, which thus represents a net loss of welfare. Under Buchanan's assumptions, there will be a net loss whenever the corrective tax is less than the difference between price and marginal revenue at the preregulation level of output.

FIGURE III-8



Source: J. M. Buchanan, "External Diseconomies, Corrective Taxes, and Market Structure," *American Economic Review*, Vol. 59, No. 1 (March, 1969), Figure 1, p. 175.

G. LONG-RUN ADJUSTMENTS

The imposition of effluent treatment requirements is a legal change exogenous to the economic system, or a change in the ground rules within which market forces are allowed to operate. The change will reduce profits and returns to entrepreneurial capacity in polluting industries, both absolutely and relative to profits and entrepreneurial rent in other industries. Capital and entrepreneurship will flow away from polluting and into non-polluting industries until equilibrium is again established. This process will result in further reductions of both the output of the good and pollution discharges, and still higher prices, as compared with the short-run equilibrium position.

Although it is helpful for short-run analysis to separate the problems of (1) determining the optimum level of pollution, and (2) selecting a means of attaining that level, the problems are inter-related in the long run. A system of financial incentives will generate long-run effects on the output of pollution-based goods, and pollution, which purely administrative regulation (quotas) will not. Take, for example, that system of pollution charges which would in the short run induce the level of pollution removal at which the marginal cost of further removals equals marginal social damage. Presumably, this level of removal could be required directly rather than induced indirectly. The same removal costs will be incurred under either regulatory system. Where charges are used, however, the firm's profits and entrepreneurial rent will be lower, because a charge must be paid on each unit pollutant discharged. Capital and entrepreneurial capacity will flow away from polluting and into non-polluting industries to a greater extent under a charging scheme, so that the long-run composition of output will include fewer pollution-based goods, more non-pollution-based goods, and less pollution than the long-run output basket produced by a quota scheme.⁹

⁹The long-run asymmetry between charges and subsidies has been noted previously. See D. F. Bramhall and E. S. Mills, "A Note on the Asymmetry Between Fees and Payments," Water Resources Research (Third Qtr. 1966), pp. 615-616.

An analogous argument applies to a system of subsidies. In the short run, charges and subsidies have symmetrical effects, since a subsidy per unit removed represents an opportunity cost to the firm in exactly the same way as a charge per unit discharged. The firm's profits and entrepreneurial rent would be greater, however, under a system of subsidies than under a quota system or a system of charges. Thus the long-run composition of output will include more pollution-based goods, fewer non-pollution-based goods, and more pollution, than the output basket produced by a quota system.

These arguments do not militate against the use of financial incentives as opposed to direct regulation, except to the extent that secondary effects whose direction but not magnitude is predictable (without knowledge of demand elasticities for pollution-based products) are undesirable. But also involved in the theoretical choice of a control mechanism (abstracting from implementation costs) are at least three long-run allocational arguments which tend to favor charges over quotas:

(1) Effluent charges provide a continuous incentive to reduce pollution discharges, whenever such reductions become cheaper than paying the charge. Pollution quota systems, by contrast, lack this research-and-development incentive, for they do not motivate polluters to reduce discharges below the quota levels, regardless of cost changes. This incentive effect of charges, however, might accentuate the "second-best" problems of a non-optimal charging scheme. If induced pollution levels were initially "too low" (charge higher than marginal damage), then the substitution of a cheaper removal process for payment of the charge on the marginal unit would increase net social product only if the savings to the firm (charge minus removal costs) exceeded the difference between lost revenue to the regulatory authority and the value of the reduction in damage (charge minus marginal damage). If induced levels were initially "too high" (charge lower than marginal damage), this problem would not arise, since there would be a gain to the firm, and the loss to the regulatory authority would be exceeded by the reduction in damage.

(2) The second allocation argument also has to do with research, but is one step further removed from actual removal costs. The argument applies both to charging and quota schemes, which embody the principle of a "right to be free from pollution," as distinguished from a subsidy scheme based implicitly on a "right to pollute," but to a greater extent to charging schemes, on account of their continuous incentive. It is that the costs of finding ways to avoid damage will generally be smaller for polluters than for the damagees. Managers of polluting firms will have knowledge of many alternative ways to reduce discharges, some of which may be cheaper than effluent treatment at individual outfalls. These might be process changes, materials recovery, better supervision, or collective treatment. The costs of organizing collective treatment would tend to be smaller for polluters than for damagees because (1) polluters would have better knowledge of current techniques and research options, and (2) there are fewer polluters, or at least polluters' representatives, than damagees. Of course, costs of finding ways to avoid damage may be small compared to the damage avoidance costs themselves. This argument does not affect our conclusion below that it will generally be more costly to remove pollutants at source than the resultant reduction in damage to downstream water abstractors would justify. That conclusion has to do with damage avoidance (pollution removal) costs, and is based on actual river flow and cost figures, the latter presumably already representing the least-cost method of removing pollutants available to the polluter.

(3) The third argument for charges depends on the existence of competitive conditions in the polluting industry: a tax on external diseconomies is a preferable means of raising government revenues than some types of taxes now in existence. Unlike an income tax, it would not distort the choice between work and leisure. And whereas excise taxes generally distort choices among goods by raising the prices of taxed goods above their social opportunity costs, taxes on external diseconomies would up to a point reduce whatever distortion already present in relative prices of pollution-based and non-pollution-based goods arises from the fact that some of the external diseconomies of the former do not appear in their prices, which are as a result below

social opportunity costs. Of course, this argument is invalid under the conditions identified by Buchanan and discussed in Section F of this chapter.

We shall again take up the debate between charges and quotas in a more practical context. (See Chapter V, Sections C and D). Our purpose here has been to demonstrate on a theoretical level the connections between the goal of optimal allocation and the methods available for attaining the goal.

H. SUBOPTIMIZATION AND SEPARATE FACILITIES

A disturbing possibility arises when the Trent River Basin is viewed, not as a separate economic entity, but in the context of the country as a whole. The net value of social product for a Great Britain in which all river systems were moderately polluted at first, might rise if the Trent river system were converted to an open sewer while other rivers were allowed to revert to a state of pristine purity.

Professor E. J. Mishan refers to this possibility as the "separate facilities" option. Even if the economy were at some sort of social optimum in the presence of external diseconomies, it might still be moved to an optimum optimorum by removing "the condition that opposite-minded groups are constrained to inhabit a common area."

More precisely, the value of the gain in social welfare in moving from the constrained optimal solution to the separate-facilities solution is equal to the minimum payment that had been necessary to compensate the affected members of the group for their loss of amenity (for once the latter solution is embraced such members do not lose any amenity and do not, therefore, require compensation) plus the maximum the erst compensators would give in order to have their separate facilities that allow them fully to indulge in the activity in question. The separate-facilities solution is, then, superior whenever this gain added to the saving of costs necessarily incurred in determining and maintaining the compensation-induced solution together exceed the costs, if any, required to provide separate facilities rather than facilities in common.¹⁰

Separate facilities arrangements abound in the real world. They are the *raison d'être* of many restrictive covenants in private property

¹⁰E. J. Mishan, *The Costs of Economic Growth*, Hammondsworth: Penguin Books Limited, 1967, note 2, pp. 115-116.

transactions, of local government zoning restrictions, and of special smoking areas on trains and in theatres, as a few examples. They are less applicable to single river basins, because of the physical interdependencies arising from the river's flow. For example, the Tame cannot be written off as an open sewer, with the idea of keeping the Trent clean, because the Tame joins the Trent before a third of the latter's journey is completed. (This is not to say that optimum quality may not be attained by leaving the Tame an open sewer until the confluence, then treating the whole stream before it empties into the Trent, particularly if the amenity value of the Tame is relatively small.) But it would be possible to reserve, say, the Dove and the Derwent, or the upstream reaches of the Trent, from all discharges. The costs of this sort of approach could be measured to some extent by the Trent river model, by placing very high quality constraints on the Dove or Derwent or Upper Trent reaches, and lower goals elsewhere.

An example will highlight some of the factors which will determine the optimal allocation of pollution among river systems: (1) recreationists' damage levels, which are a function of tastes and travel costs to alternative recreational facilities, (2) costs of transporting pollution, and (3) population adjacent to each site. Imagine that there are two neighboring "circular rivers," near each of which lives a polluter. Each polluter dumps all of his wastes into the river nearest his home, and suffers all the damage arising from his own pollution. This situation, depicted in Figure III-9 (ignoring A_2 for the time being), may not be optimal.

To begin with, assume that each of the polluters A_1 and B makes identical discharges of 50 units; costs per unit pollutant transferred from A_1 to R_2 , or B to R_1 , are identical and constant; marginal damages per unit pollutant in their respective rivers rise linearly for both A_1 and B; neither polluter is damaged by pollution in the distant river; and A_1 's marginal damages per unit are twice as high as B's. In Figure III-10, A_1 's marginal damage function is OR, and that of B is QP, reading from right to left. Before any changes are made, therefore, A is suffering marginal damages of \$25 from the 50th unit of his own pollution, and B is suffering marginal damages of \$12.50. So

FIGURE III-9

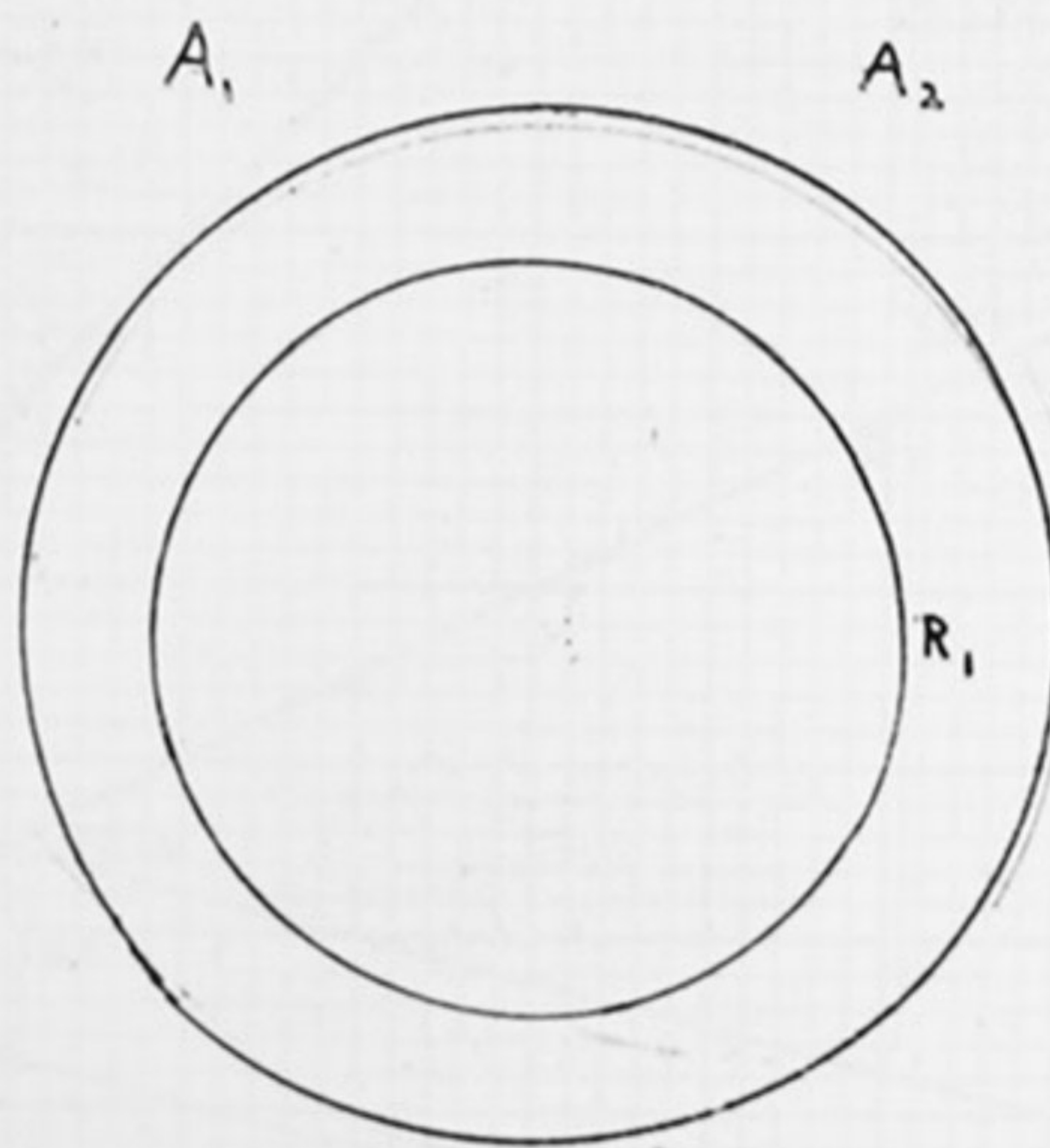
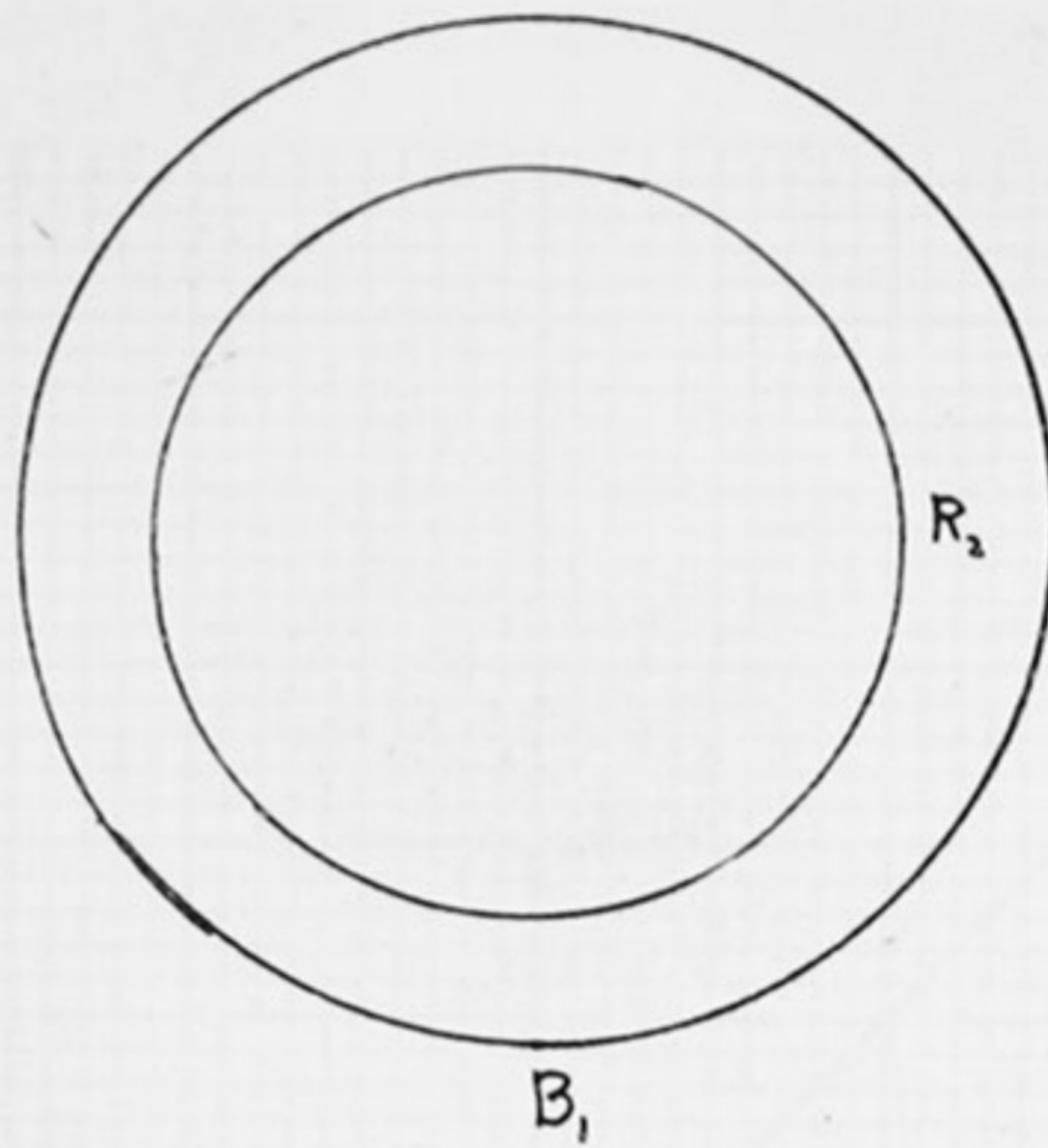
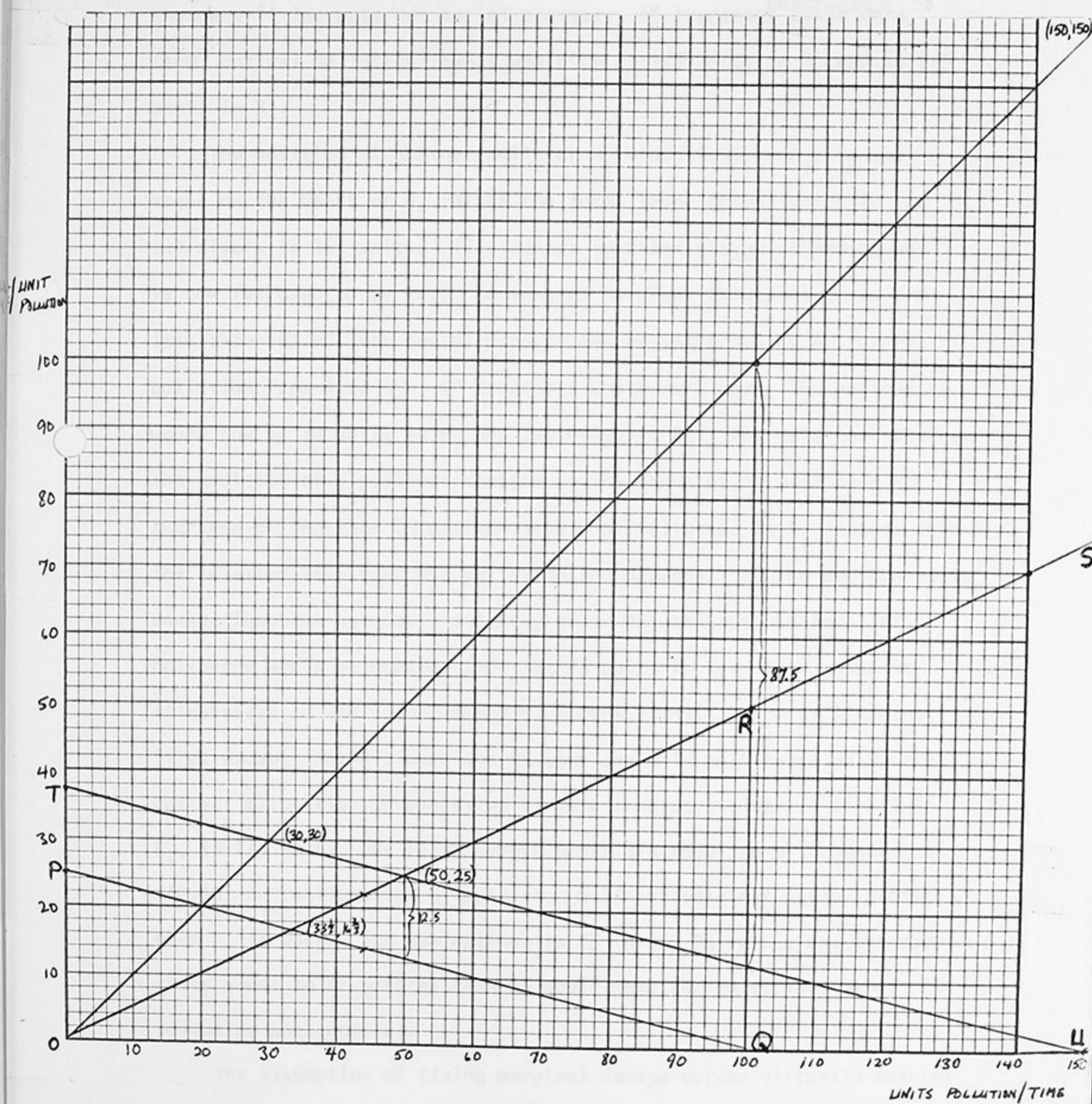


FIGURE III-10

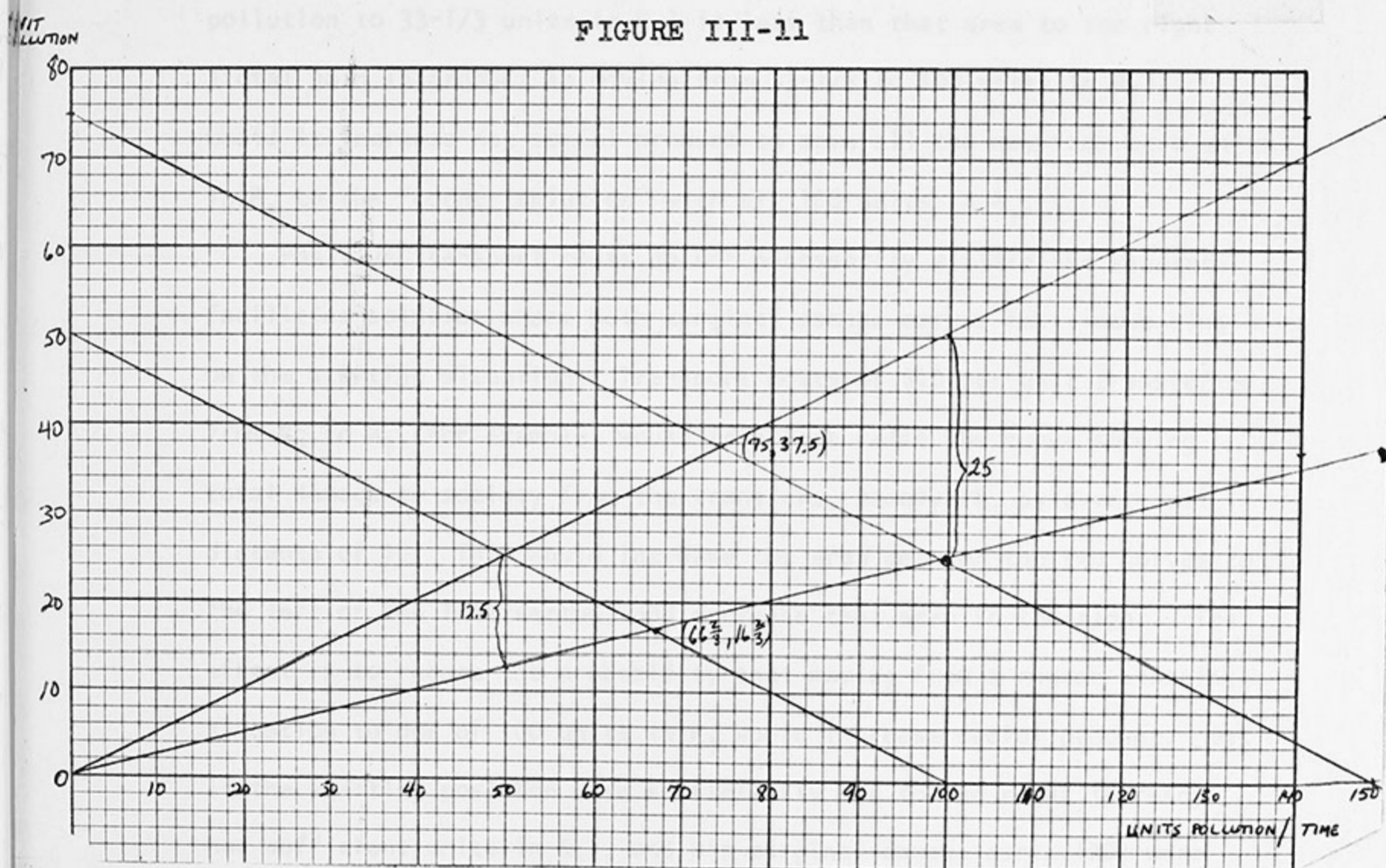


long as transport costs are less than the vertical distance between the two marginal damage functions (here \$12.50), it will increase net social product to move to the point at which transport costs equal that distance. In this case, transferring pollution from R_1 to R_2 will impose marginal costs on B, but so long as these costs added to marginal transport costs are less than marginal damages to A_1 , the change will increase net social product. If transport costs were zero, optimal pollution levels would be $33\frac{1}{3}$ units in R_1 and $66\frac{2}{3}$ units in R_2 .

The addition of another polluter A_2 , identical to A_1 , to the scene on the banks of R_1 raises the total level of pollution in the two rivers to 150 units. (B's damage function has not changed, but is now represented by TU.) So long as marginal transport costs are less than \$87.50, net social product can be increased by a transfer of pollution from R_1 to R_2 . If transport costs were zero, the optimum would now be 30 units in R_1 and 120 units in R_2 . But note that whether the addition of a polluter-damagee to the banks of R_1 will mean a decrease or increase in optimum levels of pollution in R_1 depends upon the relative levels of his pollution and damages. If the new aggregate damage function were only slightly above OS, the optimum level of pollution would be greater than $33\frac{1}{3}$ units in R_1 . This point is illustrated in the second example, Figure III-11, which is like the first except that A's marginal damages are only half those of B. The optimal allocation of pollution at zero transport costs is $66\frac{2}{3}$ in R_1 , $33\frac{1}{3}$ in R_2 , and if transport costs are equal to or greater than \$12.50, no reallocation of pollution will increase net social product. When A_2 is added, the new optimum is 75 in R_1 , 75 in R_2 , and transport costs equal to or greater than 25 would make any redistribution of pollution uneconomical.

The assumption of rising marginal damage curves virtually assures that the optimal allocation will not be "separate facilities" (except in cases where one curve is completely predominant). If, on the other hand, marginal damage curves fall, then separate facilities would generally be optimal, assuming transport costs are zero. For example, if in Figure III-10 the curve PQ represents A's marginal damage, from

FIGURE III-11

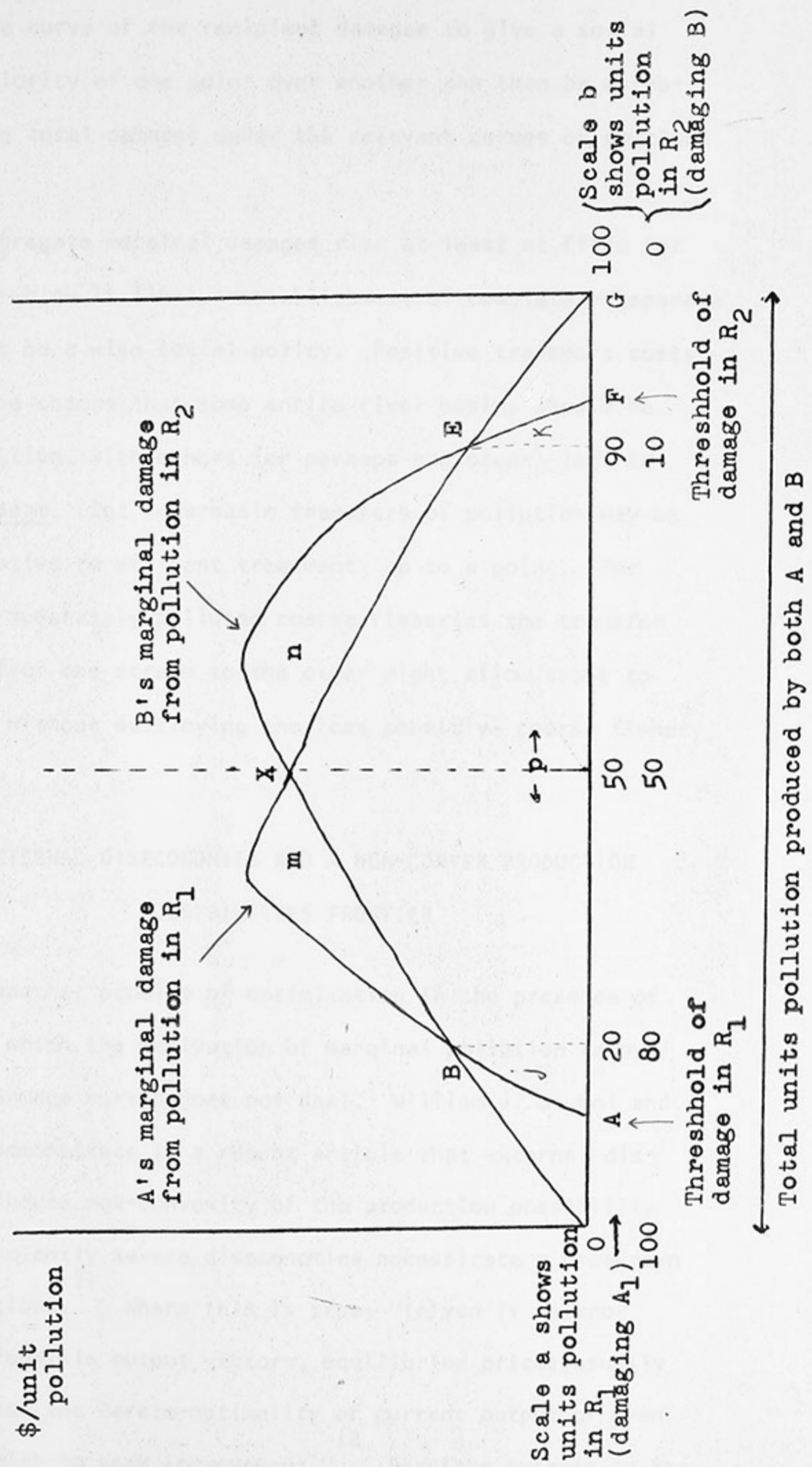


left to right, and R_0 depicts B's marginal damage, from right to left, net social product will be maximized if the 50 units originally being dumped into R_2 are all transported to R_1 . If the initial position has $33\frac{1}{3}$ or more units in R_1 , it will increase net social product by an increasing amount to shift units of pollution from R_2 to R_1 , until all units are transferred. But if the initial position has fewer than $33\frac{1}{3}$ units in R_1 , it will reduce net social product (by decreasing amounts) to shift pollution from R_2 to R_1 , until there are $33\frac{1}{3}$ units in R_1 . In this case, only if the area between the two curves to the left of their intersection (total loss in social product in moving from zero pollution to $33\frac{1}{3}$ units in R_1) is less than that area to the right (total gain in product in moving from $33\frac{1}{3}$ to 100 units in R_1), would it increase net social product to move all the way from zero units in R_1 to the "corner solution" with all 100 units in R_1 .

Positive transport costs do not necessarily vitiate the separate facilities solution where both marginal damage curves fall, depending on the starting situation. Transport costs of \$10 per unit transferred from R_2 to R_1 , for example, would in effect raise the curve showing total damage to society from the transfers, namely PQ, by a vertical distance of 10. This would increase the area between the two curves to the left of the intersection, and decrease that area to the right. The effect is to reduce the probability that moving from a random starting situation to one of 100 units in R_1 would increase social product. But if the starting position were sufficiently far to the right (already had sufficient units in R_1), and B's marginal damage curve (R_0) were sufficiently high relative to A_1 's, the optimum could still very well be 100 units in R_1 .

If marginal damages first rise (after some threshold level is reached), then fall, as in Figure III-12, the multiple intersections of the damage curves would disallow "movement towards an optimum," though not necessarily the existence of an optimum. The two allocations of pollution which are clearly superior to the others are B, at which the 20 units in R_1 cause total damages of j to A_1 , and the 80 units in R_2 cause damages of $(k + n + p)$ to B, and E, at which the 90 units in R_1 cause damages of $(j + m + p)$ to A_1 , and the 10 units in R_2 cause

FIGURE III-12



damages of k to B . If m exceeds n , the optimum is B ; if not, the optimum is E . B and E would be corner solutions if the damage thresholds were zero units. Transport costs, again, can simply be added to the marginal damage curve of the recipient damagee to give a social cost curve. Superiority of one point over another can then be established by comparing total damages under the relevant curves or portions thereof.

So long as aggregate marginal damages rise at least at first for all river systems--which is likely--establishment of completely separate facilities will not be a wise social policy. Positive transport costs further diminish the chance that some entire river basins should be reserved from pollution, with others (or perhaps the ocean) left to deteriorate ad nauseam. But interbasin transfers of pollution may be an economic alternative to effluent treatment, up to a point. For example, given two moderately polluted coarse fisheries the transfer of some pollution from one stream to the other might allow trout to live in the former without destroying the less sensitive coarse fishery of the latter.

I. EXTERNAL DISECONOMIES AND A NON-CONVEX PRODUCTION POSSIBILITIES FRONTIER

There is yet another problem of optimization in the presence of externalities with which the derivation of marginal pollution removal cost and marginal damage curves does not deal. William J. Baumol and David F. Bradford demonstrate in a recent article that external diseconomies tend to induce non-convexity of the production possibility set, and that sufficiently severe diseconomies necessitate a breakdown of convexity conditions.¹¹ Where this is true, "[e]ven if we know the entire set of feasible output vectors, equilibrium prices usually tell us nothing about the Pareto-optimality of current output or even the direction in which to seek improvement."¹² Feasible outputs to the

¹¹ W. J. Baumol and David F. Bradford, "Detrimental Externalities and Non-Convexity of the Production Set," *Economica*, Vol. 39, No. 174. (May, 1972), 160-176.

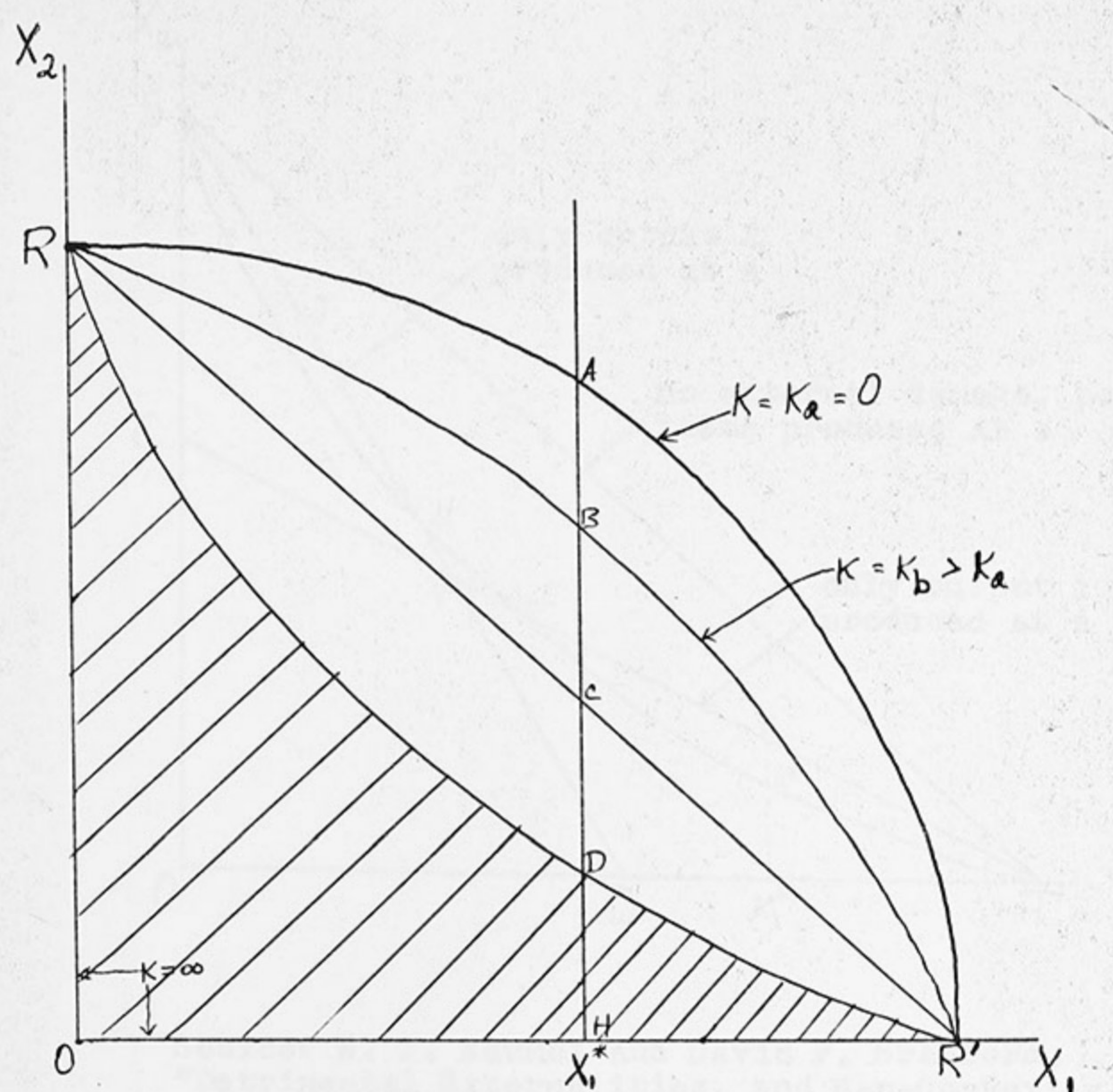
¹² Baumol and Bradford, "Detrimental Externalities," p. 173.

northeast of the price line tangent to the concave community indifference curve and the concave production possibilities frontier can be more valuable than the output basket at the point of tangency, and yet not preferred.

One of the three ways in which Baumol and Bradford prove their point involves the use of Figure III-13. In this figure, X_1 and X_2 represent, respectively, quantities of electricity, whose production creates smoke which raises the costs of the laundry producer, and laundry. The sole factor of production is labor, and RAR' represents the production possibilities frontier in the absence of externalities. The parameter k measures the incremental cost of cleaning a given batch of laundry attributable to the production of an added unit of electricity, so $k = 0$ along RAR' . As k increases, the positions of the endpoints R and R' of the production possibilities frontier remain unchanged, but all other points on the locus must shift downward. An increase in the value of k , for any given output of electricity and a fixed quantity of resources, implies that a smaller quantity of clean laundry can be produced. When electricity output is at X_1^* , for example, a sufficiently high value of k must limit the feasible production set to a non-convex area such as $RDR'O$.

Baumol and Bradford show in addition that the possibility of a separate facilities solution limits the potential extent of the non-convexity. The basic argument is from Figure III-14, which assumes linear substitution relationships in the absence of externalities, though the authors later remove this condition and generalize the argument. Outputs X_1 and X_2 can be produced at either of two locations a and b . Segment ST is the production possibilities frontier in the absence of externalities and when both X_1 and X_2 are produced at a , by hypothesis the more economical location. SD is the boundary of the smaller set of outputs (taking into account transport costs) which is possible if the production of X_1 is moved to b while that of X_2 takes place at a . CT is the production possibilities frontier when X_1 is made at a , while the production of X_2 is moved to b . Now let the externalities arising from the production of X_1 at a , grow so serious that the production possibilities frontier is reduced to $SUWT$.

FIGURE III-13



Source: W. J. Baumol and David F. Bradford,
 "Detrimental Externalities and Non-Convexity
 of the Production Set," *Economica*, Vol. 39,
 No. 174 (May, 1972), Figure 2, p. 164.

"Then, if society wishes to produce, say, quantity X_1^* of item 1, it can only obtain X_2^{*k} of X_2 if both goods continue to be produced at a. However, by separating the two production processes--shifting the manufacture of item 2 to site b--the community can increase its output of commodity 2 to X_2^{*k} ."¹³ Externalities cannot reduce the production possibilities frontier below SVT.

Baumol and Bradford prove, finally, that the tendency of external diseconomies to induce non-convexity in the production set does not necessarily mean that taxes or charges on pollution cannot be used to attain some known point on the production frontier, because "non-convexity in the social production possibility set is compatible with convexity in the sets over which individual producers make their choices."¹⁴ But the role of prices as indicators of social value is destroyed by non-convexity in the social production possibilities frontier.

¹³ Baumol and Bradford, "Detrimental Externalities," p. 167.

¹⁴ Baumol and Bradford, "Detrimental Externalities," p. 171.

CHAPTER IV

PROBLEMS OF DERIVING MARGINAL POLLUTION REMOVAL COSTS AND DAMAGE FUNCTIONS

In the last chapter we showed that there is much more to the problem of determining optimal pollution levels than the derivation of marginal pollution removal cost and marginal damage functions. In fact, there are at least four conditions under which the derivation of such curves, and nothing more, would give little help to an optimality-seeking river authority:

- (1) An optimum may not exist.
- (2) Monopolistic elements in the polluting industry may mean that the imposition of pollution taxes which are "optimal" in the sense that they equal marginal damages and marginal pollution removal costs, actually reduces net social product.
- (3) A separate facilities solution might be superior to the apparent optimum shown by the curves.
- (4) If externalities are sufficiently strong that the production set is non-convex, then the tax-induced output set, though preferred to another feasible output set, may be less highly-valued than that output set in terms of existing prices.

It is instructive, nevertheless, to consider possible means of deriving these curves in the context of the Trent River Basin. This chapter is devoted to the search for a method of constructing marginal removal cost and damage curves which are based to the extent possible on prices and quantities revealed in real-world transactions. By showing that the theoretical uncertainties of the search for optimum pollution are compounded by a myriad of practical difficulties, this exercise leads ultimately to the conclusion that the contribution of economic theory to public policy in the field of river management is limited to broad common-sense prescriptions of marginal analysis, of the type we discuss in the final chapter.

A. The Assumptions Behind the Curves

In order to construct functions relating marginal damage per unit pollutant discharged and marginal cost per unit pollutant removed, we must make several simplifying assumptions.

(1) The first might be called the "circular river assumption," that a unit of pollutant discharged at any point in the river system will cause the same damage. In an actual river system, the biodegradable pollutant concentration at a downstream abstraction point will be different from that at the discharge point, because of the regenerative action of the river on the organic load it is carrying. A discharge by the last downstream river user harms no other riparian, whereas that same discharge by the first upstream user damages all others to different extents, depending on distance from the pollution source. The harm to the average damagee is a sum of damages attributable to the discharges of many polluters. But a marginal damage curve can at best only relate changes in total (or average) levels of pollutant in the river system as a whole to changes in total (or average) damage to all damagees. The cost curve approach to determining optimal pollution levels thus will fail to some extent, on account of the aggregation inherent in the method, to make the optimal use of the assimilative capacity of the river. There can be no attempt to find different goals for different reaches. The method aims to find an optimum total amount of pollution to be discharged, from whatever source, into the river.

The "circular river" assumption is not as unrealistic as might appear at first glance, however, because of the dispersion of polluters and water users along a real river. Take, for example, a river system in which there are three identical polluters and three identical damagees (say, water treatment plants, or fishermen), and constant flow. Let the polluters (P_1 , P_2 , and P_3) be paired with the damagees (D_1 , D_2 , and D_3) in such a way that the first discharge imposes extra costs on the first water treatment facility, but is diluted and broken down to such an extent that its effect on the second and third facilities is negligible. Make the same assumption for P_2 - D_2 and P_3 - D_3 . In this case average damage will equal individual damage. Dispersion of dischargers and water users thus tends to reduce the damage differentials

resulting from the distance-proportional self-purification of the river.

- (2) The second assumption is that damages are a function of mean water quality (mean pollutant concentration). In actual fact, the quantities of many discharges vary considerably on a daily, weekly, or annual basis, and river flows fluctuate widely. For example, the flow of the River Trent at Trent Bridge, Nottingham, ranged in 1968 from a minimum of 700 mgd to a maximum of 8365 mgd.¹ It would thus be desirable, though not possible on the basis of available data, to construct marginal damage functions, for the same range of pollution discharges, for two flow conditions, summer (low-flow) and winter. Since the low-flow damage curve would be above the other, it would intersect the marginal treatment cost curve to show lower optimal pollution loads and higher associated charges. The latter could be applied during the summer periods of peak pollutant concentrations.
- (3) We assume, thirdly, that damage functions are separable, that is, that pollutants neither react synergistically nor cancel out each other's detrimental effects.
- (4) The marginal treatment cost and marginal damage functions are assumed to be continuous.
- (5) Finally, the product price confronting each polluter, output, and total units pollutant produced by each polluter, are again assumed constant.

B. THE MARGINAL WASTE TREATMENT COST CURVE

1. Published British Cost Surveys

Most of the published information which could conceivably be reinterpreted in terms of the costs of pollution is in the form of average annual costs of various types of effluent and water treatment.

The sources are:

1. Bradley, R. M. and Peter C. G. Isaac. "The Cost of Sewage Treatment." Inst. of Wat. Poll. Control, Conference Paper No. 4, Oct. 25, 1968.
2. Townend, C. B. "The Economics of Waste-water Treatment." Proc. Instn. civ. Engrs. 15, 1960, 209-230.

¹T. R. A. Annual Report, 1969, p. 83.

3. Subcommittee of Association of Joint Sewerage Boards. "Study of the costs of tertiary treatment processes." Upper Tame Main Drainage Authority, mimeo.
4. Harkness, N. "Charging for Treatment," U.T.M.D.A., mimeo.
5. Harkness, N. "Methods of Charging for the Reception, Treatment, and Disposal of Toxic Wastes." Inst. of Wat. Poll. Control, Annual Conf. (18 Sept. 1969), Paper No. 20.

The Townend and Bradley-Isaac studies survey both capital and operating costs of a sample of sewage works, but give results in terms of total annual per capita costs of various sizes of plants. The effluents received by the different plants are not necessarily identical, nor are they treated to the same standard. This makes it virtually impossible to translate the per capita figures into figures showing costs per (uniform) unit of effluent treated to a given standard. Bradley and Isaac deplore the "lack of reliable flow data" which prevents such calculations. The Harkness report of sewage treatment costs at Birmingham and Slough does calculate costs of treatment per thousand gallons of sewage passing through the system, by simply dividing total annual expenses of sewage authorities for precepting purposes by the annual average volume of sewage over the previous three years. Again, however, the sewage before treatment is not of uniform quality, nor is it treated to uniform standards. The same problem arises with the Association of Joint Sewerage Boards study of capital and operating costs of tertiary treatment, where results are expressed per thousand gallons of sewage treated. There are, however, very few other published surveys of actual municipal sewage treatment costs in Great Britain, and none which provide a breakdown of costs better adaptable to present purposes.

Certain information on the Bradley-Isaac and Towend reports can be used to support the hypothesis that marginal costs per unit pollutant removed rise as more units are removed. The three possible stages of sewage treatment remove BOD from raw sewage in roughly the following way:

Primary	350 mg/l	to	160 mg/l
Secondary	160 mg/l	to	20 mg/l
Tertiary	20 mg/l	to	5 mg/l

Bradley and Isaac estimate that the capital costs of primary and secondary treatment comprise 23 and 42%, respectively, of the total annual costs of a typical effluent treatment facility.² Assuming that capital costs attributable to sludge removal, responsible for an additional 27%, are divided about equally (primary treatment creates slightly more sludge, but it is less costly to remove from screens than from the biological filters of secondary treatment plant), primary treatment accounts for 37%, and secondary treatment 55%, of the capital costs of a treatment works. Operating costs are put at 42% for primary, and 35% for secondary treatment (including sludge removal).³ (Townend, on the other hand, says that operating costs--including sludge removal, divided equally--are 30% of the total for primary treatment, and 50% for secondary.⁴) Capital costs are by far the most important element of total annual costs: Bradley and Isaac found that debt charges consistently amounted to 69% of total annual cost--for a wide range of plant sizes--see Appendix Figure B. Data collected for the Trent Research Programme, relating to 83 sewage treatment plants of very different sizes in the Trent River Basin, indicate⁵ that annual loan repayments account for 73-75% of total annual costs. If we use only the Bradley-Isaac figures, then, primary treatment accounts for 36% of total annual costs, and secondary for 51%. (Both the Townend and Trent Research Programme data would weight the costs more heavily for secondary treatment.) Since secondary treatment generally removes somewhat fewer units than primary, it is clear that average costs per unit pollutant removed are higher for secondary than for primary treatment. Marginal costs may thus be said to be rising as raw sewage is treated from 350mg/l to 20mg/l, though this evidence is certainly no basis for constructing a continuous marginal cost curve.

² R. M. Bradley and Peter C. G. Isaac, "The Cost of Sewage Treatment," Institute of Water Pollution Control, Conference Paper No. 4, October 25, 1968, p. 6.

³ Bradley and Isaac, "Cost," p. 30.

⁴ C. B. Townend, "The Economics of Waste-water Treatment," Proceedings of the Institute of Civil Engineers, Vol. 15 (1960), p. 223.

⁵ See the computer printout table, "Additional Analysis of Sewage Works Costs: Sewage Works Costs Above 1971 ET2 Costs--As Baseline"--River Model--10B--LGORU 1970.

No comparable data is available for tertiary treatment. This additional "polishing" treatment is presently undertaken in very few plants, because of its expense (there are institutional constraints on how much local authorities can spend on sewage treatment). Since tertiary treatment will generally involve an additional filtration process, for the same volume of water as that treated by biological filtration (secondary treatment), capital and operating costs are probably similar to those of secondary treatment, though only a tenth as much BOD is removed. Treatment beyond the tertiary stage would require electrodialysis or distillation to remove the last four or five mg/l BOD, so that the end of the marginal cost curve would undoubtedly swerve sharply upward.

2. Data from the Trent Research Programme

The Trent Research Programme has projected capital and operating costs of three types of municipal sewage plant and nine types of water treatment plant. Each type of effluent treatment plant is defined by the quality of its outflow, for it is assumed to receive the same quality intake as any other type. See Appendix Figure C. Dividing the associated costs by flow gives average costs of treatment (to different standards) per unit of intake water (of the same standard). For sewage works, average flow is assumed to be 1.33 times the dry weather flow. Capital and operating costs as a function of plant capacity were best described by the following equations, calculated on the basis of survey data (where Q = dry weather flow):

$$\text{ET2: (1969 prices, £): Capital cost} = 423253Q^{0.7814}$$

$$\text{Operating cost} = 14454Q^{0.67}$$

$$\text{ET3: } 1.15 \times \text{ET2 cost (capital and operating)}$$

$$\text{ET4: } 1.25 \times \text{ET2 cost (capital and operating)}$$

Annual repayments are determined by multiplying capital cost by the factor

$$\frac{i(1+i)^n}{(1+i)^n - 1},$$

where i is the discount rate, and n the expected life of the facility.

For most model calculations the life of a sewage plant was assumed to be 30 years, and the interest rate 8 1/2% per annum; for these figures the

factor above is 0.0931.⁶

But the three types of effluent treatment plant, ET2, ET3, and ET4, do not correspond neatly to primary, secondary, and tertiary treatment. ET2 includes both primary and secondary treatment. The shift to ET3 affects ammonia levels but not BOD, and the addition of ET4 reduces BOD but not ammonia. Thus for either of these two basic pollutant parameters, the Trent Economic Model data makes possible only two calculations of cost per unit pollutant removed: (1) from ET0 (no treatment) to ET2, and (2) from ET2 to either ET3 or ET4. These figures are not very useful for constructing a marginal cost function, but some rough calculations of average cost are made with this data later in this chapter.

Each type of water treatment plant in the Trent Economic Model is defined by the quality of its intake, as shown in Appendix Figure D. All intake water is treated to the same standard of "potability," but this is a complicated standard indeed, and BOD is not one of the parameters customarily measured in drinking water (Appendix Figure E). The costs associated with each type of water treatment facility (Appendix Figures F-S) may be divided by flow to get average costs of treatment (to the same standard) per unit of intake water (of different standards), and we make some rough calculations later in the chapter. Again, however, there is simply not sufficient data to allow marginal cost calculations.

To summarize, there are two types of data for treatment plants: costs of treating the same effluent to different standards, and costs of treating different river water to the same standard. The former show average costs as a function of degree of elimination of pollutant, and the latter average costs as a function of degree of initial concentration of pollutant.

The Trent Research Programme has also provided some estimates of the cost of treating the entire River Tame, by means of a river purification lake. On the basis of data collected at experimental plants at Elford and Lea Marston, researchers have compiled a table showing the effects of a river retention lake on the annual mean quality of the

⁶This information was provided in interviews with Dr. Anthony Warn at the offices of the Water Resources Board in Reading, February, 1972.

River Tame. See Appendix Figures T, U, V, W, and X. The mean flow of the Tame at Lea Marston in 1968-69 was 282 mgd, and mean BOD concentration 20 mg/l. Roughly 8 mg BOD are thus removed from every litre of water by the lake. The annual cash flow of the river retention lake has been estimated at £645,520. (This estimate is not considered to be as reliable as those for effluent and water treatment processes, since it is not based on figures for existing installations, from which a generalized cost curve has been constructed, but instead on estimates of future land costs and costs of flow diversion facilities.) The annual cash flow is thus about 7.16×10^{-3} pence per mg BOD removed.

If the mean BOD concentration of the Tame were that of raw sewage, about 400 mg/l, then 160 mg BOD would be removed from every litre of water. Annual cash flow would then be 3.6×10^{-4} pence per mg BOD removed. These figures, besides being very rough, are not directly comparable to those derived for effluent and water treatment plants in the previous section, because of the arbitrary assumptions governing the derivation of the latter.

At this point it is helpful to recall the physical nature of the pollution problem in the Trent Basin. Most of the effluent from Birmingham's industries and municipal sewage plants is discharged to the River Tame, 80% of whose flow during the summer is sewage effluent. At the Trent confluence, the mean annual flows of the Tame and the Trent are about equal, at 280 mgd; the flow of the Trent increases to about 1600 mgd by the time it reaches Nottingham. The Trent must carry the tremendous pollution load introduced by the Tame for most of its length. The effect of the Tame purification lake described above on the downstream quality of the Trent has been estimated. See Appendix Figure Y.

An additional benefit of a river purification lake is the insurance it would provide against storm-induced pollution gluts. BOD and suspended solids levels can more than quadruple in a matter of hours during a severe storm, because of surface runoff to the combined sewerage system and the river. A lake would allow most of the excess load to settle, before the Tame flows into the Trent. It is difficult, however, to measure incremental recreational damages accruing from such storm gluts, or from accidents. If the cost of insuring against the damage is considered

a measure of the damage, then this type of damage is already accounted for in the cost of a river purification lake.

Annual cash flows have not been calculated for several lakes of different sizes and retention times, so it is not possible to construct a marginal cost function, per unit pollutant removed, for a river purification lake.

Some alternatives to treatment at individual outfalls which have been considered and used in other countries, such as mechanical reoxygenation and redistribution of effluent, have not been considered at all in the Trent context. Another alternative, river regulation by means of dams and reservoirs, has been used to control river quality in some areas of the United States by storing winter water to augment the naturally lower summer flows. Since most pollution discharges do not vary seasonally, river quality is much lower during the summer. And because recreation demand is much higher in the summer, the benefits of river regulation (reduced recreation damage in summer) may exceed the costs (of dams, reservoirs, inundated land, and increased winter damage). But the use of dams and reservoirs has been considered, for the Trent system, only as insurance that municipal water suppliers will be able to maintain constant flows to households and industries, rather than as instruments of quality regulation. Indeed, the report of the Local Government Operational Research Unit states, "It is worth noting that regulation itself does not affect mean flow; it is assumed not to affect quality either."⁷ The reservoirs which have been considered (on the Rivers Dove and Derwent within the basin, and the Severn and Dee outside) are of such a small size that their combined discharges would not have an appreciable effect on the quality of the main river.

3. The Frankel Study

A marginal cost curve of sorts, for pollutant removal by water treatment plants, can be derived from data provided by Richard J. Frankel (Figure IV-1a), from his study of the costs of municipal waste disposal and water treatment in the Eel River Basin in California. These data give marginal costs imposed on a downstream municipal treatment plant, by a

⁷L.G.O.R.U., Trent Economic Model, p. 69.

Average Total Annual Costs Imposed on Water Treatment Operation by Disposal of Raw Domestic Sewage Upstream FIGURE IV-1 (a)

		2.5-mgd Sewage Discharged 5 mi Upstream		2.5-mgd Sewage Discharged 10 mi Upstream		2.5-mgd Sewage Discharged 20 mi Upstream		2.5-mgd Sewage Discharged 50 mi Upstream						
Relative Pollution Load	Relative Flow	Streamflow (mgd)	Cumulative Probability of Occurrence	Incremental Probability of Occurrence	Additional Annual Cost of water Treatment Operation, \$/mgd*	Relative Total Cost	Relative Marginal Cost	Cp+	Additional Annual Cost of water Treatment Operation, \$/mgd	Cp	Additional Annual Cost of water Treatment Operation, \$/mgd	Cp	Additional Annual Cost of water Treatment Operation, \$/mgd	Cp
1	1	17.3	0.001	0.004	18,500	46.3	20	74	16,400	66	16,400	66	13,800	55
.56	1.8	30.4	0.005	0.005	9,300	23.3	6	47	8,900	45	7,800	39	6,600	33
.43	2.3	38.7	0.01	0.01	6,900	17.3	6.5	69	6,700	67	5,600	56	5,600	56
.34	2.9	49.3	0.02	0.03	4,300	10.8	6.5	29	4,200	126	4,000	120	3,300	99
.23	4.3	73	0.05	0.05	1,700	4.3	.3	85	1,600	80	1,500	75	1,500	75
.17	5.8	98.5	0.10	0.05	1,600	4	0	80	1,600	80	1,500	75	700	35
.13	7.4	126	0.15	0.05	1,600	4	0	80	1,600	80	1,500	75	700	35
.11	9.5	161	0.20	0.10	1,600	4	0	160	1,500	150	1,500	150	700	70
.06	16.	277	0.30	0.05	1,600	4	0	80	1,500	75	700	35	400	20
.04	23.	385	0.35	0.10	1,600	4	3	160	700	70	700	70	400	40
.02	44.	744	0.45	0.05	400	1	1	20	0	0	0	0	0	0
.01	91.	1550	0.50	0.50	0	0	0	0	0	0	0	0	0	0
Average Annual Costs†					ΣCp = \$983.5/mgd			ΣCp = \$838.1/mgd			ΣCp = \$760.6/mgd		ΣCp = \$518.3/mgd	

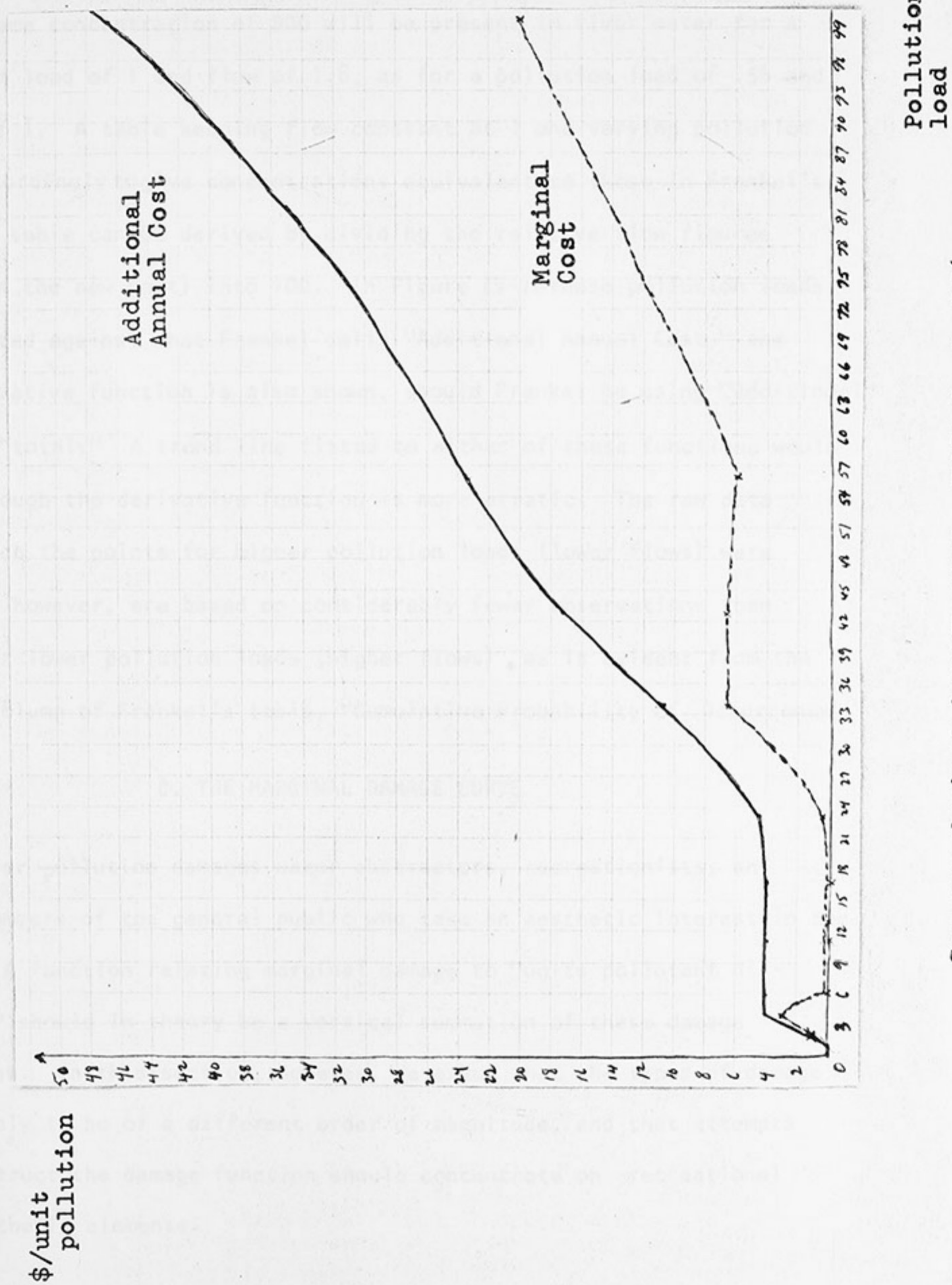
*Cost Figures Based on 2.5-mgd water treatment plant operation.

†Cp = Additional annual costs X incremental probability of occurrence.

ΣCp = Average annual costs per mgd water treated.

Source: Richard J. Frankel, "Water Quality Management: Engineering - Economic Factors in Municipal Waste Disposal," Water Resources Research, Vol. 1, No. 2 (2nd Qtr. 1965), Table 1, p. 176. Columns labeled "Relative Pollution Load," "Relative Flow," "Relative Total Cost," and "Relative Marginal Cost" have been added to Frankel's table.

FIGURE IV-1(b)



Source: derived from Frankel, Table 1, p. 176

constant BOD load discharged at various points upstream, as a function of streamflow. By making the assumption that these increased costs are entirely due to the increased concentration at low flows, we can derive a curve relating marginal costs with marginal pollution increments in the following way. Let 17.3 mgd = 1 flow unit, and calculate a table of flows based on this unit. Then if the pollution load = 100 at a flow of 1, the same concentration of BOD will be present in river water for a pollution load of 1 and flow of 1.8, as for a pollution load of .56 and a flow of 1. A table keeping flow constant at 1 and varying pollution loads accordingly to give concentrations equivalent to those in Frankel's original table can be derived by dividing the relative flow figures (based on the new unit) into 100. In Figure IV-1b these pollution loads are plotted against what Frankel calls "Additional Annual Cost," and the derivative function is also shown, should Frankel be using "additional" to mean "total." A trend line fitted to either of these functions would rise, though the derivative function is more erratic. The raw data from which the points for higher pollution loads (lower flows) were derived, however, are based on considerably fewer observations than those for lower pollution loads (higher flows), as is evident from the second column of Frankel's table, "Cumulative Probability of Occurrence."

C. THE MARGINAL DAMAGE CURVE

River pollution damages water abstractors, recreationists, and those members of the general public who take an aesthetic interest in the river. A function relating marginal damage to "units pollutant discharged" should in theory be a vertical summation of these damage functions. In this section, however, we argue that the types of damage are likely to be of a different order of magnitude, and that attempts to construct the damage function should concentrate on recreational and aesthetic elements.

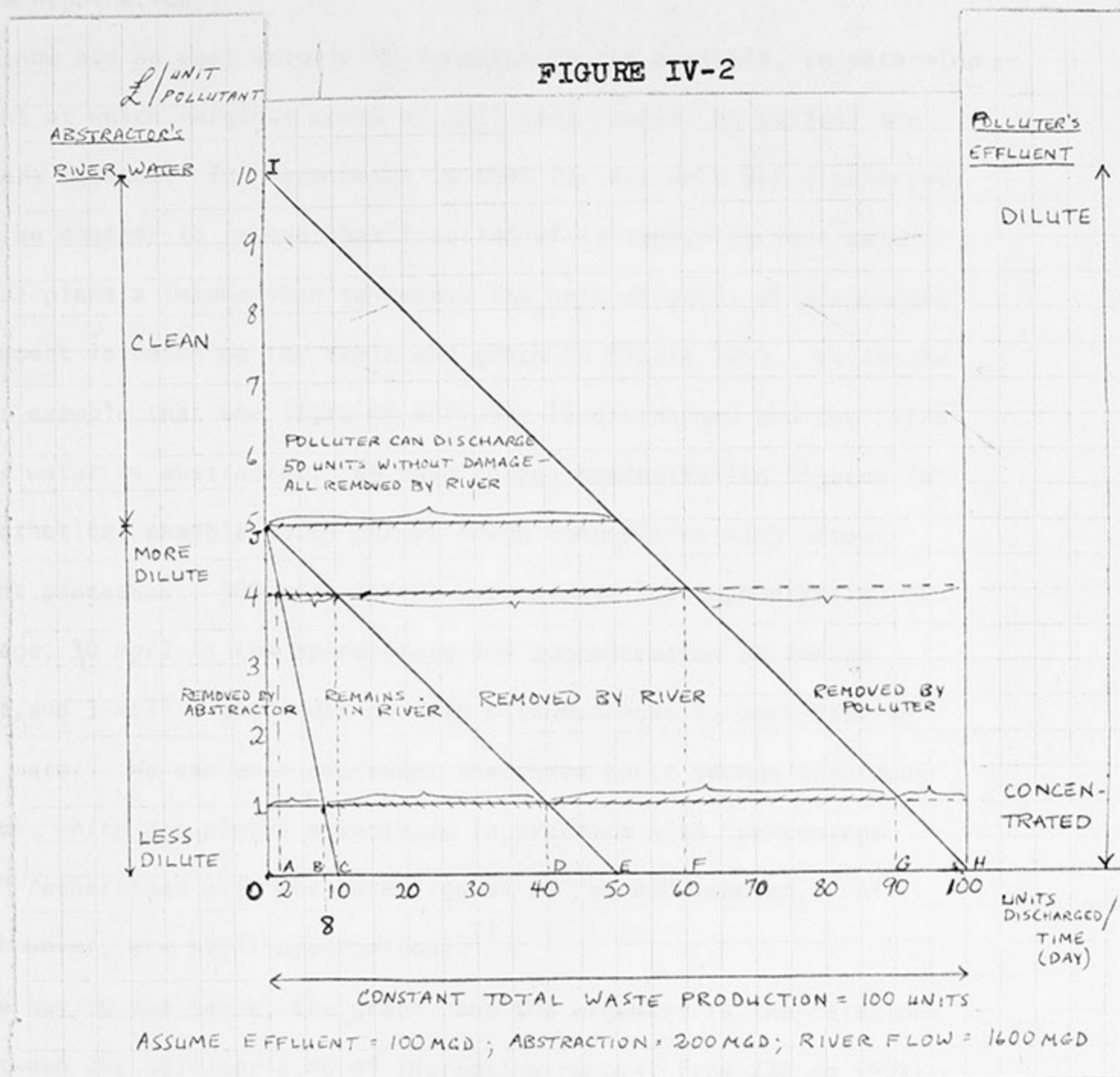
1. The Relation of Damages to Municipal and Industrial Water Treatment Facilities to Costs of Effluent Treatment at Individual Outfalls

The comparison of the costs of pollutant removal at effluent outfall and water plant intake reveals that further investment in sewage treatment will not result in substantial cost savings for plants providing municipal drinking water. We shall show that since (1) the

average Trent river flow dilutes the average effluent discharge by an overwhelming factor, and in addition breaks down a portion of the biodegradable pollutants, and (2) the average water abstraction for purposes of drinking or industrial use amounts to an insignificant proportion of average river flow, the cost of removing a unit of pollution from effluent before discharge will generally exceed the resultant reduction in damages to downstream water plants. Any relative advantage in cost per unit pollutant removed at effluent outfalls arising from the fact that effluent is more highly concentrated than river water, is more than compensated for by the fact that the average abstractor must remove from his intake only a tiny fraction of any unit of pollutant discharged. The following example to illustrate this point makes generous allowances on sides that contribute to the argument against our hypothesis. The greatest of these allowances is the assumption that there are no alternative water sources to the Trent system. In fact, the Birmingham Water Board, instead of actually treating polluted Tame or Trent water to potable standards for municipal supplies, has opted for the cheaper alternative of taking more than 200 mgd from the clean upper reaches of the Severn.⁸

Let the representative polluter discharge 100 mgd into the river. (The largest sewage treatment plant operating in the basin, at Minworth, currently discharges about this amount. The next largest plants discharge 30-35 mgd, and there are only three of these. Most plants discharge between 0.5 and 5.0 mgd.) Let the discharge be raw sewage with a BOD of 400 mg/l (milligrams per litre). The average flow of the Trent in its middle reaches is 1600 mgd, with a BOD load of about 8 mg/l. Without making any allowance for the self-purification capacity of the

⁸ This water then is introduced into the Trent system as effluent. The existence of this sizeable inter-basin transfer reveals the limitations of economic analysis which assumes that the river basin is a closed system, and creates dangers of suboptimization within a larger context. This problem was discussed in section H of Chapter III. Note that the government has proposed, in the Department of the Environment circular of 2 December 1971, that the Trent and Severn basins be united under a single Regional Water Authority.



When polluter removes GH = 10 units, MC of further removal is £1; 90 units are left in 100 mil. gal. effluent; river removes DG = 50 units, leaving 40 units in 1700 mil. gal.; abstractor removes OB = 8 units from 200 mil. gal.

When polluter removes FH = 40 units, MC of further removal is £4; 60 units are left in 100 mil. gal. effluent; river removes CF = 50 units, leaving 10 units in 1700 mil. gal; abstractor removes OA = 2 units from 200 mil. gal.

costs. Curve JC shows a relationship between pollutant levels which the abstractor must remove and polluter's MC, not abstractor's MC. "Units pollutant" are in terms of some hypothetical index; absolute costs are likewise hypothetical.

We now add an abstractor's MC function to the analysis, to determine the point at which marginal costs of pollutant removal at outfall and intake are equated. The hypothesis is that for any unit BOD discharged, it will be cheaper to remove that fraction of it appearing in a water treatment plant's intake than to remove the unit at point of discharge. The argument is based on the table and graph in Figure IV-3. We assume for this example that one litre of effluent is discharged and one litre of river water is abstracted. We have chosen concentration figures for our hypothetical example which permit rough comparisons with actual treatment processes: 300 mg/l is the approximate BOD concentration of raw sewage, 30 mg/l is the approximate BOD concentration of sewage effluent, and 3 mg/l might under certain circumstances be permitted in potable water. We can even represent the three basic sewage treatment processes, which are always associated in practice with "percentage removal" rather than with absolute figures of "mg BOD removed." All costs, however, are still hypothetical.¹¹

The key to the table, the graph, and the argument is the relationship between the polluter's MC of increasing removal from 270 mg (90%) to 297 mg (99%) out of the 300 mg in the litre, and the abstractor's total cost of removing 27 mg out of the 30 mg in his litre. They will be equal. They represent exactly the same thing. But let us be clear about what we mean by marginal cost. We refer not to the cost of removing an additional milligram of BOD, but the cost of removing an additional "comparable bloc" of BOD. For we must compare the polluter's costs of

¹¹The abstractor's total costs approximately double as we move from the removal of 3 mg from 6 mg in the litre (bottom of the chart) to 27 mg from 30 mg (top of the chart). Now, there are two opposing effects at work in the marginal cost function. One is that marginal costs rise, for the removal of a given quantity of BOD, as starting concentration falls. The other is that marginal costs rise, for a given starting concentration, as more BOD is removed. These are both aspects of the hypothesis, supported by such data as we have, that as water is made purer, it becomes increasingly costly to remove the next units of pollutant. These effects may be illustrated hypothetically as follows:

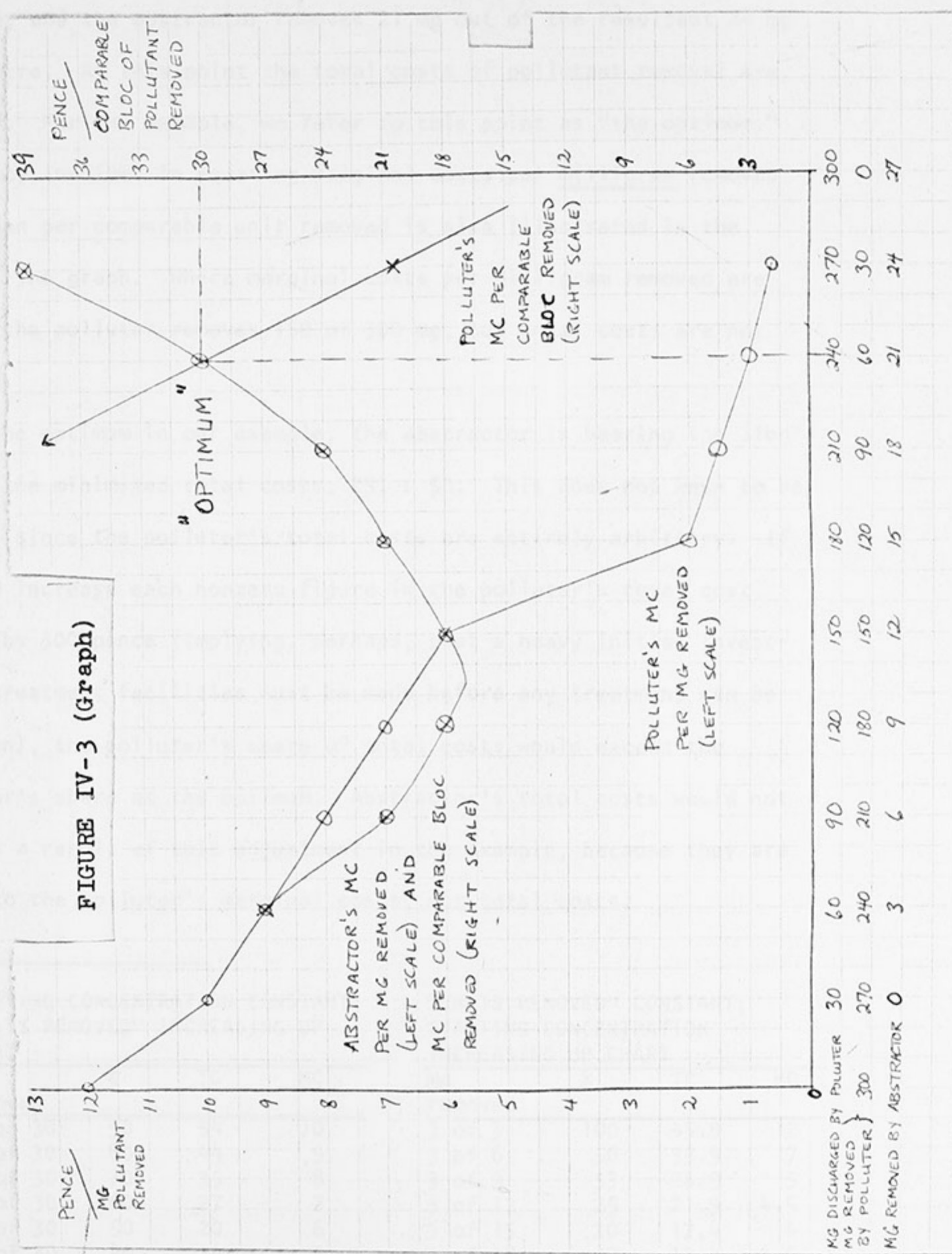
FIGURE IV-3 (TABLE)

HYPOTHETICAL COMPARATIVE COSTS OF POLLUTANT REMOVAL BY POLLUTER AND ABTRACTOR

POLLUTER'S REMOVAL	NOTE: STARTING CONCENTRATION CONSTANT	PERCENT REMOVAL	TOTAL COST (PENCE)	MC/ COMPARATIVE BLOC REMOVED (PENCE) ↓ MC/ mg removed	POLLUTER'S DISCHARGE (IN ONE LITRE)	ABTRACTOR'S REMOVAL (FROM ONE LITRE)	NOTE: STARTING CONCENTRATION REMOVAL IS FUNCTION OF POLLUTER'S DISCHARGE	TOTAL COST (PENCE)	MC/ COMPARATIVE BLOC REMOVED (PENCE) ↓ MC/ mg removed	Σ TOTAL COST (PENCE)
0 out of the 300mg in the litre discharge		0	0		300mg	27mg out of 30mg in the litre abstracted	90	360		360
30mg out of 300mg		10	20	20 1.66	270mg	24mg out of 27mg	89	321	39 13	341
60mg out of 300mg		20	50	30 1	240mg	21mg out of 24mg	88	291	30 10	341
90mg out of 300mg		30	95	45 1.5	210mg	18mg out of 21mg	86	267	24 8	362
120mg out of 300mg		40	155	60 2	180mg	15mg out of 18mg	83	246	21 7	401
150mg out of 300mg		50	335	180 6	150mg	12mg out of 15mg	80	228	18 6	663
180mg out of 300mg		60	545	210 7	120mg	9mg out of 12mg	75	210	18 6	755
210mg out of 300mg		70	795	240 8	90mg	6mg out of 9mg	66	189	21 7	984
240mg out of 300mg		80	1065	270 9	60mg	3mg out of 6mg	50	162	27 9	1227
270mg out of 300mg		90	1365	300 10	30mg	0				1365
297mg out of 300mg		99	1725	360 12	0	0				1725

ASSUMPTIONS:

- (1) Volume of discharge = volume of abstraction = 1 litre
- (2) Potability standard = 3 mg/l



removing each additional 30 units, with the abstractor's costs of removing the corresponding additional three units. The optimum condition is that marginal costs per comparative bloc removed be equal. This condition obtains when the polluter removes 60 mg out of the 300 mg in his litre, and the abstractor removes 21 mg out of the resultant 24 mg in his litre. At this point the total costs of pollutant removal are minimized. For the example, we refer to this point as "the optimum." The fallacy involved in equating marginal costs per milligram removed rather than per comparable unit removed is also illustrated in the chart and the graph. Where marginal costs per milligram removed are equated, the polluter removes 150 of 300 mg, but total costs are not minimized.

At the optimum in our example, the abstractor is bearing the lion's share of the minimized total costs, 291 : 50. This does not have to be the case, since the polluter's total costs are entirely arbitrary. If we should increase each nonzero figure in the polluter's total cost schedule by 300 pence (implying, perhaps, that a heavy initial investment in treatment facilities must be made before any treatment can be undertaken), the polluter's share of total costs would exceed the abstractor's share at the optimum. Abstractor's total costs would not change as a result of this adjustment in the example, because they are related to the polluter's marginal costs, not total costs.

STARTING CONCENTRATION CONSTANT;
"UNITS REMOVED" INCREASING UP
CHART

mg removed	%	TC	MC
27 of 30	90	54	10
24 of 30	80	44	9
21 of 30	70	35	8
18 of 30	60	27	7
15 of 30	50	20	6
12 of 30	40	14	5
9 of 30	30	9	4
6 of 30	20	5	3
3 of 30	10	2	2
0 of 30	0		

"UNITS REMOVED" CONSTANT;
STARTING CONCENTRATION
INCREASING UP CHART

mg removed	%	TC	MC
3 of 3	100	45.9	12
3 of 6	50	33.9	7
3 of 9	33	26.9	5
3 of 12	25	21.9	4.5
3 of 15	20	17.4	4
3 of 18	17	13.4	3.5
3 of 21	14	9.9	3
3 of 24	12.5	6.9	2.6
3 of 27	11	4.3	2.3
3 of 30	10	2.0	2

In the example in the text, however, starting concentration falls, and both absolute and percentage quantities of BOD removed rise, as we proceed from the top to the bottom of the chart. The effects are thus opposing. We assume that the "increased removal" effect predominates at the top of the chart, giving rising marginal costs as we proceed upward, but that it is vitiated to an increasing extent by the "reduced starting concentration" effect around the bottom of the chart, giving a positive but declining marginal cost for the first few steps upward.

The arbitrariness of the polluter's total cost schedule requires a qualification, however. Total costs of pollutant removal will be minimized where marginal costs for comparative blocs are equal, if any treatment is undertaken at all. But it could well be that zero treatment by the polluter is the optimum--as it would be if each nonzero figure in the polluter's total cost schedule were increased by 300 pence. This possibility of a "corner solution" reinforces the main argument that increased pollutant removal at outfalls will rarely be justifiable on grounds of decreased costs to downstream abstractors.

It does not necessarily follow, of course, from the fact that the polluter's marginal cost of treating his effluent to potability equals the abstractor's total cost of treating river water of the worst possible quality (resulting if the polluter provides no treatment whatsoever) to potability, that the polluter's marginal cost will everywhere exceed the abstractor's marginal cost for comparable blocs removed. But since it is not costless for the polluter to remove the first 270 units of pollutant, before he installs the water treatment equipment to remove the final 27 units, it will always be cheaper to treat a given amount of river water (diluted effluent, if you will) to potable standards than to treat that same amount of raw sewage or sewage effluent to potable standards. River dilution and self-purification always have a positive value. The complete elimination of pollutant discharges from water-courses would reduce the net value of social product, if the only damage arising from the discharges were increased water treatment costs.

The difficulties of comparing actual costs of pollutant removal by dischargers and abstractors are evident on the face of Figure IV-4, "Spectrum of Pollutant Removal Processes." There are two basic problems. The first is that pollutants which have long been considered "appropriate" criteria for sewage effluents--and for which data is thus available--do not correspond exactly with the "relevant" criteria for water treatment. Only ammonia is both (1) considered important enough to measure, and (2) measured in the same way, at both ends of the pipe. The basic biodegradable pollutant parameter is called BOD on the discharge end. But the total organic carbon (TOC) parameter at the water treatment plant measures non-biodegradable organics as well. And there are certain

characteristics of potable supplies, such as taste and hardness, which are not measured in effluent or in the river in situ. The second basic problem is that various pollutant removal processes on both ends of the pipe remove different amounts of different pollutants, all at once. Joint costs cannot be allocated to individual pollutants. A subsidiary problem is that scientific techniques for measuring pollutant levels are by no means perfect.

Figure IV-4 is a case history of twelve pollution parameters as the water which bears them proceeds from drainage pipe to household tap. Pesticides are not listed because only the minutest traces have been detected in the Trent River system; and only three of the many metallic pollutants are listed. Nitrates, which are dangerous to very young babies, causing infantile methaemoglobinaemia, are a product of the oxidation of ammonia, which causes taste and odour problems. Thus the oxidation processes which break down BOD and ammonia may increase nitrate levels substantially. "There is at present no simple process for nitrate removal..."¹² BOD, suspended solids, and TOC measure substantially, but not exactly, the same thing, and there are some (very) rough rules of thumb as to what one parameter level will be, given the level of another. The metals, phenols, and chloride are conservative; but their concentrations are affected, rather haphazardly, by sedimentation processes. Chemical precipitation or distillation may be required to remove the metals if their concentrations are high. Because ammonium chloride is a precipitate, chloride treatment not only kills coliform bacteria, but also removes ammonia; but too much chloride leaves a bad taste in the water.

This catalog of interrelationships is meant to serve as a warning that one can gain at best only a rough idea of what costs what. The joint cost problem in all available cost data, which is inherent in the physical nature of pollutant removal processes, also removes the practical possibility of constructing separate marginal cost and damage functions for individual pollutants, in an attempt to find optimal levels for each of several different pollutants. There are thus two possible approaches to

¹²Water Research Association, Trent Economic Model, Section 4--Water Treatment, Final Report, December, 1971, Volume 1, p. 23.

constructing a marginal cost function. The first is to devise a pollution index. The second is to impute all costs to one pollutant.

Since no commonly accepted pollution index has yet been devised,¹³ we are limited for all practical purposes to the second approach. The use of BOD as the representative pollutant, however, is in effect the use of a rough index, since processes which remove BOD, in both sewage and water treatment plants, also remove many other pollutants, throughout most of the range.¹⁴ The major exception is the removal of metals at the water treatment end of the scale, for which the sedimentation and filtration processes which remove BOD are ineffective. Softening and possibly desalination (electrodialysis or distillation) may be required where metallic problems are severe.¹⁵ Another problem with BOD as the representative pollutant is that it is not measured as such on the water treatment side; Great Britain sets potability standards in terms of TOC instead. Only the World Health Organization bothers to set a BOD standard for potable water sources (6 mg/l). No standard is given for drinking water. Ammonia is the only widespread pollutant measured at effluent outfalls, in the river, and at water treatment plant outlets. The ordinary effluent treatment and water treatment processes remove substantial amounts of ammonia, as well as many other pollutants. But if ammonia were the only pollutant, special ammonia reduction processes would be used in lieu of the ordinary ones, at substantial cost savings per unit ammonia removed.

¹³Not that researchers haven't been trying. See, for example: Robert M. Brown, *et al.*, A Water Quality Index--Do we Dare? National Symposium on Data and Instrumentation for Water Quality Management, University of Wisconsin, July 1970; and

Robert K. Horton, "An Index Number System for Rating Water Quality," Journal of the Water Pollution Control Federation, Volume 37, No. 3 (March, 1965).

In Great Britain, Mr. G. M. Woodward, Principal Scientific Officer for the Trent River Authority, Mrs. Pauline Marstrand, of the University of Sussex, and researchers at the Water Pollution Research Laboratory at Stevenage are currently working to devise pollution indexes.

¹⁴In experiments conducted by the Water Resources Association for the Trent Research Programme, "[b]iological filtration and sedimentation affected [sic] considerable amounts of ammonia removal (about 75%), which is sufficient to reduce the raw water ammonia to below 0.5 mg/litre most of the time." Water Research Association, Volume 2, p. B10.

¹⁵The regulatory agencies in the United States assume that no heavy metals are removed by conventional water treatment processes. The FWPCA standards for new water sources are identical with the U. S. Public Health Service standards for drinking water, for most metals.

To complete the argument that increased effluent treatment cannot be justified on the basis of savings to downstream abstractors, we use both BOD and ammonia as representative pollutants. The argumentative procedure is again to make extremely generous empirical concessions to the opposing hypothesis. The cost figures which we use have been derived for the Trent Economic Model. Figure IV-4 and Appendix Figures C and D explain the categories of treatment upon which the model's cost figures are based. The model defines three types of effluent treatment plant. ET2 is a combination of primary and secondary treatment, that is, a typical sewage treatment facility. ET3 adds to this an ammonia reduction process, which is assumed not to affect BOD levels. ET4 further adds tertiary treatment, which is assumed not to affect ammonia levels. There are eight types of water treatment plant, which consist of various combinations of a basic plant and certain "extras" directed at more specific pollutants.

We use calculated 1971 costs for effluent treatment by an ET4 plant,¹⁶ and projected 1972 costs for water treatment by a WT4 plant.¹⁷ We have not bothered to convert the figures by some inflation index to a common base, because such a conversion would aid our argument, by increasing the relative cost of effluent treatment. All costs are in terms of "annual cash flow," which is the sum of annual operating costs and capital amortisation payments. The model assumes (1) that all capital borrowing is repayed in equal annual installments; (2) that the interest rate is 8 1/2%; (3) that all plant facilities have a life of thirty years, except for granular carbon adsorption installations, which last fifteen years; (4) that when any facility wears out, it is replaced at 1971 prices; and (5) that operating costs remain constant forever. Thus, "annual cash flow" represents an annual payment in perpetuity.

¹⁶ Taken from two computer printout tables, "Analysis of Sewage Works Costs" and "Additional Analysis of Sewage Works Costs: Sewage Works Costs Above 1971 ET2 Costs--As Baseline"--River Model--10B--LGORU 1970. The capital and operating costs are considered functions of capacity and flow, and are computed on the basis of a generalized equation developed statistically from many sources, not limited to the Trent River Basin. All plants are existing ones.

¹⁷ Water Research Association, Volume 1, Table E: "Cost of Water Treatment Plants for the Trent at Nottingham--p/m³ (1972)". All plants are hypothetical, as the Trent is nowhere used as a source for potable water supplies at the present time; but the costs are projected on the basis of costs of existing water treatment plants.

We must dispose initially of the problem of economies of scale, which are pronounced in both effluent and water treatment.¹⁸ On the effluent side, for ten existing ET4 plants whose 1971 flow is about 50% of capacity, the annual cash flow per million gallons per day treated ranges from £43,000 for a plant treating 1.15 mgd to £18,000 for a plant treating 33.5 mgd. We shall use figures for the largest plant. On the water side, costs in terms of pence per cubic metre treated range from 3.18 for a plant treating 4.75 mgd to 2.63 for a plant treating 47.53 mgd. We shall use figures for the smallest plant. We compare average costs of removing comparable units of BOD and ammonia, on opposite sides of the drainage pipe. The assumption for the model is that the increase of treatment from ET2 to ET4 reduces BOD levels (95 percentile) from 20 to 10 mg/l, and ammonia levels from 30 to 3.5 mg/l. (See Appendix, Figure C.) Since it is cheaper per unit to remove the first units of BOD from raw sewage (from 300 or 400 mg/l to 20 mg/l) than it is to polish the effluent (20 mg/l to 10 mg/l), and we wish purposely to bias effluent treatment costs downward, we use average costs per mg BOD removed (400 mg/l to 10 mg/l), by considering the costs of ET2 treatment as well. ET2 does not have much effect on ammonia levels, so we do not add in ET2 costs to find average cost per mg NH_3 removed--this would increase the average cost figure substantially. Thus we introduce a double bias against our hypothesis. A WT4 water treatment plant is assumed to reduce ammonia from 1.5 to .05 mg/l, and BOD (we assume--the model does not deal with BOD on this side) from 9 mg/l, the river concentration at Trent Bridge, Nottingham, to 1 mg/l.

On these assumptions, the average cost of BOD removal through effluent treatment is 1.8×10^{-4} pence per mg BOD removed; the average cost of water treatment is 4.0×10^{-4} pence per mg BOD removed. If we continue to say, unrealistically, that the river dilution factor is a mere 10:1, the cost per comparable unit removed by effluent treatment is $18/4 = 4.5$ times greater than the cost for water treatment. The average cost of ammonia removal through effluent treatment is 2.6×10^{-3}

¹⁸ Both the Bradley-Isaac and Townend studies of municipal waste treatment costs produced strong evidence of economies of scale, which is reproduced in Appendix Figure B.

pence per mg NH_3 removed; the average cost of water treatment is 2.2×10^{-3} pence per mg NH_3 removed. The cost per comparable unit removed by effluent treatment is thus $26/2.2 = 12$ times greater than the cost for water treatment.

On assumptions slightly more favorable to our assertion--and somewhat more realistic--the average effluent treatment cost is over 100 times greater than its counterpart water treatment cost. Although these are not marginal cost figures, they do suggest strongly that effluent treatment cannot in general be justified solely on the grounds of savings to water treatment facilities. Richard J. Frankel also came to this conclusion after his study of municipal waste disposal costs in the Eel River Basin in California.¹⁹ Frankel's cost-benefit calculations are reproduced in Figure IV-5. The Delaware Study provided further support of this conclusion, and the Preliminary Report stated, "It is probable that the net monetary benefits in terms of dollar savings in treatment costs at Philadelphia's Torresdale Plant will be relatively small at the alternative levels of water quality enhancement." It was found that increased dissolved oxygen levels in the river would actually increase costs for industrial users, because of the additional corrosion which would result.²⁰

2. Consumer's Surplus

The economic damages of pollution are best defined in terms of willingness to pay to remove it. If there were a way to find aggregate marginal willingness to pay to avoid or remove a unit of pollution, for a continuous series of pollution levels, the intersection of that function with an aggregate marginal cost function for pollutant removal would determine the optimal pollution load, assuming the proper slopes. The intersection would be the point at which it would cost polluters more to reduce discharges further, than damagees would be willing to pay for those reductions.

¹⁹ Richard J. Frankel, "Water Quality Management: Engineering-Economic Factors in Municipal Waste Disposal," Water Resources Research, Vol. 1, No. 2 (2nd Qtr. 1965), p. 180.

²⁰ Delaware Study, Preliminary Report, pp. 71-74.

FIGURE IV-5

TABLE 4. Ratio of Cost Savings of Downstream Water Treatment Plants to Costs of Additional Treatment of Upstream Sewage Treatment Plants*

Size of Sewage Treatment Upstream, mgd	Distance Downstream, miles	Treatment Change				
		Raw to Primary†	Primary to H.R. Trickling Filter‡	H.R. Trickling Filter to Tertiary§	Primary to H.R. Acting Sludge	H.R. Acting Sludge to Tertiary¶
2.5	5	Negligible	0.038	0.023	0.019	0.062
	10	Negligible	.033	.019	.014	.055
	20	Negligible	.031	.009	.012	.051
	50	Negligible	.009	.023	.008	.025
10.0	5	0.0014	.106	.046	.050	.087
	10	Negligible	.098	.040	.048	.079
	20	Negligible	.079	.041	.042	.071
	50	0.0012	.067	.034	.036	.067

*Cost savings based on average annual operating costs of 2.5-mgd water treatment plants.

†Primary treatment plant with 2-hour settling.

‡High-rate trickling filter 2-hour, 40 = BOD/1000 ft³/day.

§High-rate trickling filter plus oxidation ponds 15 days detention.

||High-rate activated sludge 2-hour aeration.

¶High-rate activated sludge plus oxidation ponds 25-days detention.

Source: Richard J. Frankel, "Water Quality Management: Engineering-Economic Factors in Municipal Waste Disposal," Water Resources Research, Vol. 1, No. 2 (2nd Qtr. 1965), p. 180.

It is highly unlikely, however, that more than three or four points on a marginal damage curve could be derived. This is because recreation enthusiasts and aesthetic damagees could be expected to distinguish among only a few "sub-ranges" of the entire range of potential pollution in the Trent system, illustrated in Figure IV-6. The initial discharges would damage no one, for they would be broken down and diluted by the river. The first casualties of additional pollution would be the water contact sports, especially swimming, followed by trout fishing, coarse fishing, and the aesthetic appeal of the river. But pollution levels would have to change by large amounts relative to total potential pollution levels in order to affect successive, specific recreational opportunities or aesthetic appreciation. Although aggregate marginal damages would probably be positive over the entire range AQ in the figure, any individual would be unlikely to be able to specify his damages over the continuous range, but would probably base his decision on whether or not to travel to the river on a small number of simple tests, for example: (1) Is it safe to swim? (2) What kind of fishing is available? (3) Is the site pleasant? In other words, an individual would distinguish between pollution levels W, X, Y, and Z, but smaller increments or decrements would not mean much to him, except perhaps over the range in which the fishery is suffering. On an intuitive level, it seems that there would be several peaks in the marginal damage function--points where total damages rise sharply--when swimming becomes so dangerous that it is for all practical purposes eliminated, when various species of fish are eliminated, when offensive smell begins, and when unsightly foam and perhaps debris appear on the surface of the water. The relative levels of the peaks cannot very well be deduced; but that the marginal damage function will neither rise nor fall continuously over pollution ranges relevant to the Trent system is very likely.

This leads to certain problems in the search for an optimum level of pollution. If neither the marginal damage nor the marginal effluent treatment cost function dominates the other, then there will be two types of intersection, as shown in Figure IV-7. If fewer than ZH units of pollution were being removed initially, then it would cost more to remove the next unit than the reduced damage would justify. But if ZY

FIGURE IV-6

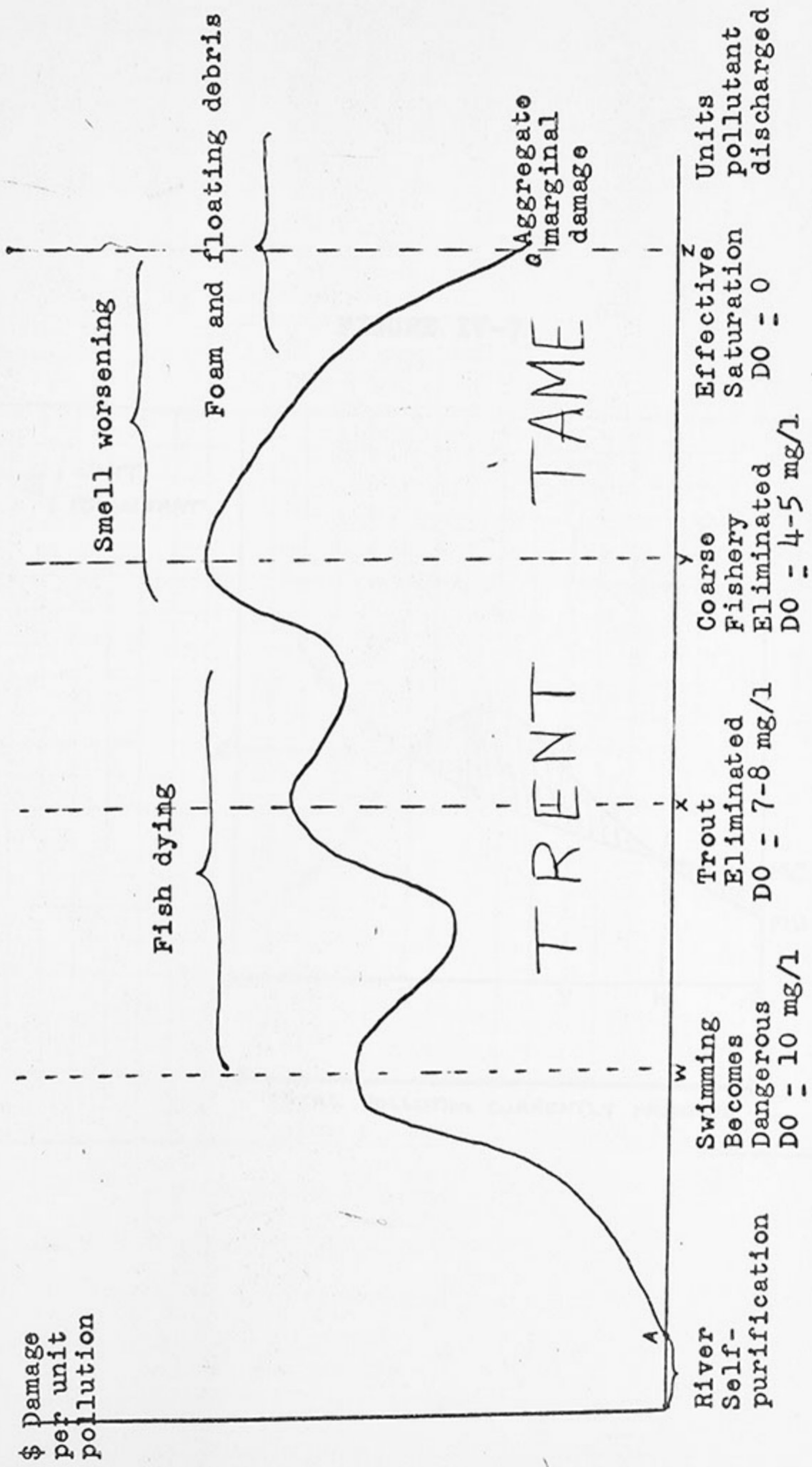
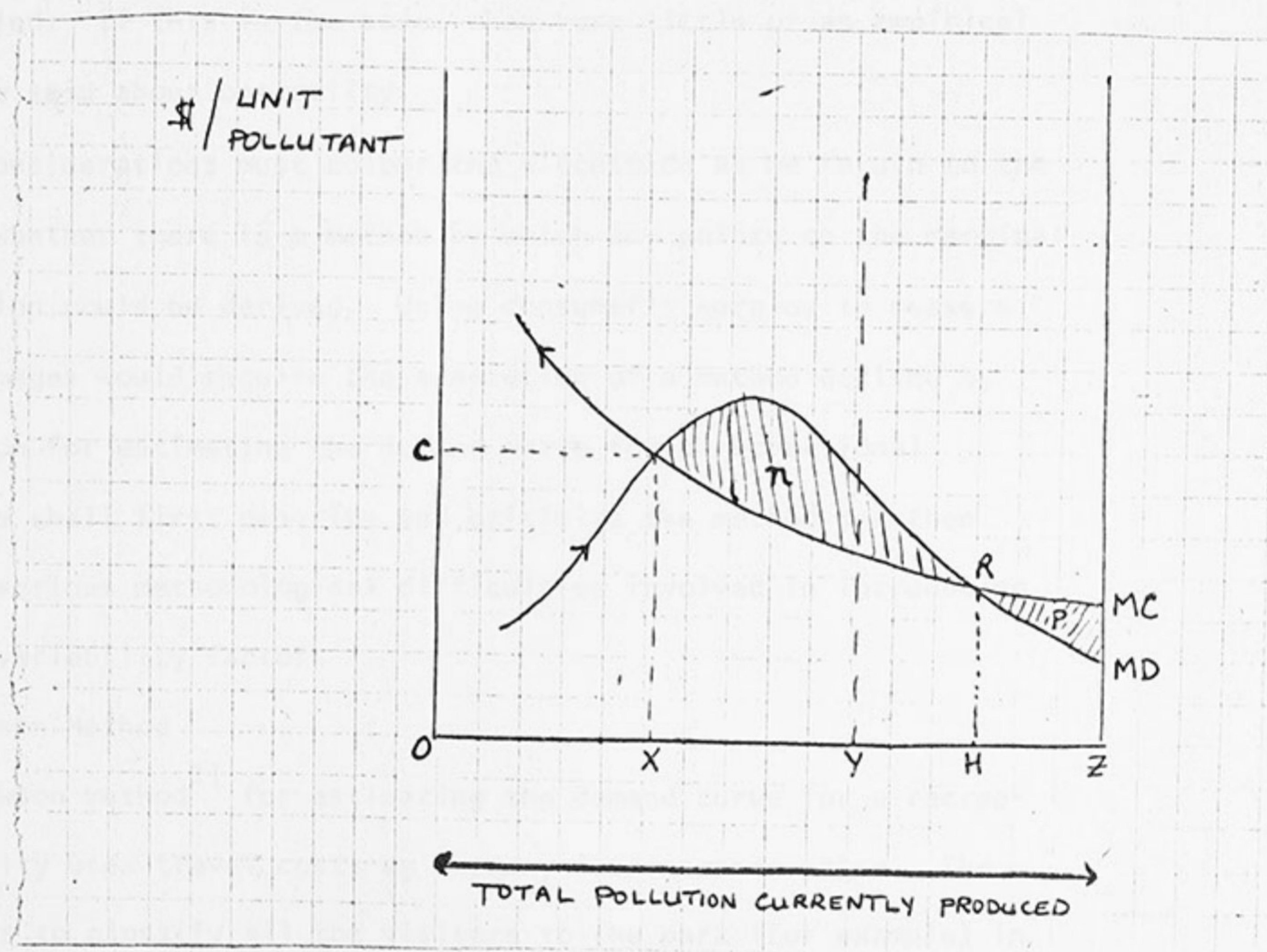


FIGURE IV-7



units were already being removed, the additional reduction of discharges from OY to OX would increase net social product. Even if no treatment were being undertaken initially, net social product would rise if pollution were reduced from OZ to OX, perhaps by the imposition of the per-unit charge c on polluters, provided area n exceeded area p .

If the marginal damage curve falls, and the absolute value of its slope exceeds that of the marginal cost curve, then an intersection will not be an optimum. What are the policy implications of such a situation? In Figure III-4, a perverse situation can be transformed into an "optimum-producing" situation with only a slight manipulation of the total cost data--and vice versa. It could be that these fundamental theoretical distinctions are submerged within the range of error of any data which can be compiled. If this is the case, then very little of an empirical nature can be said about optimality.

These considerations must colour the discussion as we return to the question of whether there is a method by which any points on the marginal damage function could be derived. Using consumer's surplus to measure pollution damages would require the adaptation of a method devised by Marion Clawson for estimating the demand curve for a recreational facility. We shall first describe and criticize the method and then discuss the serious methodological difficulties involved in introducing a pollution-variability factor.

a. The Clawson Method

The Clawson method²¹ for estimating the demand curve for a recreational facility uses travel costs as a proxy for entrance price. The first step is to classify all the visitors to the park (for example) in any year according to the distance they have travelled, that is, according to their residence in concentric zones surrounding the park (Figure IV-8). When the population of each zone has been determined, a graph showing "demand for the entire recreational experience" can be drawn, as in Figure IV-9. Although the information on visit rates for travel costs of \$4 would be collected from Zone C visitors, it is assumed that of any

²¹ As described in Marion Clawson and Jack L. Knetsch, Economics of Outdoor Recreation, Baltimore: Johns Hopkins, for Resources for the Future, Inc., 1966.

FIGURE IV -8

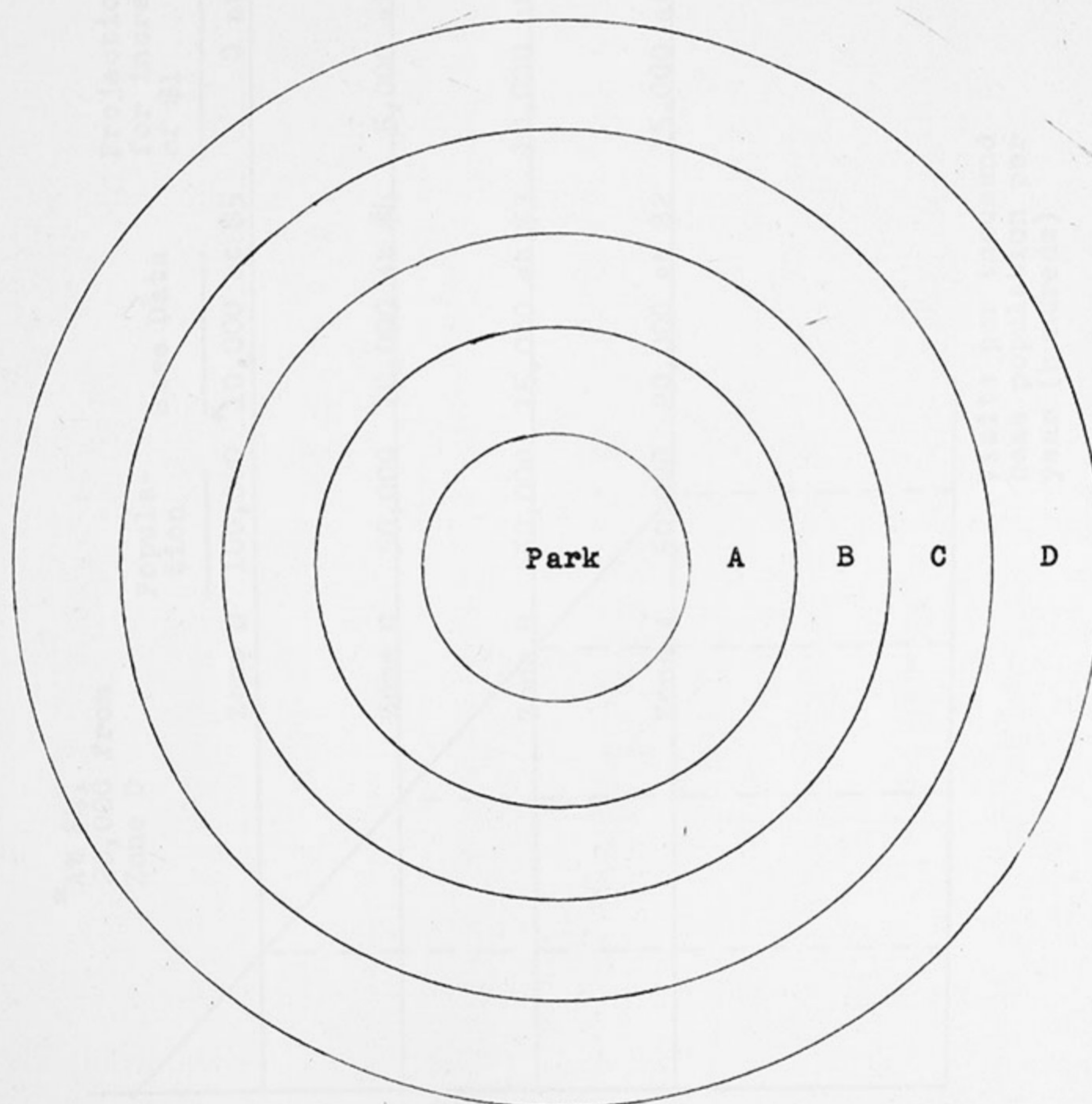


FIGURE IV-9

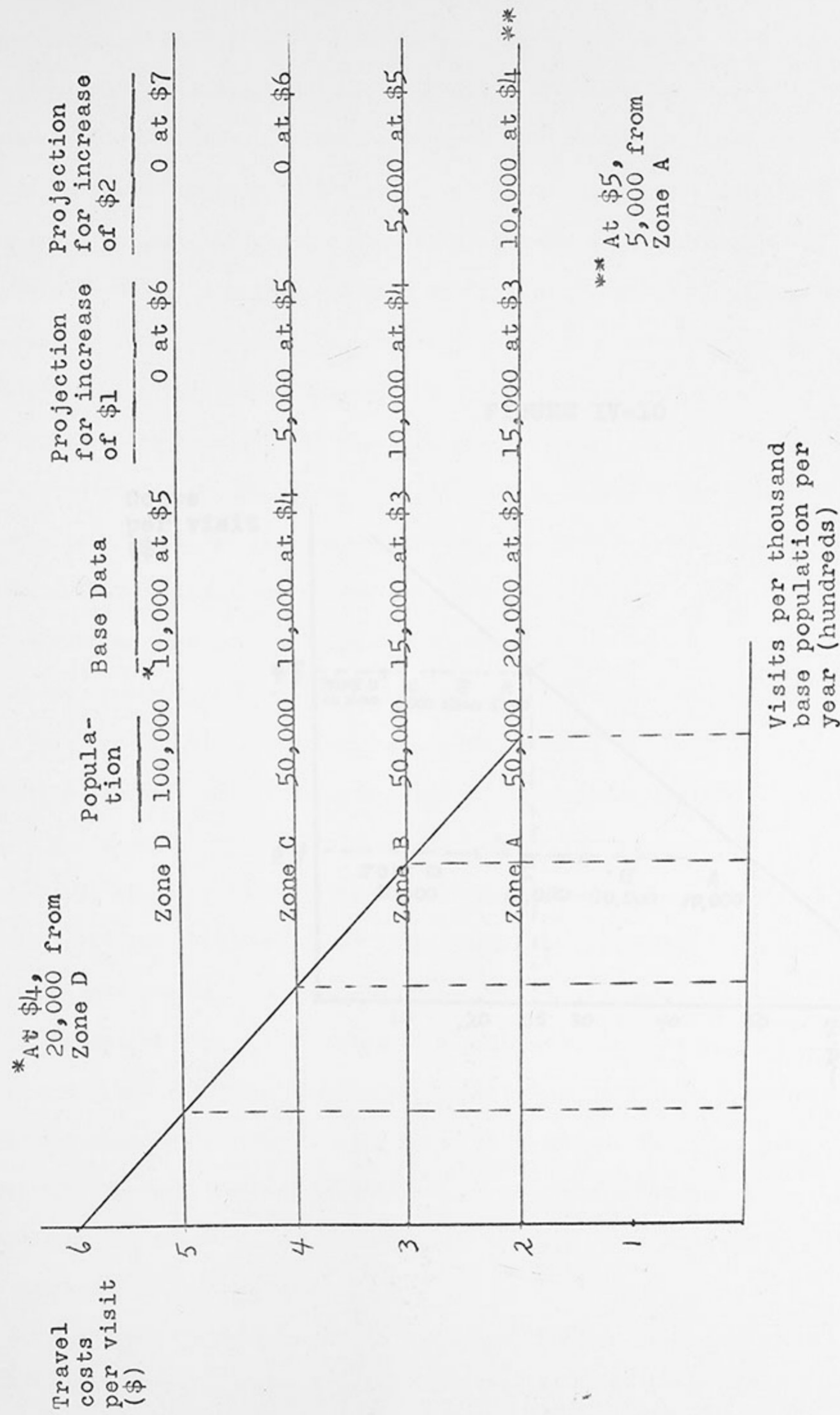
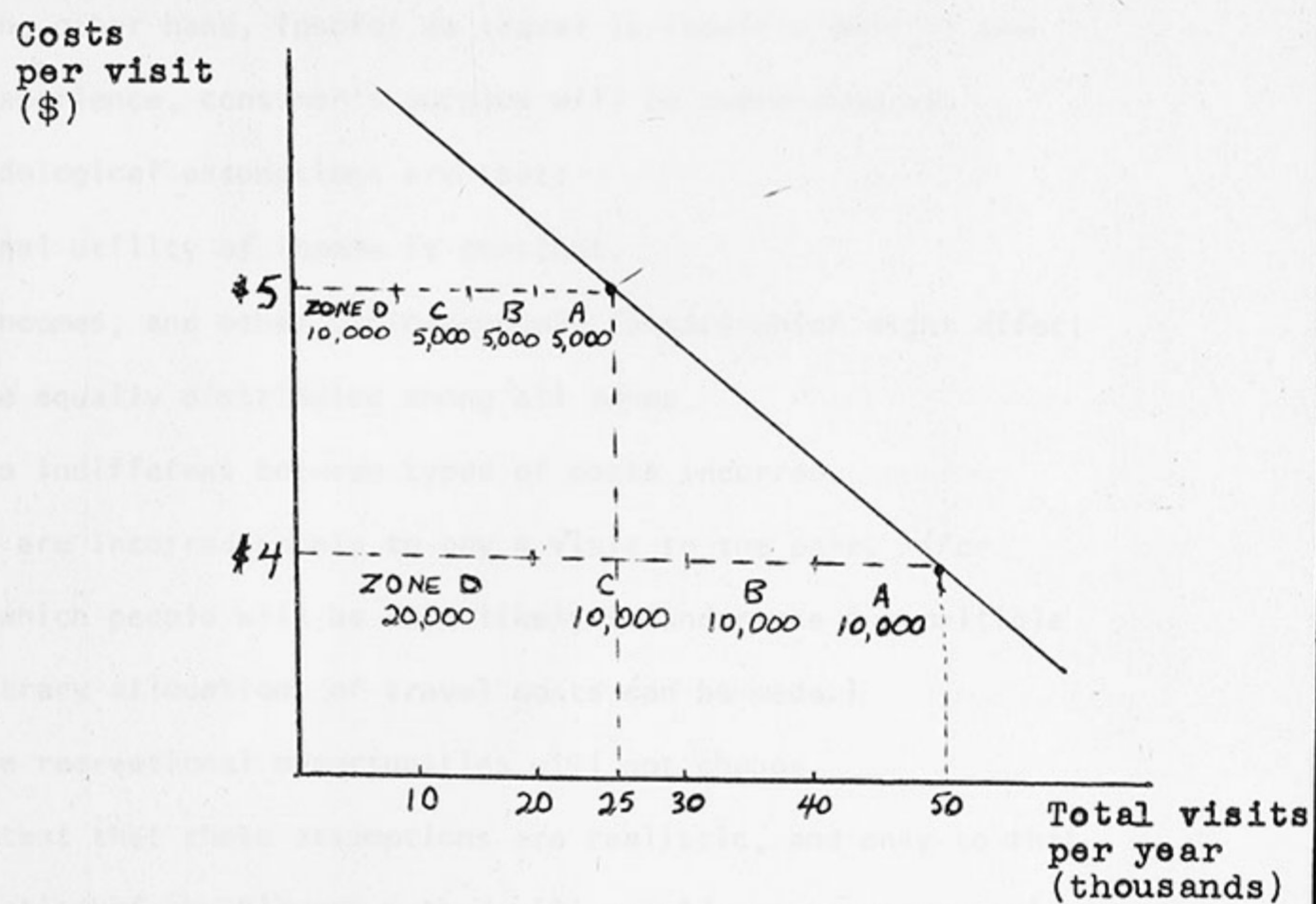


FIGURE IV-10



thousand people facing total costs (of any kind) of \$4, two hundred will visit the park. This data can be used to project visitation rates from the various zones at higher or lower prices, to give a demand curve for the recreational facility, two points of which are shown in Figure IV-10.

The most rudimentary Clawson model uses only travel costs as a proxy for price or revealed willingness to pay. More sophisticated models add time costs and, where they exist and can be ascertained, entry fees to obtain a better estimate of total willingness to pay. The area under a Clawson demand curve measures total consumer's surplus at a zero price, and will be an underestimate to the extent that certain costs of using the recreational resource are not monetized and incorporated. On the other hand, insofar as travel is itself a part of the recreational experience, consumer's surplus will be overestimated.

The methodological assumptions are that:

- (1) The marginal utility of income is constant.
- (2) Tastes, incomes, and other socio-economic factors which might affect visit rates are equally distributed among all zones.
- (3) People are indifferent between types of costs incurred.
- (4) All costs are incurred solely to pay a visit to the park. (For longer trips, which people will be more likely to undertake for multiple purposes, arbitrary allocations of travel costs can be made.)
- (5) Substitute recreational opportunities will not change.

To the extent that these assumptions are realistic, and only to that extent, application of the Clawson method will provide an accurate estimate of aggregate willingness to pay for a recreational facility. The usefulness of figures derived by this method as a basis for spending decisions by the government thus depends on the degree of acceptance of three propositions:

- (1) Aggregate willingness to pay is the proper measure of the benefits of public investment in recreational facilities to be compared with associated costs.
- (2) The assumptions of the Clawson method are realistic. That is, the area under a Clawson demand curve would give an accurate estimate of aggregate willingness to pay.

(3) Survey techniques are sufficiently sophisticated to collect the data required to draw an accurate Clawson demand curve.

The first proposition is fairly generally accepted in the field of economics. Economists differ about the extent to which non-economic considerations should enter into government decision-making. But consumer's surplus, which at a zero price is the amount a person is willing to pay rather than go without the good in question, is usually taken as a common-sense concept of benefits, suitable for policy-making, and the summation of all consumers' surpluses is regarded as a proper measure of the aggregate economic benefits of providing an indivisible public good.

The second proposition is much more dubious. In the first place, the use of travel costs as a proxy for total willingness to pay is bound to understate consumer's surplus, at the hypothetical zero price, for the same reason that observed total revenues for a good sold in a competitive market do not reveal the total amount that consumers of the good would have been willing to pay rather than go without it. That is, the Clawson method does not reveal how much any visitor might have been willing to pay, above those travel costs, time costs, and entrance fees which he actually incurred. There is thus a bias toward underestimation of the true level of consumer's surplus in the very conceptual basis of the method. The usefulness of the results of a Clawson study for guiding public policy must be severely qualified by an awareness of this point, and of the biases of the assumptions listed above.

(1) The assumption of a constant marginal utility of income is not required for the existence or measurement of consumer's surplus in general, but it is required if the area under a demand curve is to be considered the measure of consumer's surplus. The use of that area overstates the true level of consumer's surplus in the case of a normal good. And since the income elasticity of demand for recreational facilities is not only likely to be positive, but large relative to other normal goods, the extent of this overstatement may be significant enough to require consideration.

(2) The assumption that all other socio-economic factors than those explicitly under consideration (travel and time costs, and entrance fees) which might affect visit rates are equally distributed among zones, is

vital to the scientific methodology, but may be responsible for significant errors on either side of the true level of aggregate willingness to pay. It is plausible, for example, that people with particular tastes for the recreational activity will already be more highly concentrated in the proximity of the facility, than in other zones, before the study is undertaken, so that travel and time costs will underestimate aggregate willingness to pay. And that average income levels are skewed geographically is beyond doubt. If richer recreation enthusiasts lived closer to the recreation area, as would seem likely, aggregate consumer's surplus would be understated.

(3) The assumption of indifference to type of cost is unlikely to be responsible for serious error, though to the extent that travel gives rise to non-monetized pleasure or pain, people will not be indifferent between travel costs and, say, fishing license fees.

(4) The fact that many outings which include a recreational visit have other purposes as well imparts a bias toward overestimation of aggregate willingness to pay.

(5) Lack of a means of determining the effects of the availability of substitute recreational opportunities, however, is perhaps the most serious problem with the application of the Clawson method in the Trent Research Programme. The proximity of alternative sites will have a great influence on visit rates to the site under consideration. This presents no problem if government planners, or perhaps potential buyers, are concerned to calculate consumer's surplus for just the one site. They would be interested in willingness to pay to visit the site, given the availability of other sites. But in the Trent Research Programme's study of fishing benefits, there are 32 contiguous sites, and six of the seven residence zones surrounding any one site will overlap at least one and perhaps as many as six zones applicable to other sites. The practical policy questions are which of the sites to upgrade or downgrade (with respect to water quality), and by how much. The ceteris paribus assumption about alternative sites thus limits the use of fishing benefits study as a guide to policy.

Work has been proceeding in the Programme to determine, first, fishing benefits associated with present water quality levels in the

Basin, and then benefits as a function of pollution levels. We consider each of these tasks in turn, in the process casting considerable doubt on the third proposition above, that suitable techniques are available for drawing an accurate Clawson demand curve.

b. Fishing Benefit Calculations in the Trent Research Programme²²

The first step in the Trent study of fishing benefits (fishing is the only recreational activity for which a value was calculated) was to break the river system down into units around whose geographical centers concentric rings can be drawn. The study used for these purposes the same reaches which form the basic units of the mathematical model (Figure IV-11). Questionnaires were sent to a sample of anglers, who identified fishing sites and revealed how often they visited the sites (for the year 1968-69). Of the 5400 questionnaires sent out, 1600, representing about one percent of total license holders, were completed and returned. The results for the 1% sample, after researchers translated this information into visits per model reach, are presented in Figure IV-12. Calculation of visitation rates per 100,000 population was the next step (Figure IV-13).

Total annual fishing benefits were calculated for all the 32 reaches, for two different valuations of time costs, 12.5p and 25p per hour. (Alternative valuations were used because no one really knows the proper measure of time costs.) An angler's total costs of visiting a particular fishing site were taken as average travel outlays from the concentric zone in which he lives (Figure IV-14a), plus entrance fees (Figure IV-14b), plus travel time costs, and the sum was taken to represent his willingness to pay to visit that site or any site of similar quality, at that "price." The raw data from the questionnaires on site visits were used to construct tables like that in Figure IV-15 for each reach. Two equations were then derived to relate the visit rates (column 5) with

²²We must acknowledge at the outset the invaluable assistance of John Gibson, lecturer in the Department of Industrial Economics and Business Studies at the University of Birmingham, in providing data and analysis of the fishing benefits study he conducted for the Trent Research Programme. Much of the data is in two papers:

N. J. Kavanagh and J. G. Gibson, "Measurement of Fishing Benefits on the River Trent," Institute of Water Pollution Control, The Trent Research Programme: Proceedings of Symposium (15-16 April 1971), pp. 26-32; and

"The Trent Recreation Study: Measurement of Angling Benefits" (manuscript).

FIGURE IV-11

The River Trent Recreation Study Location Map

Source: The Trent Research Programme



FIGURE IV-12

NUMBER OF VISITS 1968-69 (from postal survey;
responses from a 1% sample of all anglers)

Zone Stretch	Miles from center of stretch							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
*T1	--	--	--	--	--	--	--	--
T2	--	--	--	--	--	--	--	--
T3	24	1	--	--	--	--	--	--
T4	7	13	--	--	--	--	--	--
T5a	76	6	--	--	--	--	--	--
T5b	61	--	--	1	--	3	1	--
T6a	508	82	43	36	3	7	1	--
T6b	1444	409	22	37	56	4	7	1
T7a	511	129	50	3	9	5	12	1
T7b	374	240	63	126	4	65	57	8
T7c	95	391	49	86	17	22	50	2
T8a	276	336	343	540	67	27	30	5
T8b	17	214	86	148	27	3	2	--
T9a	58	22	254	268	13	16	8	5
T9b	24	4	35	--	--	--	--	--
T9c	2	--	5	--	1	--	--	--
*S1	297	6	26	--	2	--	1	--
S2	39	2	--	--	--	--	--	--
S3	33	--	--	--	--	--	--	--
*DT1b	74	111	60	10	2	--	--	--
DT1a	123	28	--	1	--	--	--	--
DT2	334	29	--	--	--	2	--	--
*AM1	56	--	--	--	--	--	--	--
AM2	--	8	--	--	--	--	--	--
*D1b	226	16	9	--	--	--	--	--
D1a	15	211	3	7	--	--	--	--
*CH	83	3	--	--	--	--	--	--
*LT	--	--	--	--	--	--	--	--
*MT	--	--	--	--	--	--	--	--
*UTa	--	--	--	--	--	--	--	--
UTb	--	--	--	--	--	--	--	--
*Anka	107	95	--	--	--	--	--	--
Ankb	5	--	--	--	--	--	--	--
Total	4869	2356	1048	1463	238	154	168	22

Total visits all zones = 10,119

Source: The Trent Research Programme

*Key:

T1 = Trent stretch 1
 S = Soar
 DT = Derwent
 AM = Amber
 D = Dove
 CH = Churnet
 LT = Lower Tame
 MT = Middle Tame
 UTA = Upper Tame stretch
 Anka = Anker Stretch a

FIGURE IV-13

VISITATION RATES PER 100,000 POPULATION (from postal survey;
responses from a 1% sample of all anglers)

Zone Stretch	Miles from center of stretch							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
T1	--	--	--	--	--	--	--	--
T2	--	--	--	--	--	--	--	--
T3	10.64	0.03	--	--	--	--	--	--
T4	3.06	0.52	--	--	--	--	--	--
T5a	21.10	0.60	--	--	--	--	--	--
T5b	12.2	--	--	0.02	--	0.10	0.02	--
T6a	64.7	8.0	4.41	0.92	0.12	0.24	0.028	--
T6b	230.64	42.71	2.148	1.56	1.405	0.14	0.17	--
T7a	84.84	13.82	4.56	0.18	0.22	0.15	0.30	0.035
T7b	79.40	23.24	5.54	7.76	1.91	1.43	1.33	0.36
T7c	71.17	37.29	4.67	4.45	1.33	0.48	1.04	0.09
T8a	289.4	35.24	35.95	25.82	4.12	0.912	0.532	0.203
T8b	17.82	42.67	5.96	7.46	1.42	0.12	0.03	--
T9a	79.18	6.0	15.22	11.94	0.71	0.73	0.22	0.11
T9a	32.764	0.667	2.138	--	--	--	--	--
T9c	2.37	--	0.37	--	0.054	--	--	--
S1	75.05	0.50	1.88	--	0.07	--	0.03	--
S2	13.45	0.13	--	--	--	--	--	--
S3	4.20	--	--	--	--	--	--	--
DT1b	45.362	7.655	3.542	0.367	0.037	--	--	--
DT1a	26.936	2.509	--	0.022	--	--	--	--
DT2	65.29	2.88	--	--	--	0.06	--	--
AM1	18.228	--	--	--	--	--	--	--
AM2	--	0.551	--	--	--	--	--	--
D1b	16.80	20.64	0.14	0.16	--	--	--	--
D1a	63.15	2.33	0.23	--	--	--	--	--
CH	20.61	0.57	--	--	--	--	--	--
LT	--	--	--	--	--	--	--	--
MT	--	--	--	--	--	--	--	--
UTa	--	--	--	--	--	--	--	--
UTb	--	--	--	--	--	--	--	--
Anka	45.84	3.58	--	--	--	--	--	--
Ankb	1.99	--	--	--	--	--	--	--

Source: The Trent Research Programme

FIGURE IV-14(a)

COSTS PER MILE FROM 1968-69 QUESTIONNAIRES

Zone	New Pence							
	Miles from center of stretch							
Stretch	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
T1	--	--	--	--	--	--	--	--
T2	--	--	--	--	--	--	--	--
T3								
T4								
T5a								
T5b	2.00	1.18	1.44	1.14	--	--	0.38	--
T6a	3.25	1.18	0.89	0.98	0.88	0.73	0.65	--
T6b	2.75	1.19	0.90	1.07	0.88	0.90	0.55	0.35
T7a	3.05	1.43	1.03	2.14	0.50	--	0.41	--
T7b	2.00	1.66	1.35	0.85	0.61	0.92	0.69	0.66
T7c	2.00	1.28	1.22	0.81	0.85	0.71	0.57	1.41
T8a	3.08	1.22	0.96	1.07	0.90	0.63	0.53	1.39
T8b	1.03	2.15	1.41	1.10	0.57	0.50	--	1.07
T9a	1.56	1.15	1.18	1.34	0.64	0.58	0.45	0.57
T9b	--	3.29	2.18	--	--	--	--	--
T9c	2.00	--	0.89	--	--	--	--	--
S1	1.43	2.32	0.54	0.42	--	--	--	--
S2	1.39	--	--	--	--	--	--	--
S3	3.77	1.85	--	--	--	--	--	--
DT1b	4.17	1.64	1.43	0.42	3.33	--	--	--
DT1a	1.89	1.14	--	1.25	--	--	--	--
DT2	2.38	1.19	--	--	--	0.55	--	--
AM1								
AM2								
D1b	--	0.53	0.70	--	--	--	0.94	--
D1a	2.00	1.42	1.00	--	--	--	0.73	--
CH	1.88	1.50	--	--	--	--	--	--

For those not computed--zero or insufficient observations.

Source: The Trent Research Programme

FIGURE IV-14(b)

AVERAGE ENTRANCE PRICE 1968/69 QUESTIONNAIRES

Stretch	Price, New Pence
T1	---
T2	---
T3	5
T4	10
T5a	
T5b	10
T6a	10
T6b	10
T7a	10
T7b	10
T7c	10
T8a	10
T8b	10
T9a	10
T9b	5
T9c	10
S1	7.5
S2	2.5
S3	10
DT1b	20.0
DT1a	12.5
DT2	7.5
AM1	2.5
AM2	7.5
D1b	20.0
la	10.0
CH	5
LT	--
MT	--
UTA	--
UTb	--
Anka	12.5
Ankb	15

Source: The Trent Research Programme

FIGURE IV-15

Cost of Visits and Visitation Rates: River Trent, Radcliffe to Kneeton

Zone (1)	Distance from center of Stretch (miles) (2)	Visits (3)	Population (in 100,000's) (4)	Visits per 100,000 Population (5)	Cost of Visit	
					(6) at 12.5p per hour p	(7) at 25 p per hour p
A	0-9	374	4.71	79.40	51.85	58.28
B	10-19	240	10.32	23.25	70.52	90.84
C	20-29	63	11.37	5.54	105.85	129.82
D	30-39	126	16.23	7.77	126.93	160.34
E	40-49	41	21.39	1.92	138.74	181.66
F	50-59	65	45.22	1.44	167.35	219.79
G	60-69	57	42.81	1.33	180.50	242.49
H	70-79	8	21.75	0.37	206.78	278.34

Source: John Gibson, The Trent Recreation Study: Measurement of Angling Benefits, Table 5.

visit costs (columns 6 and 7). For the Radcliffe-Kneeton reach, the equations were:²³

Time value 12.5p per hour:

$$\text{Log } (v + 1) = 7.7221 - 2.8150 \text{ Log } C$$

$$\bar{r}^2 = 0.9516$$

Time value 25p per hour:

$$\text{Log } (v + 1) = 7.3303 - 2.5464 \text{ Log } C$$

$$\bar{r}^2 = 0.9560$$

where v = visits per year per 100,000 population

C = total costs per visit, pence

Both curves (Figure IV-16) are asymptotic to the Y axis, so the total area under them cannot be calculated. The area under these curves from $C = 10$ to the intercept on the X axis came to 240.05 @ 12.5p per hour and 353.90 @ 25p per hour time value. Since the curves were calculated and drawn on the basis of raw data representing 1% of total license holders in the Basin, these figures were multiplied by 100 to give aggregate consumer's surplus of £24,005 and £35,390, respectively. There was an average existing entrance fee of 10p for fishing on this stretch, so the observed revenue of £9,740 was added to each of these figures to get total benefits of £33,745 and £45,130, respectively. Similar calculations for each reach allowed the construction of Figure IV-17.

There is no alternative data by which the accuracy of the calculated equations can be tested throughout most of their range. For the range from zero to 10p on the horizontal axis, the area CDF0 (Figure IV-16) amounts to £87.90, and the area ABF0 is £93.10. The area under either curve between 10 and a point very close to zero on the horizontal axis would appear on inspection to be about half again as much. Observed revenue was £97.40. The equation predicts 879 visits at a total entrance cost of 10p, and there were in fact 974 visits. The 10% deviation here, admittedly the least reliable range of the curve, nevertheless raises doubts about the predictive value of the equation, since the equation was initially derived from data including the observation of 974 visits at 10p.

²³Source: "The Trent Recreation Study."

FIGURE IV-16 (Table)

Final Demand Schedule for River Trent, Radcliffe to Kneeton,
March, 1968 - March 1969.

Entrance ^a Charge (p)	Visits		Entrance Charge (p)	Visits	
	at 12.5p per hour	at 25p per hour		at 12.5p per hour	at 25p per hour
10	879 ^b	931 ^b	85	68	144
15	723	800	90	58	129
20	601	694	95	48	113
25	502	605	100	41	101
30	423	529	110	28	80
35	356	467	120	19	65
40	302	413	130	13	51
45	256	366	140	8	40
50	217	326	150	5	31
55	183	290	160	3	24
60	153	258	170	1	18
65	130	231	180	1	14
70	109	205	190	0	11
75	93	183	200	0	8
80	80	163	210	0	5
			220	0	3
			230	0	2
			240	0	1
			250	0	1
			260	0	0

^a10 pence was the average existing entrance charge for this stretch.

^bThis is the estimate of visits using equations (3), not the observed level of visits at the existing entrance charge.

Source: John Gibson, "The Trent Recreation Study: Measurement of Angling Benefits," Table 6.

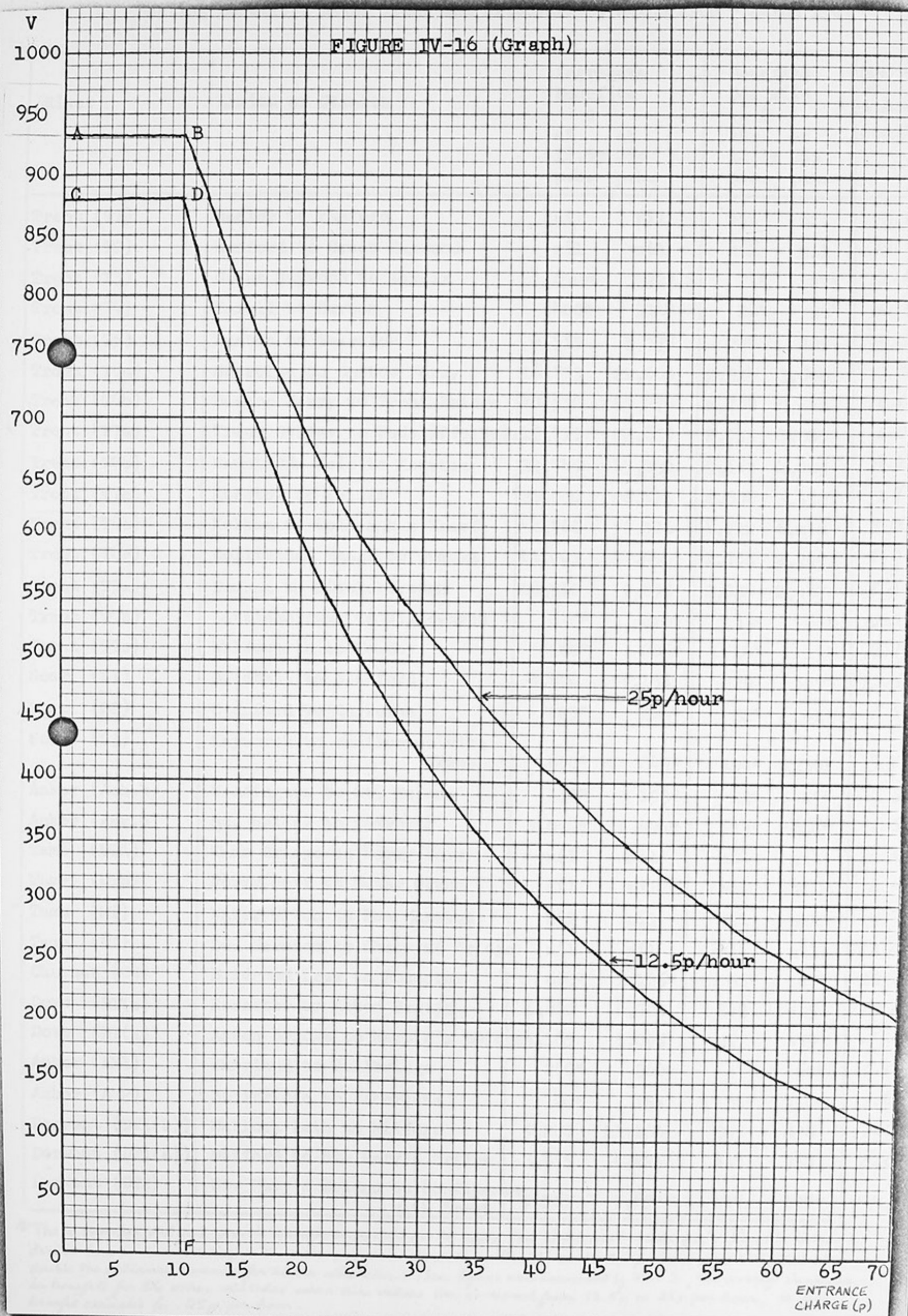


FIGURE IV-17

Source: John Gibson, "The Trent Recreation Study: Measurement of Angling Benefits," Table 7.

Angling Benefits: River Trent and Tributaries, March 1968 - March 1969

River	Limits of Stretch	Aggregate Benefits £		Benefits per mile £		LENGTH OF STRETCHES (MILES)
		at 12.5p p.h.	at 25p p.h.	at 12.5p p.h.	at 25p p.h.	
Trent (T1)	Hanley to Hanford	nil	nil	nil	nil	2.8
Trent (T2)	Hanford to Great Haywood	nil	nil	nil	nil	19.3
Trent (T3)	Great Haywood to Yaxall	250*	322*	21*	27*	12.0
Trent (T4)	Yaxall to Burton	400*	514*	28*	36*	14.3
Trent (T5)	Burton to Shardlow	4,515	5,775	230	295	19.6
Trent (T6a)	Shardlow to Barton Ferry	16,735	21,660	2,324	3,008	7.2
Trent (T6b)	Barton Ferry to Trent Bridge	40,550	51,275	6,758	8,548	6.0
Trent (T7a)	Trent Bridge to Radcliffe Weir	17,755	22,830	2,959	3,805	6.0
Trent (T7b)	Radcliffe Weir to Kneeton	33,745	45,130	3,668	4,905	9.2
Trent (T7c)	Kneeton to Kelham	20,080	26,425	2,608	3,432	7.7
Trent (T8a)	Kelham to Collingham Wharf	44,760	58,505	4,712	6,158	9.5
Trent (T8b)	Collingham Wharf to Dunham	14,005	17,995	1,751	2,249	8.0
Trent (T9a)	Dunham to Littleborough	16,310	19,895	2,039	2,487	8.0
Trent (T9b)	Littleborough to Wildsworth	630*	810*	53*	68*	12.0
Trent (T9c)	Wildsworth to Keadby	160*	206*	14*	19*	11.1
Soar (S1)	Birstall to Stanford	5,490	7,155	429	559	12.8
Soar (S2)	Stanford to Keyworth	205*	264*	32*	41*	6.5
Soar (S3)	Keyworth to confluence with Trent	660*	849*	194*	250*	3.4
Anker (Ank.b)	Weddington to St. Helena	150*	193*	13*	17*	7.5
Anker (Ank.a)	St. Helena to Tamworth	5,050*	6,494*	673*	856*	11.5
Tame (UTA)	Tame Bridge to Perry Barr	nil	nil	nil	nil	6.8
Tame (UTB)	Perry Barr to Water Orton	nil	nil	nil	nil	8.4
Tame (MT)	Water Orton to Lea Marston	nil	nil	nil	nil	4.7
Tame (LT)	Lea Marston to Chetwynd Bridge	nil	nil	nil	nil	18.6
Churnet (CH)	Bridgend Leek to Rocester	860*	1,106*	36*	47*	23.6
Dove (D1(b))	Rocester to Aston Bridge	5,820	6,700	448	515	13.0
Dove (D1(a))	Aston Bridge to Martin's Bridge	4,185	5,095	377	459	11.1
Amber (AM1)	Shirland to Bullbridge	280*	360*	47*	60*	6.0
Amber (AM2)	Bullbridge to Ambergate	120*	154*	86*	110*	1.2
Derwent (DT1(b))	Matlock Bath to Milford	9,260	11,180	827	978	11.2
Derwent (DT1(a))	Milford to St. Mary's Bridge	3,375	4,425	447	553	8.0
Derwent (DT2)	St. Mary's Bridge to confluence with Trent	5,965	7,690	417	538	14.3

*These stretches did not provide enough observations to apply the statistical technique. Benefits were derived from evidence relating to the more popular stretches. Benefits at 12.5p per hour were estimated at double the entrance revenue for those stretches. These figures were increased by 28.6%, the average increase in benefits for the other stretches when time values are increased from 12.5p to 25p per hour, to give benefit estimates for 25p per hour.

c. Problems of Deriving a Pollution Damage Curve from a Clawson Demand Curve

A Clawson demand curve (Figure IV-18 (a)) could be used to construct a curve relating marginal decreases in aggregate willingness to pay for recreation associated with the Trent, and incremental pollution loads (b). The Clawson curve assumes constant water quality (an unchanging recreation site). Several such curves could be drawn for different pollution levels, as in Figure IV-19. In this figure, aggregate annual willingness to pay for recreation visits to the river, when its BOD load is 12,800 kg (that is, two mg/l in an average flow of 1600 mgd), is represented by the area OAD. When the BOD load is 32,000 kg, the total is OBC. The difference between these two totals, that is, the area ABCD, would measure the marginal decrease in aggregate willingness to pay, as a function of units BOD discharged.

Angling participation is no doubt a function of the probability of catching fish. The latter depends to some extent on the skill of the angler, but to a large degree on the number of fish in the stream. The quantity of fish is in turn dependent upon the availability of dissolved oxygen and the concentration of toxic materials. Unfortunately, it would be very difficult to determine, from two sets of annual data on angling participation and BOD, NH_3 , and heavy metal levels, the relative roles of the pollutants in influencing angling. We would be as dependent upon the use of BOD or NH_3 as a "representative" or "index" pollutant in calculating marginal damages as in computing marginal effluent treatment costs.

There are four potential ways to introduce a pollution variability factor into the fishing benefit analysis:

- (1) Exactly the same calculation methods could be applied to use of the river by anglers in two years in which mean BOD levels were significantly different. The major problem with this intertemporal approach is that significant changes in pollution levels will occur only over long periods; yet the longer the time between experiments, the more likely such factors as changing tastes and population will explain much of the variation in calculated benefits.

FIGURE IV-18

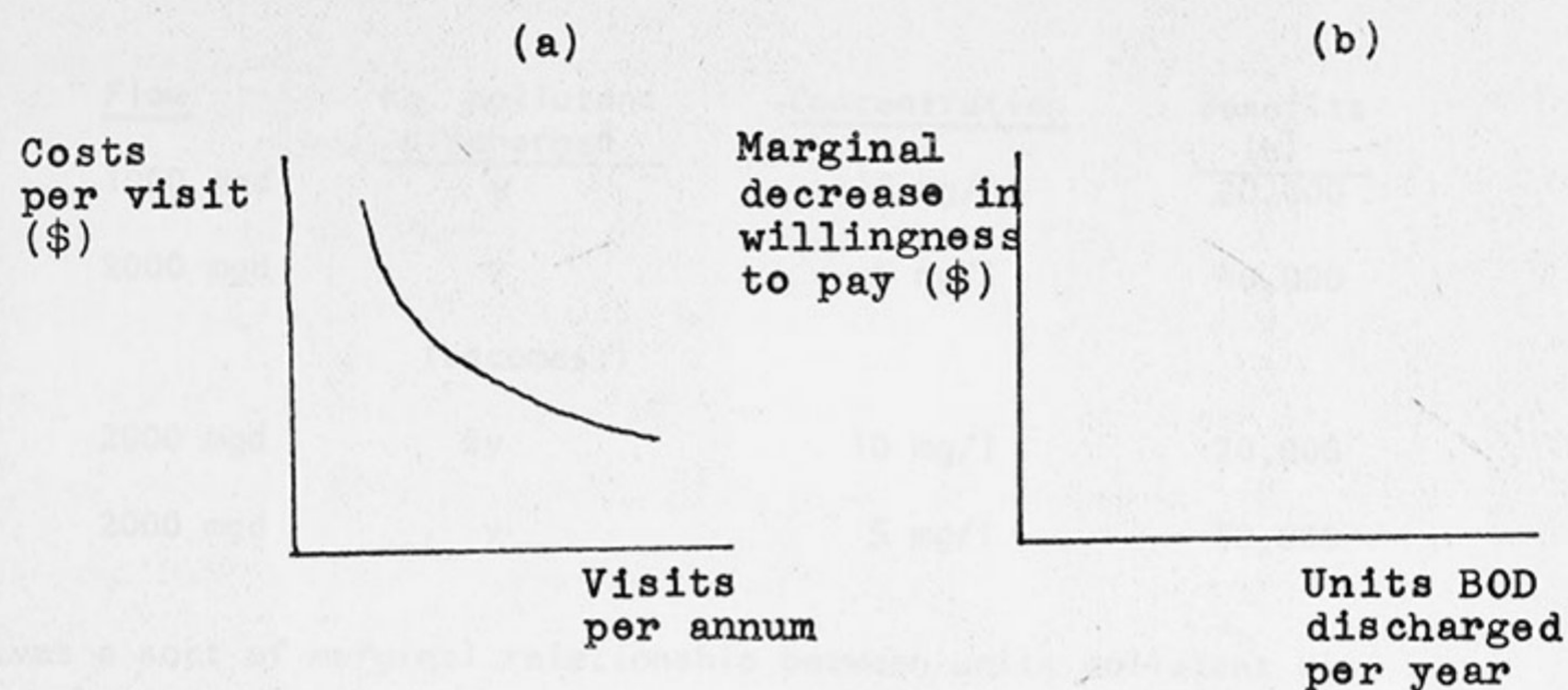
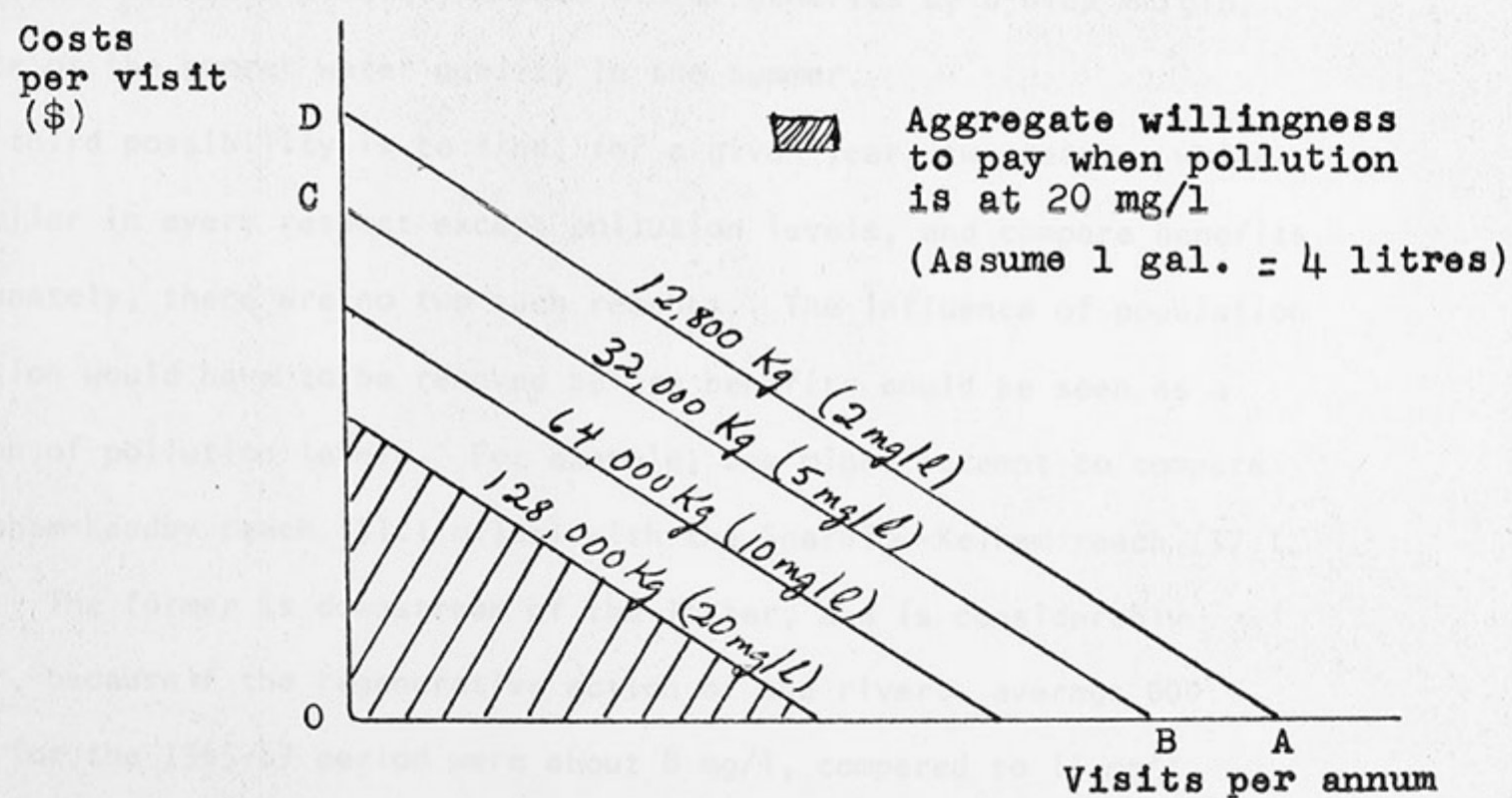


FIGURE IV-19



(2) An alternative method involving intertemporal comparisons is to calculate fishing benefits in a given reach for low-flow, high-concentration summer periods and high-flow, low-concentration winter periods. It must be assumed that pollutant discharges do not vary seasonally. The next step is to convert figures for constant BOD and variable flow into figures for constant flow and variable BOD, in the following manner:

	<u>Flow</u>	<u>Kg. pollutant discharged</u>	<u>Concentration</u>	<u>Benefits (£)</u>
SUMMER	1000 mgd	y	10 mg/l	20,000
WINTER	2000 mgd	y	5 mg/l	40,000
(becomes:)				
SUMMER	2000 mgd	2y	10 mg/l	20,000
WINTER	2000 mgd	y	5 mg/l	40,000

This gives a sort of marginal relationship between units pollutant discharged and monetary benefits: when pollution discharges are doubled, benefits are halved. The problem is that the weather factor, which disappears when annual figures are used, is probably much more significant in explaining fishing participation rates than pollutant levels. Summer benefits would probably exceed winter benefits by a wide margin, in spite of the poorer water quality in the summer.

(3) A third possibility is to find, for a given year, two reaches which are similar in every respect except pollution levels, and compare benefits. Unfortunately, there are no two such reaches. The influence of population dispersion would have to be removed before benefits could be seen as a function of pollution levels. For example, one might attempt to compare the Dunham-Keadby reach (31.1 miles) with the Shardlow-Kelham reach (37.1 miles). The former is downstream of the latter, and is considerably cleaner, because of the regenerative action of the river: average BOD levels for the 1965-67 period were about 8 mg/l, compared to 11 mg/l for the Shardlow-Kelham reach. However, the Shardlow reach is surrounded by the heavily-populated Nottingham district, whereas the river from Dunham to Keadby flows through a relatively rural area. Benefits for the cleaner reach and better fishery have been initially calculated in the Trent Research Programme at £17,790 per annum, or £572 per mile per annum, while benefits for the Shardlow-Kelham reach are set at £137,420 per annum, or £3704 per mile per annum.

Benefit calculations would thus have to be adjusted for population and taste changes with the first method, seasonal effects with the second method, and population levels and dispersion with the third method. Calculations under the second and third approaches would require only one set of annual data, though the second approach would require two surveys, one for each season. The first approach would probably require annual data for two years at least five years apart; its applicability hinges on the assumption that pollution levels will be significantly different, for some two years, to affect angling activity, but there is no particular reason why this should be the case. To isolate the pollution factor with any method would require either some very broad assumptions about other factors, or a collection of data so comprehensive that it is for all practical purposes unobtainable.

(4) The fourth method, requiring only one set of annual data and involving a statistical explanation of differences in calculated benefits per mile among reaches, has been the subject of study in the Trent Research Programme. Explanatory variables which were considered in the first experiment were (1) number of anglers which the reach can accommodate physically, (2) type of fishery available (water quality), and (3) population density in the surrounding area. The population index used was

$$\sum_{i=1}^7 P_i / d_{ij}^2, \quad ,$$

where i is the number of the concentric zone around the recreation site (seven in all), P_i is the population of the i th zone, and d_{ij} is the average distance between the zone and the site. Figure IV-20 classifies the relevant data for all reaches which showed positive fishing benefits. From these data were estimated the following linear equations:

Time value 12.5p per hour:

$$X_1 = -1099 + 242X_2 - 127X_3 + 2309X_4 + 2048X_5 - 89X_6 + 2952X_7$$

$$r^2 = 0.69$$

Time value 25p per hour:

$$X_1 = -1509 + 308X_2 - 182X_3 + 2916X_4 + 2723X_5 - 153X_6 + 4510X_7$$

$$r^2 = 0.69$$

Unfortunately, the use of these equations to calculate benefits for each reach under alternative quality conditions, by letting each of the

FIGURE IV-20

Benefits per mile, Accommodation Capacity, Type of Fishery, and
Population Indexes: River Trent and Tributaries, 1968-69

Stretch	Benefits per mile		Number of Anglers Accommodated	Type of Fishery				Population Index
	12.5p	25 p		Fair	Good	Very	Mixed	
	p.h.	p.h.		Coarse	Coarse	Good		
	X_1		X_2	X_3	X_4	X_5	X_6	X_7
T3	21	27	3	0	0	0	0	0.1802
T4	28	36	5	0	0	0	0	0.1813
T5	230	295	5	1	0	0	0	0.1715
T6(a)	2324	3008	7	0	1	0	0	0.2232
(b)	8758	8548	7	0	1	0	0	0.1922
T7(a)	2959	3805	7	0	1	0	0	0.1845
(b)	3668	4905	7	0	0	1	0	0.1632
(c)	2608	3432	7	0	0	1	0	0.1057
T8(a)	4712	6158	7	0	0	1	0	0.0941
(b)	1751	2249	7	0	0	1	0	0.0851
T9(a)	2039	2437	7	0	0	1	0	0.0769
(b)	53	68	5	0	0	0	0	0.0825
(c)	14	19	3	0	0	0	0	0.0754
S1	429	559	2	1	0	0	0	0.1576
S2	32	41	5	0	0	0	0	0.1499
S3	194	250	5	1	0	0	0	0.2203
DT1(b)	827	998	5	0	0	0	1	0.1466
(a)	447	553	5	0	0	0	1	0.1812
DT2	417	538	5	0	0	0	1	0.1833
AM1	47	60	1	0	0	0	0	0.1623
AM2	86	110	1	0	0	0	0	0.1466
D1(a)	377	459	5	0	0	0	1	0.1713
D1(b)	448	515	5	0	0	0	1	0.1300
CH	36	47	1	0	0	0	0	0.1742
Ank.(a)	673	866	2	0	1	0	0	0.1782
(b)	13	17	2	0	0	0	0	0.1761

Source: John Gibson, "The Trent Recreation Study: Measurement of Angling Benefits," Table 9.

quality variables $X_3 - X_6$ equal 1 while the others equal zero, in turn, produced some strange results, showing benefits to decline as the fishery improves from poor coarse to fair coarse, and from very good coarse to mixed. Those results are not intuitively plausible. It was thought that letting X_1 be benefits per unit of surface area or perhaps benefits per unit of flow would greatly increase the figures for the only existing trout fisheries, DT1(a), DT1(b), DT2, D1(a), and D1(b), relative to those for the much wider and deeper reaches T(6) - T9(a). Another factor which was not taken into account in the initial figures is that the best trout fisheries on the Derwent and Dove are upstream of the reaches used in the river model, and these close substitute trout fishing opportunities would reduce visitation rates to the river model reaches, as reported in the survey responses.

These considerations led to a second attempt at correlating fishing benefits and pollution levels, this time producing more intuitively logical results. Figure IV-21 reproduces R. J. Anderson's own description of the methodology, and his initial calculations of the benefits of improving quality in four reaches, T5, S1, T6, and T7A. This approach bears much more promise than the other. But the intuitive consistency of the results is only one factor bearing on the policy value of the consumer's surplus figures derived in this way. Criticisms of the accuracy of the base data, the statistical processes employed, and the Clawson method itself all bear on the question of how these and other total and marginal benefit estimates are to be used for water quality management in the Trent River Basin.

FIGURE IV-21 (page 1)

TRENT FISHING MODEL : ESTIMATION OF CONSUMERS' SURPLUS

by R. J. Anderson

Estimating the Equation(s) The method was to aggregate the data from all stretches. Trips per 100,000 to a given stretch were regressed on cost of travel, length of stretch and represented by dummy variables, quality of fishing and width of stretch. The only variables found to be significant at the 5% level were cost of travel and quality of fishing. Here is the equation, with standard errors in brackets :

<u>Trips/00000 pop.</u>	<u>Travel Cost</u>	<u>Fair</u>	<u>Good</u>	<u>Very Good</u>	<u>Mixed</u>
$\log (T + 1) =$	$-3.013 \log C$	$+ 7.524$	$+ 7.972$	$+ 8.169$	$+ 7.659$
	(0.178)	(0.437)	(0.445)	(0.441)	(0.424)

$$\bar{R}^2 = 0.79$$

When we are considering separate grades of fishing, the equation decomposes into 4 separate equations each with a different constant term, but sharing the same coefficient on the log C term. Next, in order to allow the possibility that the slope of the demand curve is different for each grade of fishing, data for each grade of fishing was treated separately, the resulting four equations being:

Fair

$$\log (T + 1) = -2.077 \log C + 5.273$$

(0.484) -(1.167)

$$\bar{R}^2 = 0.57$$

Good

$$\log (T + 1) = -3.45 \log C + 9.047$$

(0.277) (0.684)

$$\bar{R}^2 = 0.91$$

Very Good

$$\log (T + 1) = -3.515 \log C + 8.837$$

(0.449) (1.056)

$$\bar{R}^2 = 0.74$$

Mixed

$$\log (T + 1) = -3.017 \log C + 8.18$$

(0.239) (0.589)

$$\bar{R}^2 = 0.84$$

FIGURE IV-21 (page 2)
by R. J. Anderson
for The Trent Research Programme

Consumers' Surplus Arising from Improved Quality in Fishing

Firstly calculate surplus for each quality of fishing on its own. How is this to be done? The surplus calculation must be done at stretch level. From the cost readings we have for each stretch we have the lower bound of an integral. We calculate the integral with these as lower limits and an upper limit, which is in each case the cost at which no trips would occur. The upper limit of integration is found as follows. Consider the equation for fair fishing :

$$\log (T + 1) = -3.013 \log C + 7.524$$

The upper limit of integration is given by

$$C_{T=0} = \left(\frac{1}{10^{7.524}} \right) \left(\frac{1}{-3.013} \right) \text{ i.e. } C_{T=0} = \left(\frac{1}{10^{7.524}} \right)^{-\frac{1}{3.013}}$$

Surplus from fair fishing at any stretch, assuming n cost readings in the original data is

$$\sum_{i=1}^n \int_{C_i}^{C_{T=0}} \left\{ \frac{C^{-2.013}}{-2.013} \times 10^{9.524} - C \right\} dC$$

The surplus resulting from improving a stretch from fair to good is

$$\sum_{i=1}^n \int_{C_i}^{C_{T=0}} \left\{ \frac{C^{-2.013}}{-2.013} \times 10^{7.972} - C \right\} dC - \sum_{i=1}^n \int_{C_i}^{C_{T=0}} \left\{ \frac{C^{-2.013}}{-2.013} \times 10^{7.524} - C \right\} dC$$

The cost at which no trips occur is calculated separately for each quality.

Results for the whole equation case are given below :

Value of improvements to fishing quality £ p.a.

		To →	
From ↓		<u>Good</u>	<u>Very Good</u>
Fair	(T5	17,821	42,090
	(S1	14,280	30,468
Good	(T6		26,769
	(T7A		11,864

Results for the separately estimated equations:

		To →	
From ↓		<u>Good</u>	<u>Very Good</u>
Fair	(T5	25,587	45,963
	(S1	17,793	31,673
Good	(T6		23,531
	(T7A		10,436

CHAPTER V

TOWARD IMPROVED WATER QUALITY MANAGEMENT

IN THE TRENT RIVER BASIN

A. BENEFIT-COST ANALYSIS IN THE TRENT RESEARCH PROGRAMME

The 1968-1969 fishing benefit figures shown in Figure IV-17 are presently being incorporated into the river model computer runs in the following way. As the program proceeds downstream from installation to installation (within each reach are several installations, such as sewage plants or factories, for which the cheapest treatment facility which will meet the quality goals must be chosen), the least-cost collection of facilities satisfying all constraints up to whatever stage the dynamic program has reached is "remembered". At the end of a reach, the fishing benefits for the reach are simply subtracted from the total costs shown by the program so far, to give a "net cost" figure. This means that if enough benefits existed and were quantified, net costs for constructing a series of new treatment facilities would come out zero or negative by the end of the computer run, indicating that benefits exceed costs.

In current computer runs, however, benefits come nowhere near even the order of magnitude of costs. For example, in River Model Run 10B (LGORU 1970), net costs for attaining quality state 5 in the final reach and associated qualities in the upstream reaches (representing a substantial overall improvement from present quality in the river) came to £9,774,800. Total benefits were £245,100, and total costs were £10,019,900. The problem is that benefit figures for the existing set of 1968-69 qualities--the only benefit figures available--were subtracted from computed costs for an improved set of qualities. But the two figures are simply not comparable. What is needed is a way of estimating additional benefits for the improved qualities, so that these might be compared with additional costs of attaining those qualities.

Research is still proceeding on the statistical method described in Chapter IV, to correlate fishing benefits and water quality. If sufficiently trustworthy "marginal" benefit figures could be derived, they could be used in connection with the river model to make incremental benefit-cost comparisons which will assist planning for specific reaches. The procedure by which the program automatically subtracts benefits from costs at the end of each reach would first have to be eliminated. The program could then be run with no constraints except a certain quality improvement (for example, from fair coarse to good coarse) in an individual reach. It would find the least-cost combination of facilities which must be built upstream of the reach in question to effect that improvement. (Of course, it would not be necessary to run the program beyond the reach in question.) This figure could then be compared with the benefit figures for that same quality improvement in that reach, plus the benefits from whatever quality improvements in upstream reaches arise from the new facilities. In addition, the effect of any individual discharge on river quality in all downstream reaches can be determined by first running the model with the discharge included, and then without. If the discharge has significant enough effects on quality to change a quality state (from, say, good coarse to fair coarse), then the marginal damages of the discharge can be calculated. The Trent Research Programme has thus produced some very sophisticated tools for cost-benefit analysis of individual decision-makers' options in an interdependent river pollution system. Such analysis would be more useful for planning specific improvements than the comparisons of overall costs and benefits for the entire river system which have so far been made. The major uncertainty for the policy-maker, of course, would still be the trustworthiness of the benefit figures. The sophistication of the calculation methods, ingenious as they are, does not necessarily ensure that the results are accurate enough to determine policy, by themselves. Furthermore, fishing benefits do not represent all the benefits of improved water quality. An alternative measure of overall recreation benefits, similar to that used in the Delaware Study, should be provided for planning purposes.

B. BENEFIT-COST ANALYSIS IN THE DELAWARE ESTUARY
COMPREHENSIVE STUDY

The Delaware Study, in which the derivation of a mathematical river model was only one of several tasks, established four groups of improved quality goals, called Objective Sets (Figures V-1 and V-2). The Preliminary Report and Findings describes these Objective Sets in qualitative terms:¹

Objective Set I. This set represents the greatest increase in water use and water quality among all of the objective sets. Water contact recreation is indicated in the upper and lower reaches of the estuary. Sport and commercial fishing was set at relatively high levels consistent with the make-up of the region. A minimum daily average DO goal of 6.0 mg/l is included for anadromous fish passage during the passage periods. Thus anadromous fish passage is included as a definitive part of the water quality management program. Fresh water inflow control will be necessary to repulse high chloride concentrations to Chester, Pa., thereby creating a potential municipal and industrial water supply use.

Objective Set II. The area of water contact recreation is reduced somewhat from that of Objective Set I (OS-I). A reduction in dissolved oxygen (DO) is considered to result in a concomitant reduction in sport and commercial fishing. DO goals for anadromous fish passage remain as in OS-I. Chloride control would be necessary to prevent salt water intrusion above the Schuylkill River.

Objective Set III. This set is similar in all respects to OS-II except for the following three changes. First, the specific DO criteria [sic] for anadromous fish passage is not imposed. However, substantial increases in anadromous fish passage will result from the treatment requirements imposed to control DO during the summer assuming that the waste load reductions are carried out during the anadromous fish run periods. Second, a general decrease in the sport and commercial fishing potential is imposed through a lowering of the DO requirements. Third, the quality at points of municipal water supply were reduced.

Objective Set IV. This set represents a slight increase over present levels in water contact recreation and fishing in the lower reaches of the estuary. Generally, quality requirements are increased slightly over 1964 conditions (OS-V) representing a minimally enhanced environment.

Objective Set V. This set represents a maintenance of 1964 conditions, i.e., a prevention of further water quality deterioration.

The next step was to compare the costs of moving from the fifth Objective Set (current quality) to each of the others, using alternative control measures. Analysis was confined to 44 industries and municipalities in the Estuary, whose discharges accounted for about 97% of the 1964 carbonaceous oxygen demand waste load in the Estuary. Low-flow conditions of 3000 cubic feet per second (1620 million gallons per day) were assumed throughout. The control measures considered (Figure V-3) were all variants of the direct regulatory approach. These include a uniform treatment

¹ Delaware Study, Preliminary Report, pp. 54-55.

FIGURE V-1

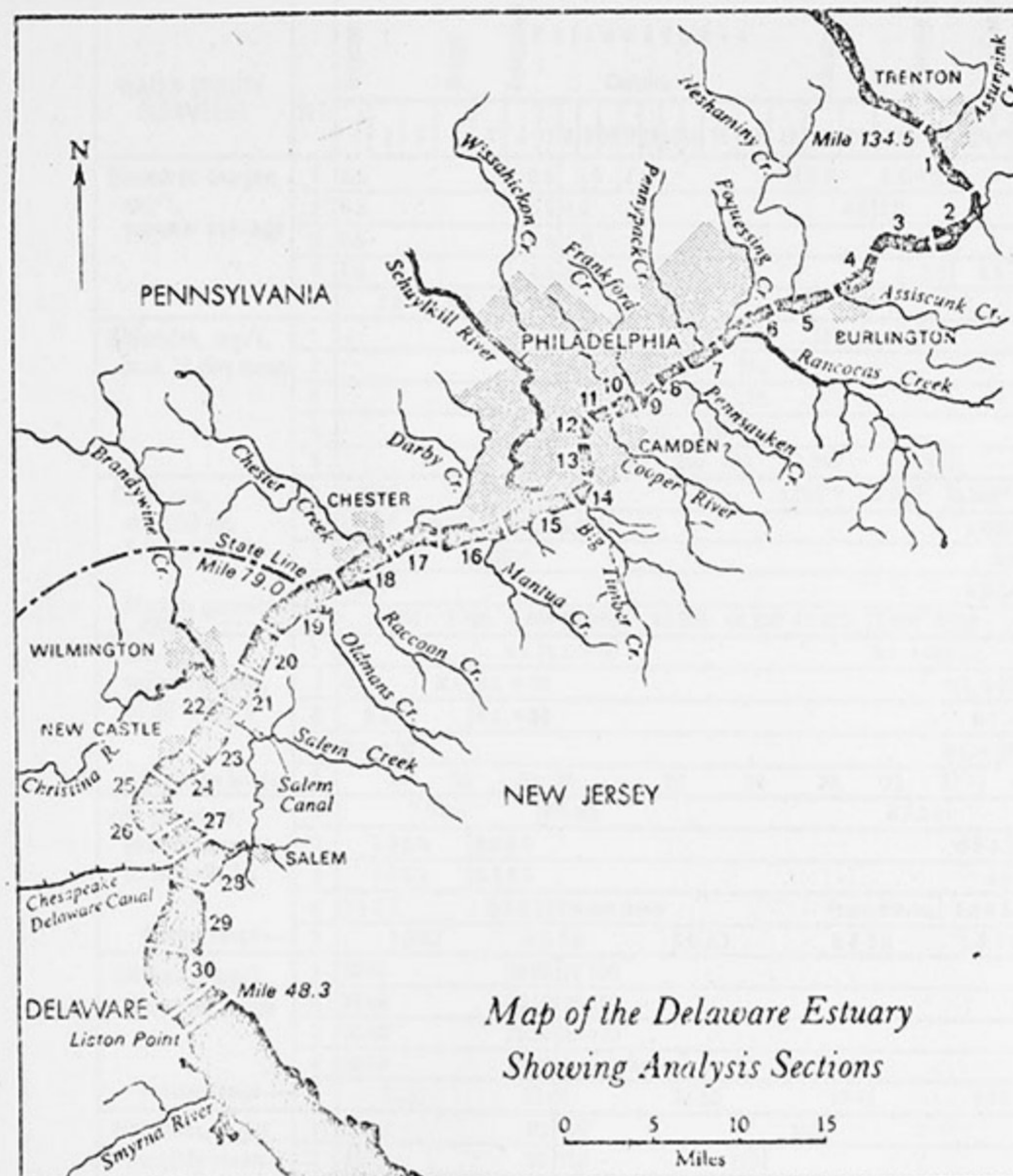


Figure 38. Source: FWPCA, Delaware Estuary Comprehensive Study.

Reproduced in Kneese and Bower, Managing Water Quality: Economics, Institutions, Technology, Baltimore: Johns Hopkins, for Resources for the Future, Inc., 1968, p. 228.

'FIGURE V-2'

Comparison of Water Quality Goals for Objective Sets 1-5
(Set 5 represents conditions in 1964)

WATER QUALITY PARAMETER:	SET	SECTION:																																	
		Trenton			Bristol			Torresdale			Philadelphia										Camden			Chester			Wilmington			New Castle			Lisbon Point		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
Dissolved oxygen, mg/l, summer average	1	6.5					6.5	5.5	4.5								4.5	5.5	5.5	6.5							6.5	7.5	7.5						
	2	5.5					5.5	4.0											4.0	5.0							5.0	6.5							
	3	5.5					5.5	3.0													3.0	4.5				4.5	5.5	6.5							
	4	4.0					4.0	2.5														2.5	3.5					5.5							
	5	7.0	5.1				5.8							1.0					1.0				4.2						7.1						
Chlorides, mg/l, max. 15-day mean	1																50	250																	
	2																50	250																	
	3																50	250																	
	4																50	250																	
	5							50	100	250	400								1,340			2,400													
Coliforms, #/100 ml, 5/30 - 9/15	1	4,000 ^a					4,000 ^a	5,000 ^a										5,000 ^a	5,000 ^b	4,000 ^a						5,000 ^b	4,000 ^a								
	2	4,000 ^a	4,000 ^a				5,000 ^a	5,000 ^b																		5,000 ^b	4,000 ^a								
	3	4,000 ^a					5,000 ^b																			5,000 ^b	4,000 ^a								
	4	5,000 ^b																								5,000 ^b	4,000 ^a								
	5	2,600	2,700	6,800	25,000			63,000	66,000	51,000	22,000	7,000	1,500	700																					
Turbidity, turbidity units, 5/30 - 9/15	1	N.L.					N.L.	N.L. + 30												N.L. + 30	N.L.														
	2	N.L.					N.L.	N.L. + 30													N.L. + 30	N.L.													
	3	N.L.					N.L.	N.L. + 30													N.L. + 30	N.L.													
	4	N.L. + 30																			N.L. + 30	N.L.													
	5	23	28				29	24					22			24		27		27	37	43			43										
pH, pH units, desirable range, 5/30 - 9/15	1	7.0-8.5					6.5-8.5													6.5-8.5	7.0-8.5														
	2	7.0-8.5					6.5-8.5															6.5-8.5	7.0-8.5												
	3	7.0-8.5					6.5-8.5																6.5-8.5	7.0-8.5											
	4	6.5-8.5					6.5-8.5	Present levels											Present levels		6.5-8.5	7.0-8.5													
	5	7.0-8.7					6.9-7.6						6.6-7.3					6.4-7.0		5.6-7.5	6.1-7.8														
Alkalinity, mg/l, desirable range	1	20-50					20-50	20-120																											
	2	20-50					20-50	20-120																											
	3	20-50					20-50	20-120																											
	4	20-50					20-50	Present levels																											
	5	25-51					33-46						34-50					13-41		4-25	10-49														
Hardness, mg/l, monthly mean	1	95					95	150											150																
	2	95					95	150																											
	3	95					95	150											150																
	4	95					95	150					150																						
	5	83						122											467																
Phenols, mg/l, monthly mean	1	.001																	.001	.01															
	2	.001					.001	.035											.005	.01															
	3	.001					.001	.005											.035	.01															
	4	.005											.005	.01																					
	5	.01	.02				.03	.04					.03	.05			.05				.06														
SECTION:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				

a. Maximum level. b. Monthly geometric mean. N.L. = Natural levels

Source: Delaware Estuary Comprehensive Study.
Information summarized in Kneese and Bower,
Managing Water Quality, Table 13, p. 229.

FIGURE V-3

ESTIMATED TOTAL COSTS OF OBJECTIVE SETS (MILLIONS OF DOLLARS)
Flow = 3000 cfs at Trenton

OS		Uniform	A-Zoned	B-Zoned	Municipal-Industrial	Cost Minimization
I	DO Cost (3)	460	460	460	460	460
	Bact.	30	30	30	30	30
	Total	490	490	490	490	490
II	DO Cost (3)	315	275	275	315	215
	Bact.	20	20	20	20	20
	Total	335	295	275	335	235
III	DO Cost (3)	155	130	120	120	85
	Bact.	20	20	20	20	25(1)
	pH	-	15(2)	15(2)	25(2)	25(2)
	Total	175	165	155	165	135
IV	DO Cost (3)	130	90	80	90	65
	Bact.	15	15	15	15	20(1)
	pH	-	15	15	15	15(2)
	Total	145	120	110	120	100

Notes: 1. To meet bacterial goals, additional chlorine dosages needed by several sources not in DO program.
2. To meet pH goals, pH control needed by several sources not in DO program.
3. Other water use goals (except chlorides) assumed to be met by DO, pH and bacterial control measures. Chlorine goal requires fresh water flow regulation. Meeting the phenol goal for OS-I in sections 18-22 may require supplemental phenol control measures. All DO costs include \$50 million cost of maintaining OS V.

Source: Delaware Estuary Comprehensive Study:
Preliminary Report and Findings, p. 66, Table 16.

FIGURE V-4

ESTIMATED RECREATIONAL BENEFITS (1975-1980)
MILLIONS OF DOLLARS (PRESENT VALUE)

OS	Net Benefits /1		Net Marginal Benefits	
	Max.	Min.	Max.	Min.
I	355	155	35	20
II	320	135	10	10
III	310	125	30	10
IV	280	115		

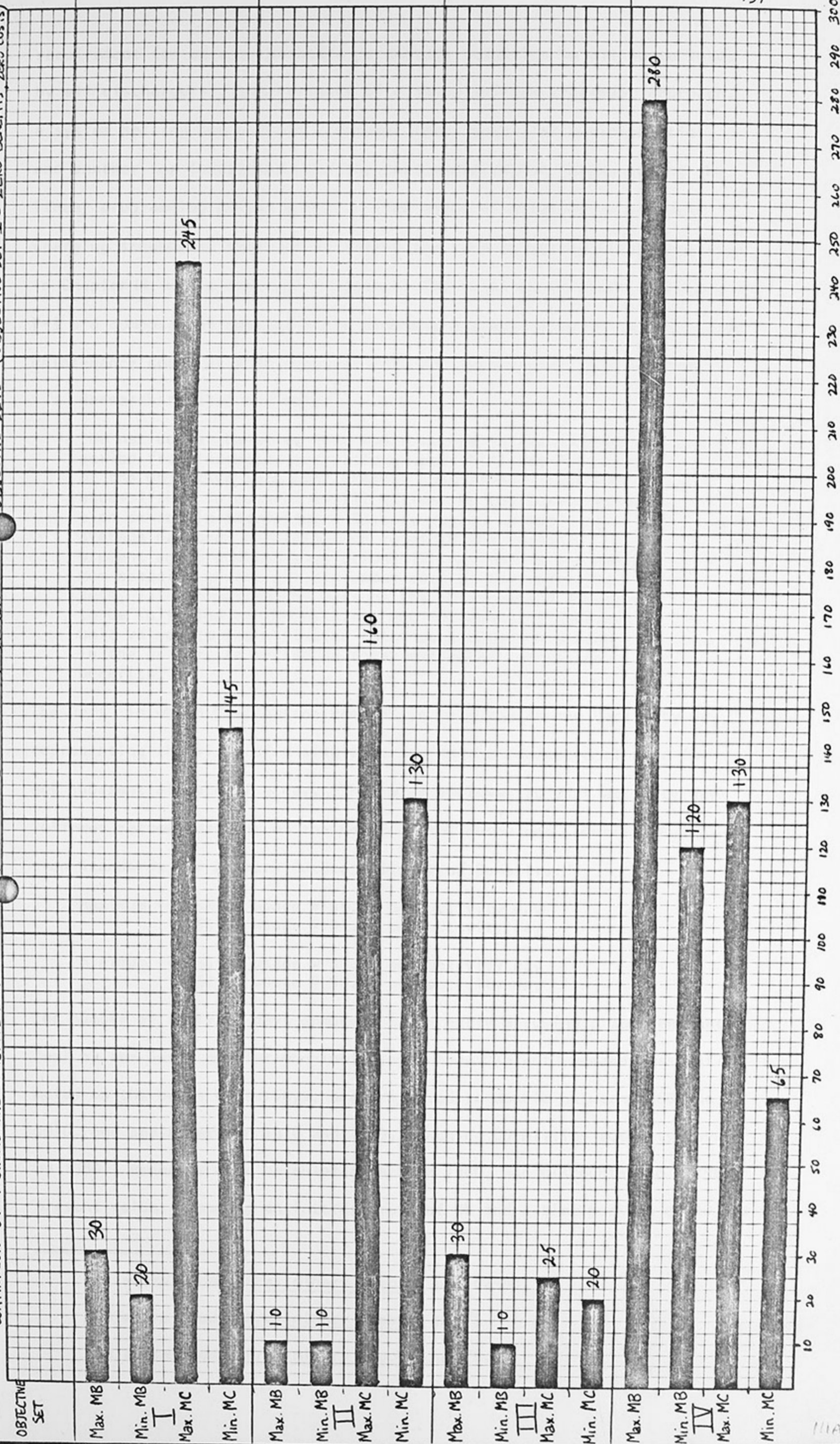
/1 Net Benefits above OS-V.

Source: Delaware Estuary Comprehensive Study:
Preliminary Report and Findings, p. 77, Table 20.

FIGURE VI-5

DELAWARE ESTUARY COMPREHENSIVE STUDY:

COMPARISON OF INCREMENTAL BENEFITS AND COSTS OF ATTAINING SUCCESSIVELY HIGHER OBJECTIVE SETS (OBJECTIVE SET II = ZERO BENEFITS, ZERO COSTS)



SOURCE: PRELIMINARY REPORT AND FINDINGS OF DEL. 77 78, 81

requirement (an across-the-board percentage reduction in all waste loads by all dischargers), two variants of a zoned uniform treatment approach, a system setting one uniform treatment requirement for municipalities and another for industries, and the cost minimization scheme (using the linear programming primal model). (The study of alternative effluent charging schemes as means of attaining the same Objective Sets, described in Chapter II, was a separate project.) The total costs shown in Figure V-3 are composed of capital costs plus the present value of operating and maintenance costs at a 3% discount rate and twenty-year time horizon.²

Researchers then estimated³

the net dollar benefits that would accrue in the 1975-80 period from increased recreational possibilities for each of the Objective Sets over present conditions. This was accomplished in general by (1) estimating the total recreation demand in the Delaware Estuary region by applying average national participation rates to the region's present and projected population, (2) estimating the maximum capacity of the estuary under each of the objective sets, (3) estimating the part of the total demand expected to be fulfilled by the estuary, and (4) applying monetary unit values to the estimated total participation demand in the estuary to arrive at total estimated recreation benefits.

The unit in which "recreation demand" is measured is the "activity day," representing the visit of a single person to the recreational site for any substantial part of a day. The value assigned to each activity day followed recommendations of the Ad Hoc Water Resources Council, "Evaluation Standards for Primary Outdoor Recreation Benefits:"⁴

Maximum -- 25% of usage @ \$5.00 per activity day
75% of usage @ \$1.25 per activity day

Minimum -- 25% of usage @ \$3.00 per activity day
75% of usage @ \$0.75 per activity day

The number of activity days demanded (apparently assuming a zero entrance fee) by the basin population--including a huge "latent" demand--was estimated on the basis of surveys, and projected to double between 1960 and 1970, and again between 1970 and 1980, reaching 80 million activity days by 1980. Benefits were calculated through 1980, and discounted to a 1964 present value, assuming an interest rate of 3% and a time horizon of 20 years.

² Delaware Study, Preliminary Report, pp. 62-63.

³ Delaware Study, Preliminary Report, p. 75.

⁴ Delaware Study, Preliminary Report, p. 76.

Benefits for the present quality state, objective set V, were then subtracted from benefits accruing to improved quality states I-IV, to give net benefit figures as shown in Figure V-4.

This data is not suitable for drawing continuous curves showing marginal cost per unit pollutant removed, mainly because the additional blocs of various pollutants which would be removed in escalating from one objective set to another are not identical. But the rough comparisons between marginal costs and benefits which these figures allowed (Figures V-3, V-4, and V-5) formed the basis of unique policy discussions among the various groups in the Delaware Basin who take a direct interest in water quality. The most widely acceptable goal was Objective Set 3, with conservation groups generally committed to Objective Set 2, though the study indicated that the marginal costs of moving from O.S.3 to O.S.2 exceeded the marginal benefits by a wide margin. Such a position is by no means irrational, however. Conservationists might feel that higher values should be placed on activity days, or that since costs of attaining quality goals are to be spread over all taxpayers, the additional benefits of O.S.2 accruing to the individual conservationist exceed his share of the additional cost. After the extensive public consultation process, the Basin Commission adopted slightly higher quality goals than those represented by O.S.3; marginal benefits and costs are roughly equal at these goals.

The figures, of course, are all painfully inexact. The obvious criticism is that the values assigned to "activity days" are arbitrary. The researchers' presentation of alternative maximum and minimum values mitigates criticism of the research method, but does not help the policymakers to whom the report is presented to know which of the wide range of possible benefit figures is most appropriate. No sensitivity analysis seems to have been done for alternative interest rates and time horizons. The 3% rate used is well below the 1964 opportunity cost of funds in private markets, and the 20-year time horizon is much shorter than the usual 50-year period used for recreational projects in federal government benefit-cost analysis.

The activity day itself is not a homogeneous unit. Estimates of "latent demand" were based on simple sampling techniques, using questionnaires, and projections of "activity days demanded" seem to have been based on a linear trend line, at least through 1980. No claim was made in the Study that the calculated total present value of recreational benefits is a measure of consumer's surplus, the maximum amount that people of the basin would be willing to pay to have the recreational facility (the river in one or another of the five quality states). The values recommended by the Ad Hoc Water Resources Council were based on previous Clawson-method studies of particular recreation sites, but were arbitrarily generalized and have not been adjusted for inflation.

To call the goals which the Basin Commission adopted "optimal pollution levels" is thus stretching the theoretical concept, even if the calculated costs and benefits are perfectly accurate. The goals were not derived from the intersection of two continuous curves with the requisite slopes, but rather from the comparison of four sets of ranges of marginal costs and benefits, selecting the set in which the ranges are most nearly identical. Second-order conditions for an optimum were thus completely ignored. But the widespread public support for Objective Set 3, though certainly influenced by the presentation of calculated marginal costs and benefits in such a way that Objective Set 3 seems the obvious choice, indicates that the associated costs probably do not exceed aggregate willingness to pay. In any event, the Delaware Basin Commission's choice of water quality goals has for the first time been based upon an explicit consideration of marginal concepts.⁵

C. THE ROLE OF POLLUTION CHARGES IN THE TRENT RIVER BASIN

Charges levied by the Upper Tame Main Drainage Authority, as described in Chapter 1, are essentially SECH's for each pollutant. There

⁵ Whether the costs of such research studies exceed their benefits is an intriguing question. The Delaware Estuary Comprehensive Study cost U. S. taxpayers \$1,200,000. The Trent Research Programme required a remarkably similar sum from the taxpaying public in the United Kingdom: more than £500,000.

is no differentiation of charges according to location on the river. All polluters discharging the same loads pay the same charges. Whether the charges are often the binding constraint on pollution discharges is a moot point; where pretreatment requirements are imposed, the charges may be only a small part of the total outlays on pollution removal which the polluter is required to make. Charge receipts totalled £397,198, more than 10% of the UTMDA's income of £3,562,230, in the 1969-1970 fiscal year. (Remember that the UTMDA does not collect charges for the City of Birmingham.) The burden of charges on individual firms is evident from the histogram in Figure V-6, which shows, of the 335 firms in the UTMDA area who pay more than £5 per six-month charging period, the number who paid total charges for the six-month period 1 April 1971--30 September 1971 in each of the nine ranges. Descriptions of the discharges of the 22 firms who paid more than £1,000 in that period are listed separately. Note that one brewery paid £12,469.84 in the six-month period. An annual effluent charge bill for one plant of about £25,000 is not inconsiderable, and must certainly have some effect on production decisions.

If the existing mixed regulatory system of quotas, pretreatment requirements, and charges were replaced by a system of charges as the single binding constraint on pollution discharges, however, it is not clear from this or any other available data how high charges would have to be just to keep industrial discharges at their present levels. A still more difficult question is what charges would have to be levied on direct discharges to the river system, by both firms and municipal sewage plants (who in turn levy charges on industrial dischargers to their sewers, and presumably on households, in the form of user charges or simply sewage rates), in order to maintain current quality levels through the lone regulatory device of a charging scheme.

The Delaware Estuary simulation results, reproduced in Figures V-7, 8, and 9, provide some idea of the order of magnitude of charges required for certain quality changes. Edwin L. Johnson comments on this last table:⁶

⁶ Edwin L. Johnson, "Study," p. 300.

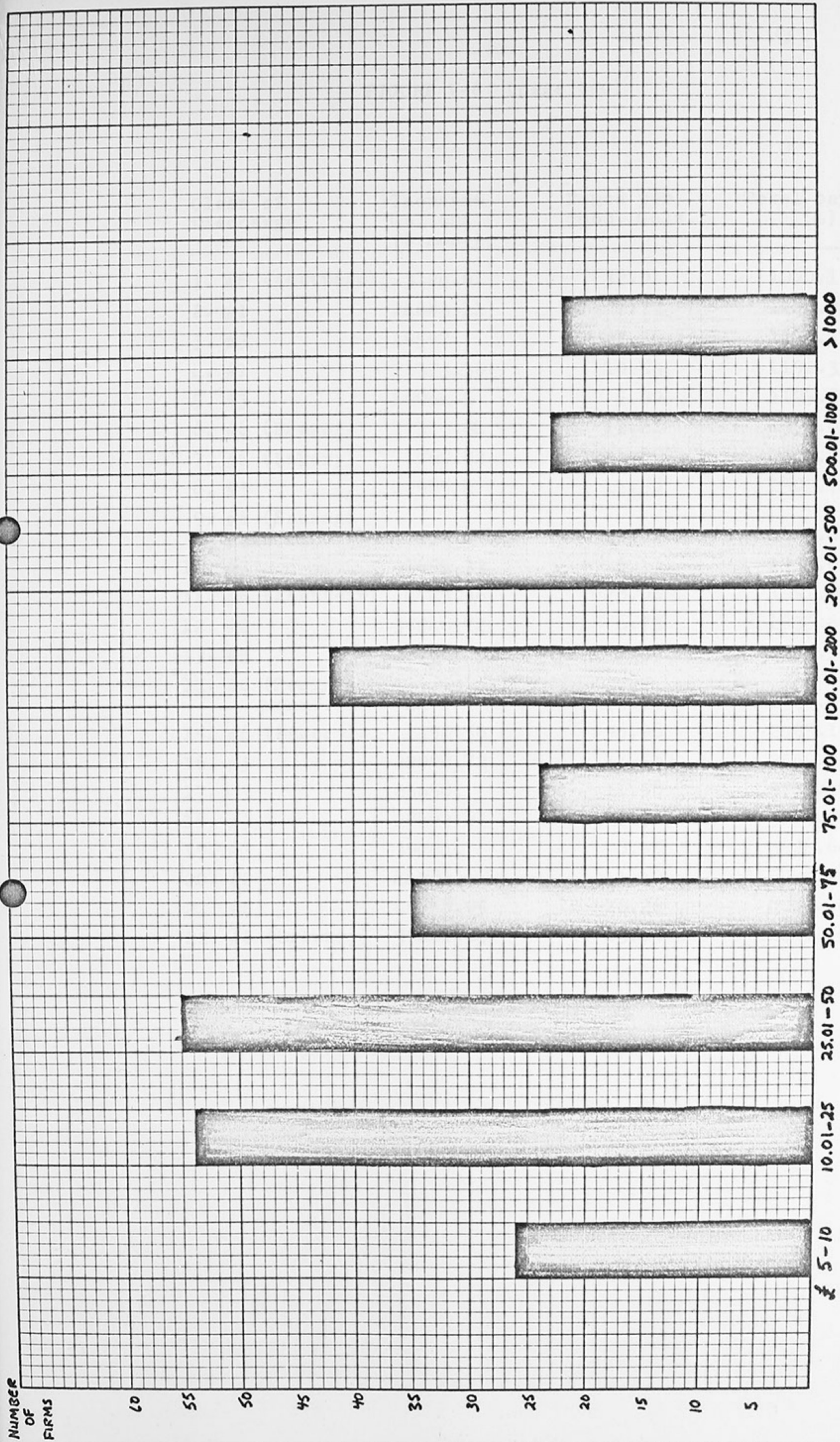


FIGURE V-6: EFFLUENT CHARGE PAYMENTS TO U.T. M.D.A., \$, FOR SIX-MONTH PERIOD 1 APRIL 1971 - 30 SEPTEMBER 1971

FIGURE V-6 (page two)

Class of Discharge	Thousand Gallons (6 mos.)	Pence per Thou. Gals.	Total payment (£)
1. #6 (Abattoir)	3124.61	32.01	1000.19
2. #1	14683.11	7.77	1140.88
3. #3	15597.	7.55	1177.57
4. #1	11323.36	10.53	1192.35
5. #3	19964.5	5.99	1195.88
6. #6 (Brewery)	12113.04	11.21	1357.87
7. #6 (Bakery)	6868.82	21.89	1503.48
8. #3	12985.4	11.58	1503.71
9. #6 (Sausage skin manuf.)	8257.8	22.11	1825.80
10. #3	31654.33	6.11	1934.08
11. #6 (Abattoir)	4143.36	48.06	1991.30
12. #2	30246.72	6.73	2035.60
13. #5	42780.09	5.38	2301.57
14. #6 (Resin manuf.)	2400.	97.69	2344.56
15. #6 (Bakery)	2490.50	98.98	2465.10
16. #3	22098.72	11.58	2559.08
17. #3	23658.	11.58	2739.60
18. #3	28403.2	11.58	3289.09
19. #3	39404.	8.95	3526.66
20. #2	44283.	11.40	5048.26
21. #6	49748.95	16.26	8089.18
22. #6 (Brewery)	90821.83	13.73	12469.84

Source of Figures V-7 and V-8: World Bank, "A Study in the Economics of Water Quality Management," World Resources Research, Vol. 3, No. 2 (1977), pp. 270, 275, Table 3 and Table 4.

FIGURE V-7

Minimum Uniform Effluent Fee Estimated To Meet Specified DO Goals
and Cost of Associated Program

DO Goals	R*	Effluent Fee (\$/l), with sludge		Total Treatment Cost, w/sludge†	
		Removed	Not Removed	Removed (\$10 ⁶ /yr)	Not Removed (\$10 ⁶ /yr)
2	0.1	0	2.5	0	2.32
	0.2	0	4	0	2.45
	0.4	0	5.25	0	6.51
Mixed 2-3	0.1	1.5	2.5	0.34	2.32
	0.2	2.5	6	2.32	7.73
	0.4	4.5	6	4.68	7.73
3	0.1	2.5	4.5	2.32	4.68
	0.2	3	6	2.40	7.73
	0.4	6	23	7.73	12.00
Mixed 3-4	0.1	4	6	2.45	7.73
	0.2	6	23	7.73	12.00
	0.4	25.5	NS‡	13.25	NS

* Recirculation rate.

† Cost of sludge removal not included.

‡ NS indicates goal not attainable even with 100% removal of loads considered.

FIGURE V-8

Minimum Zoned Effluent Fees Estimated To Meet Specified DO Goals
and Cost of Associated Treatment Programs

DO Goal, ppm	R*	Effluent Fee (\$/l) with Sludge						Total Cost of Treatment with Sludge	
		Removed			Not Removed			Removed,† \$10 ⁶ /yr	Not Removed, \$10 ⁶ /yr
		Zone			Zone				
		1	2	3	1	2	3		
2	0.1	0	0	0	4	2	0	0	1.13
	0.2	0	0	0	4	4	4	0	2.45
	0.4	0	0	0	6	10	4	0	7.36
Mixed, 2-3	0.1	2	2	0	6	0	0	0.42	3.00
	0.2	4	0	0	4	8	2	1.01	6.26
	0.4	6	0	0	...‡	...	...	3.00	...
3	0.1	4	2	4	6	0	4	2.45	4.32
	0.2	6	2	4	6	6	6	3.32	7.36
	0.4	4	8	6	10	10	10	5.96	8.65
Mixed, 3-4	0.1	4	2	4	6	12	4	2.45	7.50
	0.2	10	10	10	10	10	10	6.66	8.65
	0.4	20	0	20	NS‡	NS	NS	10.01	NS
4	0.1	6	0	4	6	12	4	4.32	7.50
	0.2	6	6	4	NS	NS	NS	6.88	NS
	0.4	NS	NS	NS	NS	NS	NS	NS	NS

* Recirculation rate.

† Cost of sludge removal not included.

‡ ... indicate missing data.

§ NS indicates that it is impossible to attain the goal, even with 100% removal of the load considered in this study.

Source of Figures V-7 and V-8: Edwin L. Johnson,
"A Study in the Economics of Water Quality Manage-
ment," Water Resources Research, Vol. 3, No. 2
(2nd Qtr. 1967), pp. 298, 299, Table 3 and Table 4.

FIGURE V-9

Single Effluent Fee, DO Improvement, and Total Costs

Fee, ¢/lb of BOD	DO Increase mg/l for Reaeration Rate of			Treatment Cost, \$1000/yr	Payments for Waste Discharged, \$1000/yr
	0.1/day	0.2/day	0.4/day		
2	0.4	0.2	0.1	457	5,982.4
4	2.0	1.0	0.5	2,447	8,686.2
6	3.4	1.8	0.9	7,723	5,595.0
8	3.5	1.9	1.0	7,955	7,012.7
10	3.8	2.0	1.0	8,650	7,303.5
12	3.8	2.0	1.1	8,788	8,688.6
14	3.8	2.1	1.1	9,226	9,780.6
16	3.8	2.1	1.1	9,226	9,215.7
18	4.1	2.2	1.1	10,661	10,361.3
20	4.2	2.3	1.2	13,179	8,551.2
30	4.4	2.4	1.2	19,333	4,656.0
40	4.4	2.4	1.2	19,424	5,944.9
50	4.5	2.4	1.2	20,662	5,468.3
60	4.5	2.4	1.2	20,933	4,183.5
70	4.5	2.4	1.2	21,276	2,574.9
80	4.6	2.4	1.2	21,728	2,055.7
90	4.6	2.4	1.2	22,776	420.5
100	4.6	2.4	1.2	22,776	467.2

Source: Edwin L. Johnson, "A Study in the Economics of Water Quality Management," Water Resources Research, Vol. 3, No. 2 (2nd Qtr. 1967), p. 300, Table 5.

[D]ecreasing marginal improvements with increasing charge are quite evident at a relatively low charge for the waste discharge configuration considered. Thus, one might elect a charge in the neighborhood of 12¢/lb as an initial estimate and be fairly confident of achieving a significant quality improvement. Of course, more refined cost functions will allow establishment of a charge that more closely approaches the goal without overshooting it, but this is not required as an initial cut [sic], particularly since the flexibility of charge revision should allow for more ready adjustment than schemes depending upon hearings and court action.

Do the Delaware simulations have any relevance to the Trent Basin?

The average flow of the Delaware is three or four times as great as that of the Trent. Its quality in the middle reaches, however, is considerably worse than that of the Trent after the Tame confluence. Under low-flow summer conditions (low-flow conditions of 3000 cubic feet per second, or 1620 million gallons per day, were assumed for most analysis in the Delaware Estuary Comprehensive Study), dissolved oxygen is almost entirely absent from the section from Torresdale, Pa. to the Pa.-Del. line, and the river smells. This is not the case in the poorest-quality reaches of the Trent, though low-flow dissolved oxygen concentrations are so low that no fish can survive there. Clearly the tonnage of BOD discharged to the Delaware is much higher than that to the Trent. The daily BOD loading in the Delaware was estimated in 1964 to be 1,600,000 lbs/day. If we take the average flow of the Trent to be 1600 mgd, and the average BOD concentration to be 8 mg/l, and assumed four litres to the gallon, BOD loads in the river must average about 110,000 lbs/day, meaning that perhaps 150,000--200,000 lbs BOD are discharged to the river system daily. The Delaware pollution problem is thus relatively more severe: although the river flow is only three or four times that of the Trent, the BOD loading is eight or ten times as great.

The relevance of the Delaware Study of single effluent charges to the Trent Basin is further complicated by the likelihood of differences in effluent treatment cost functions among the two basins. The types of industries producing the BOD are somewhat different, and effluent treatment costs are heavily dependent not only on the type of industry, but also the location and technology of the individual firm. While the technology of effluent treatment processes is very similar in the United States and Great Britain, the relative prices of treatment equipment,

FIGURE V-10

(page 1)

COMPARISON OF DELAWARE AND TRENT BASINS

DELAWARE	TRENT
<u>(1) Main river length</u>	
Total: 296 miles	Total: 171 miles
Study area: Trenton, N. J. to Liston Point,	Middle and tidal reaches: 111 miles
Delaware: 86 miles	
<u>(2) Flow</u>	
Trenton (52-year annual average): 6300 mgd	Average flow at Trent Bridge, Nottingham:
Trenton, dry weather flow (used	1965: 1925 mgd
as basis for model) : 1620 mgd	1966: 2270 mgd
	1967: 1590 mgd
	1968: 1700 mgd
	1969: 1824 mgd
	1970: 1562 mgd
	Average annual flow figures were used in the model.
<u>(3) Size of drainage basin</u>	
Total: 12,765 square miles	Area administered by the Trent River
Study area: 4,550 square miles	Authority: 4,029 square miles
<u>(4) Population of basin</u>	
1964 estimate: 6,000,000	1965 (actual): 6,276,000
	1975 (estimated): 6,948,000
<u>(5) Abstractions</u>	
Total (1964): 5204 mgd	Total: 3181 mgd (1970)
Municipal: 204 mgd	Municipal: 187 mgd
Industrial (95% for cooling): 5000 mgd	Industrial (97% for cooling): 2994 mgd
Sources: Delaware Estuary Comprehensive Study: Preliminary Report and Findings; Trent River Authority Annual Reports, Water Resources Preliminary Study.	

FIGURE V-10

(page 2)

(6) Waste dischargesMunicipal

Total municipal effluent: 500 mgd

Eight large plants discharge 90% of all municipal BOD; no information on what proportion of flow in municipal sewers arises from industrial discharges.

Industrial

There are 18 major waste sources. Range of flows is great; there are no estimates of totals.

44 industrial and municipal waste sources are analyzed in the model.

In 1964, of the total carbonaceous BOD loading of about a million pounds per day, 660,000 lbs/day arose from municipalities (65%), and 370,000 lbs/day from industries (35%), as follows:

Petroleum:	99,000 lbs/day
Chemicals:	212,000 lbs/day
Paper:	33,000 lbs/day
Other:	26,000 lbs/day

Nitrogenous BOD amounted to 600,000 lbs/day (both municipal and industrial), and sludge and bottom deposits exerted 200,000 lbs/day BOD.

Sources: (same as page 1)

Municipal

Dry weather flow (1970): 337 mgd

The eight largest plants have 58% of the volume capacity; 1971 sewage flows were roughly proportional to capacity. About 40% of the volume of effluent in municipal sewers originates from industrial sources.

Industrial

There are 646 direct industrial discharges. Flows range from 1,500 to 4,500,000 gpd, totalling 70-90 mgd. 23 industrial and 83 municipal waste sources are analyzed in the model.

The major industrial effluents are:

- Potter's slip (clay suspension)
- Metal finishing wastes
- Brewery effluent
- Dyeing wastes
- Chemical wastes
- Colliery wash (usually very saline)

Perhaps 150,000 - 200,000 lbs/day total BOD is charged to the Trent system.

FIGURE V-10

(page 3)

(7) Present quality

Quality deteriorates rapidly as river passes from Trenton through densely-populated, highly industrialized area. Between Torresdale, Pa. and the Pa.-Del. line, dissolved oxygen drops to zero, with septic conditions in the summer. Gradual improvement downstream. Saline in lower reaches.

Quality drops dramatically after the Tame confluence; fish cannot survive for thirty miles downstream. Gradual improvement after that. Saline in lower reaches.

Sources: (same as page 1)

and land, and labor, will surely differ, and the in-plant alternatives for reducing discharges may differ substantially as well. Furthermore, the Delaware cost functions which were used to compute the charges represent reduced profits, taking account of U. S. federal and local tax breaks with respect to private pollution control facilities, none of which would of course apply in the United Kingdom.

It was estimated that the sum of induced treatment costs plus charge payments would amount to less than 1.2% of value of output for most firms--not taking account of tax breaks--in the Delaware Basin, for a charge level of 10¢/lb BOD, and a maximum of 2.1--5.0% for paperboard mills and 4.0% for organic chemical plants.⁷ The value of output of the major polluting firms in the Delaware Basin was over \$2 billion in 1964.⁸ No estimate was given of costs plus payments as a percentage of profits, a figure which would be more helpful in predicting whether some firms would be forced to shut down. The "macro" conclusions of the Delaware Study thus do not bear directly on the question of the proper level of charges in the Trent River Basin. One must keep in mind, of course, that however small a proportion of value of output is comprised by pollution charges, the charges may greatly affect pollution levels in the Basin and thus net social product.

A trial-and-error approach could be used in the Trent River Basin to find that level of charges which would maintain present water quality, in place of the mixed regulation system. But there are risks in this approach. Too low charges might result in a sudden influx of pollution and perhaps a fish kill. Too high charges (to maintain present quality) would impose an unintended burden on polluting firms (perhaps driving some out of business) and their customers.

The safest approach in the face of this uncertainty would appear to be a gradual transition to substantially complete reliance on charges to constrain pollution. Quotas and pretreatment requirements could be

⁷Johnson, "Study," p. 303.

⁸Delaware Study, Preliminary Report, p. 21

eliminated for a few firms at a time, with across-the-board increases in charges whenever such eliminations resulted in heavier discharges. The net effect would be to spread over all polluting firms any costs of ad hoc administrative regulation which have imposed disproportionate burdens on individual polluters. Recall that any SECH, optimal or not, is the cheapest way for society as a whole to attain the standards which the imposition of the SECH in fact produces. In the face of uncertainty about the optimal level of pollution, a SECH still represents a more efficient regulatory device than a quota system.

The Trent River Authority is probably already empowered by the general regulation clauses of the Water Resources Act 1963 to impose pollution charges on all dischargers, including local authorities. The government has stated its intention to empower the new Regional Water Authorities to cover their costs of operation through the use of charges, though this implies an upper limit to the flexibility of the new Authorities in experimenting with alternative charging levels.

Since the new RWA's will apparently be taking over control of local authority sewage plants, the charging scheme will be applicable to two groups. By far the larger, in terms of volume of effluent discharged, will be the RWA's own sewage plants, to which many industries discharge. The other group will be industrial firms which discharge directly to the river. It will be in the interest of any private discharger to minimize the sum of treatment costs and charge payments. But this direct financial incentive would not apply to the manager of a non-competitive enterprise like a municipal sewage plant. A charging scheme would be futile if sewage plant managers, without bothering to adjust discharges, merely received an Exchequer grant with which to pay RWA charges. The charges would be somewhat more effective if each sewage treatment facility were placed on a break-even basis, levying its own charges on the households and industrial firms which use it, and paying its own costs, including RWA charges. But the near-monopolistic position of most sewage plants would still limit the incentive effects of charges on them.

D. CONCLUSIONS AND RECOMMENDATIONS

The chances of deriving marginal treatment cost and marginal damage functions, optimal pollution levels, and an associated optimal charge per unit pollutant discharged, which will be both accurate enough to satisfy the demands of economic theory and plausible enough to gain sufficient credence in policy-making circles to stand a fair chance of forming the basis of a river quality management policy, are very slim indeed for the foreseeable future. The theoretical and practical problems are formidable if not overwhelming. Therefore we conclude that the Trent River Authority should not attempt to derive marginal effluent treatment cost and marginal damage functions for pollution in the basin. The techniques for finding points on the curves are simply not good enough to trust the extrapolated results as a basis for "finely-tuned" policy decisions. Decisions by those responsible for water quality management must have more modest aims, since they must be based on rougher concepts. But economic analysis should help to shape those concepts. The maximization of net social product is a common-sense as well as a theoretical ideal, and that it can underlie and guide a river regulation policy has already been demonstrated in the Delaware Estuary Comprehensive Study.

The Trent Research Programme has developed the tools for much more refined benefit-cost analysis than was possible in the Delaware Estuary Comprehensive Study. We recommend, first of all, the systematic application of these tools, that is, the dynamic river model and the Anderson model for correlating fishing benefits with pollution levels, in the manner described in Section A of this chapter, to present one set of benefit-cost comparisons for alternative water quality improvements in specific reaches. But these comparisons should not be the exclusive determinants of water quality goals. In addition, rough benefit estimates like those made in the Delaware Study should be provided as a check on the sophisticated calculations, and to be compared with model-calculated costs in their own right.

For example, total annual "activity days" (for all recreational pursuits such as angling, boating, or picnicking by the side of the river) could be estimated for each reach, for different qualities of water. For very high qualities, there would be a large number of activity days

devoted to swimming and other water contact sports. It could well be the case, therefore, that whereas the costs of moderate improvements in water quality could not be justified by the benefits, the higher costs of greater improvements, to swimming standards, would be justified. Whatever the estimates for activity days, multiplication of the figures by alternative arbitrary valuations, then comparison of the results with model-calculated costs of attaining the relevant qualities in the reach, would at least reveal how high a valuation would have to be placed on the recreation benefits before incurring the necessary costs of quality improvement would be justified.

It has been estimated that the 175,000 fishing license holders in the Trent River Basin, together with anglers under the age of 16, make more than 5,000,000 visits to the river system each year.⁹ In addition to these 5,000,000 activity days arising from fishing, there are many activity days devoted to boating, picnicking, and hiking along the river. If the total number of recreational activity days in a year is, say, 7,000,000, and the value of an activity day is between £1 and £2, then the total current annual recreational benefits of the river system are between £7 million and £14,000,000. Whether the costs of quality improvements should be incurred depends upon the magnitude of the increases in benefits which would result from the improvements. For example, before the quality improvements represented in computer run 10B (examined above) should be made, at an annual cost of about ten million pounds, it should be shown that the annual number of recreational activity days would approximately double, since annual benefits for an extra 7,000,000 activity days would be 7-14 million pounds. The activities whose levels would be most sensitive to water quality would be fishing and swimming. Increases in boating and picnicking would certainly result from improved water quality, but these and other activities depending primarily on the aesthetic appearance of the river rather than its chemical analysis would not be as sensitive to water quality improvements after the elimination of septic conditions.

⁹W. F. Lester, "The River Trent and the Economic Model Research Programme, I.W.P.C., Trent Research Programme: Proceedings of Symposium (15-16 April, 1971), p. 14.

Our second recommendation with respect to the determination of quality goals is that public officials, and the public at large, whose views the officials presumably mirror in some fashion, abandon the prevalent notion that water quality improvement is a good to be attained at any cost. There is a substantial possibility that the costs of further improvements in the quality of the Trent, which is already cleaner than most rivers in the world which drain similarly industrialized and heavily populated areas, simply cannot be justified on grounds of net fishing benefits. If other aesthetic and recreational benefits were thought not to make up the minimum estimated "cost deficit" for the particular set of quality goals under scrutiny, then the construction of the additional treatment facilities required to meet those goals could not be justified at all.

This possibility was not even considered at the Symposium on the Trent Research Programme, held at Nottingham on April 15 and 16, 1971, where it seemed to be generally accepted that "improvement" is a "necessity", and the extent of the improvement is and should be limited only by the availability of government funds for building effluent treatment facilities. The fishing benefits study was received with considerable skepticism, partly because of the shortcomings of the methodology, but partly also because of a widespread belief that the benefits of pollution control are so obvious, and so large relative to costs, that attempted measurement of the benefits is at best a superfluous exercise. Participants at the Symposium were mainly representatives of local authorities and sewage authorities, other local and national government employees concerned with protecting the environment, representatives of angling associations, and representatives of various industries. The representative of the general amenity-loving public was Eldon Griffiths, MP, Under Secretary of State, Department of the Environment, who not only accepted that "improvement" is a "necessity", but seemed to think that the function of benefit-cost studies is to prove it:¹⁰

¹⁰ Eldon Griffiths, "Pollution in Relation to the Problem of Water," Symposium Proceedings, p. 24.

I am very glad that the Trent Study has included a cost-benefit assessment of the effects on water-based sport and angling of the various methods of improving the quality of the river water. The increasing leisure time and greater mobility through car ownership of our society make the development of water-based recreation an essential part of policies for water conservation. Water-based recreation is one of the great growth industries of this country. During an average summer weekend there are more people in this country in boats than there are on an average winter weekend watching professional football matches. The great contribution of the Midlands to industrial output and to exports merits an increase in local opportunities for recreational activities such as angling. I look forward to the day when the banks of the Trent at Burton and at Tamworth are thronged with fishermen and I hope that the computer will tell us that this can be made possible in the not too distant future.

In his role as representative of the general taxpaying public, Mr.

Griffiths admitted that the "programme of river improvement" would be "expensive to implement":¹¹

In the case of the Trent, the sum of money that will be involved between now and the end of the century will be of the order of £80m. In addition, based on the capital value of the facilities in the Trent area today, a new investment of something like £160m will be required. Nationally, of course, the sum will be very much greater. Public expenditure on sewerage and sewage treatment is rising continually and there is likely to be an increase of about 50 per cent expenditure in real terms in the next five years as compared with the last five years, so that by the end of the century we may be spending something of the order of several thousand millions of pounds.

The higher the level of expenditure, the better, according to this view.

It would seem that economic analysis can make a major contribution to public policy in this area by providing constant reminders of the fact that water quality improvement is costly, and the simple common-sense principle that an action should not be undertaken if the costs, including non-monetized costs, are thought to exceed the benefits.

Our recommendation with respect to means of attaining whatever water quality goals are chosen is that a gradual transition be made to a control system relying to a much greater extent upon pollution charges to constrain discharges. Experiments could be conducted with a peak-load charging scheme, based upon flow conditions, so that, for example, one

¹¹Griffiths, "Pollution," p. 24.

charging scheme would apply during the six winter months, and a system of higher charges would apply during the summer. Room will certainly remain for certain types of direct administrative regulation, such as the arbitrary prohibition of discharges of oily wastes into the river. But an across-the-board charging scheme for all municipal and industrial dischargers to the river system, administered by the new Regional Water Authorities, would be more efficient than the current mixed system in attaining and maintaining any set of quality goals. It would also be fairer than the current system, since pretreatment requirements and quotas are not now imposed in any systematic way to all applicants for discharge permits.

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APPENDIX FIGURE A(a); Trent Water Quality, 1970-71 (page 1)
 Source: Trent River Authority, Annual Report for the Year Ended 31st March, 1971
 TABLE 1

ANALYTICAL FIGURES AT KEY POINTS

River and Station Numbers	Period (Averages)	Flow m.g.d.	MILLIGRAMS PER LITRE						Temp. °C	pH	Biotic Index	Classification and Remarks
			P.V. (4 hour)	B.O.D. (5 days at 20°C)	Suspended Solids	Ammonia as N	Nitrate as N	Chlorides as Cl	Alkalinity as CaCO ₃			
Trent HANFORD No. 4	1970 (25) Range (1970) 1969 1968-70 1965-67 1962-64	40	7	14	57	4.2	3.7	120	167	13.2	I	Poor Badly polluted by sewage and industrial effluent from Stoke
			7.8	6.36	10.183	1.3-6.4	0.5-6.3	40-640	86-215	4.0-20.0	I	
			8	17	71	4.1	3.2	90	190	16.5	I	
			7	13	55	4.4	3.5	102	184	14.1	I	
			12	15	67	5.6	4.1	111	186	12	I	
Trent STONE No. 5	1970 (46) Range (1970) 1969 1968-70 1965-67 1962-64		16	22	—	8.4	4.0	109	190	14	I	Poor Very similar quality to Hanford. Contains S.W. effluent
			8	14	57	5.7	4.9	123	175	11.9	II	
			4.25	6.31	6.488	1.9-9.8	1.9-7.7	34-370	88-218	4.0-18.5	II	
			8	13	43	4.7	5.3	107	177	12.1	II	
			8	12	46	5.1	5.1	114	179	11.4	II	
Trent GREAT HAYWOOD No. 6	1970 (118) Range (1970) 1969 1968-70 1965-67 1962-64	60	9	10	58	6.6	5.0	95	186	11.0	I	Poor Incapable of supporting a fishery
			11	15	—	9.5	5.3	98	205	12.0	I	
			8	14	53	3.9	5.1	131	174	15.3	III	
			3.24	3.26	3.478	0.7-10.0	2.3-7.7	42-405	88-225	1.0-20.5	III	
			8	13	63	3.3	5.6	127	182	11.5	III	
Trent YOXALL No. 8	1970 (122) Range (1970) 1969 1968-70 1965-67 1962-64	262	10	12	68	5.4	4.6	122	189	13.3	IV	Medium Supports a fishery. Improved by relatively clean Rivers Sow and Blithe
			10	14	—	7.1	5.2	129	197	11.0	III	
			7	8	37	1.0	6.5	184	162	10.2	V	
			4.23	3.28	3.300	0.2-4.8	0.3-8.2	52-450	96-195	0.5-22.7	V	
			6	8	38	1.3	6.6	194	171	11.0	V	
Trent WALTON No. 10	1970 (129) Range (1970) 1969 1968-70 1965-67 1962-64	390	7	11	—	2.6	6.2	240	184	11.0	IV	Poor Badly polluted due to grossly polluted River Tame. Does not support fish
			9	13	47	3.5	8.1	129	150	11.2	III	
			7.21	4.52	8.520	0.8-8.3	3.3-11.7	60-304	90-190	Nil-25.0	III	
			9	14	47	3.6	7.5	127	169	11.5	III	
			9	13	48	3.9	7.1	128	160	11.8	III	
			12	14	58	6.7	5.6	134	173	11.0	III	
			17	22	—	9.2	4.7	149	175	12.0	II	

APPENDIX FIGURE A(a) (page 2)

Trent WILLINGTON No. 12	1970 (122) Range (1970) 1969 1968-70 1965-67 1962-64		8 5-14 7 8 9 13	13 5-37 13 12 13 18	40 10-240 41 42 46 —	1.7 0.7-4.4 2.0 2.0 3.8 6.5	7.4 2.3-10.8 6.8 6.6 5.1 4.5	112 42-195 107 107 105 125	146 98-180 162 154 166 172	7.1 Nil-14.2 6.6 6.3 5.3 4.3	12.1 3.5-24.0 13.1 12.9 13.0 14.0	7.4 6.9-7.8 7.3 7.4 7.5 7.4	III III III III III	Medium Improved by clean River Dove. Fish live precariously
Trent SHARDLOW No. 14	1970 (122) Range (1970) 1969 1968-70 1965-67 1962-64	505	7 5-12 7 7 9 11	10 4-26 11 11 13 18	37 8-192 42 39 37 —	1.0 0.1-4.2 1.3 1.3 3.0 5.4	7.9 4.1-12.9 7.5 7.1 5.7 5.6	102 44-187 104 102 108 124	142 96-180 162 150 166 172	6.2 1.1-10.0 5.7 5.2 4.5 3.7	14.6 3.0-25.0 16.6 16.5 17.0 20.0	7.4 6.8-7.8 7.3 7.4 7.5 7.4	III III III III III	Medium Recent improvement maintained but oc- casional low dis- solved oxygen con- centrations still re- corded. Some rela- tive lowering of high temperatures caused by power stations
Trent SAWLEY No. 15	1970 (124) Range (1970) 1969 1968-70 1965-67 1962-64	700	6 4-9 6 6 8 9	9 4-26 10 10 10 13	32 7-169 36 34 36 —	1.0 0.2-3.3 1.2 1.2 2.4 3.8	6.8 4.2-10.4 6.6 6.3 4.7 5.5	115 44-170 91 99 94 109	141 94-180 153 150 159 168	7.3 1.5-11.5 6.9 6.7 6.3 6.1	13.9 4.5-24.5 15.8 15.5 16.0 18.0	7.5 7.0-7.9 7.4 7.5 7.4 7.5	III III III III	Medium Dilution by clean River Derwent im- proves quality
Trent TRENT BRIDGE No. 17	1970 (178) Range (1970) 1969 1968-70 1965-67 1962-64	800	6 4-10 6 6 8 9	9 3-20 8 9 11 13	31 6-168 28 33 42 —	1.1 0.2-3.6 0.9 1.1 2.2 3.5	7.3 5.1-9.9 7.3 6.8 5.5 5.5	101 43-150 102 97 94 101	146 102-180 156 153 162 166	7.8 4.2-10.8 7.2 7.5 7.2 6.7	14.5 5.0-27.0 16.5 15.3 16.0 17.0	7.5 6.9-7.9 7.5 7.5 7.6 7.5	IV III IV IV	Medium Much improved qual- ity in recent years continues
Trent KELHAM No. 19	1970 (31) Range (1970) 1969 1968-70 1965-67 1962-64	865	6 4-9 7 7 7 8	9 4-12 9 9 11 14	27 8-73 39 34 35 —	1.0 0.3-2.8 1.1 1.1 2.2 3.7	8.0 6.0-10.7 6.8 7.0 6.1 5.7	108 64-160 94 99 99 108	151 105-172 150 154 173 169	7.7 5.4-10.8 7.7 7.5 7.1 6.5	18.0 7.5-28.0 17.0 17.1 17.0 18.0	7.6 6.9-8.0 7.4 7.5 7.5 7.5	III III III III III	Medium A good coarse fish- ery. High average temperature caused by power stations

APPENDIX FIGURE A(a) (page 3)

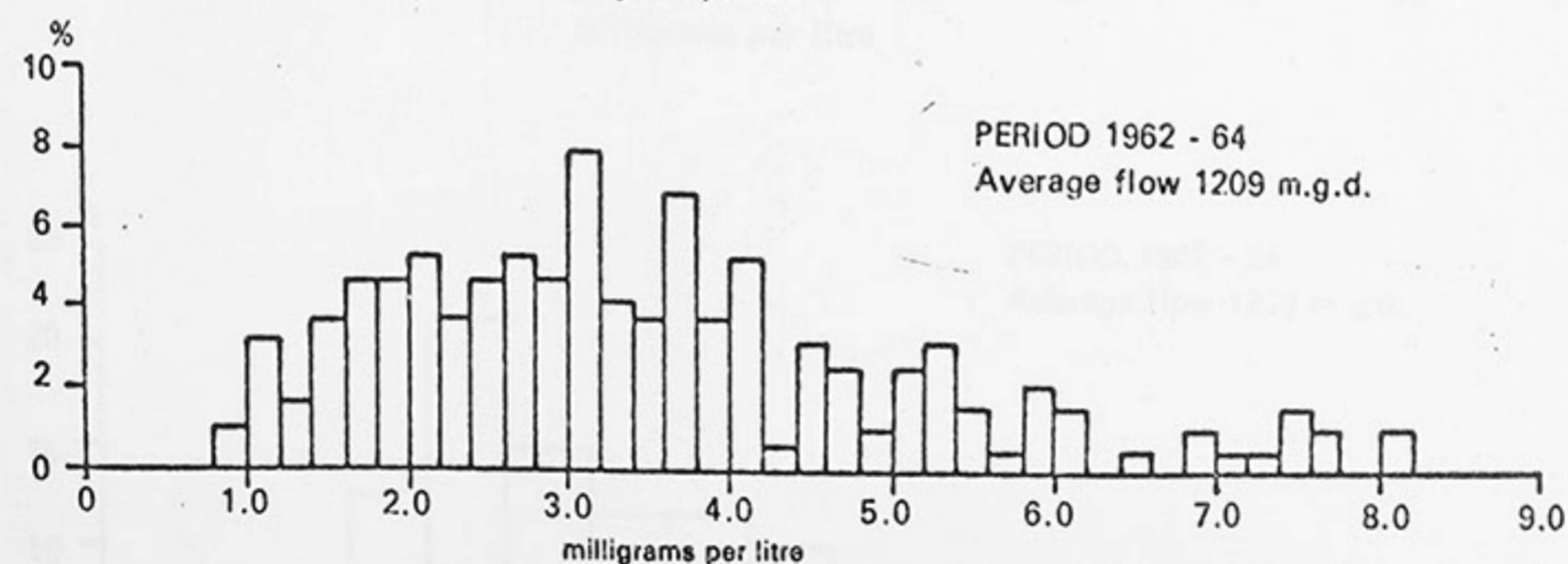
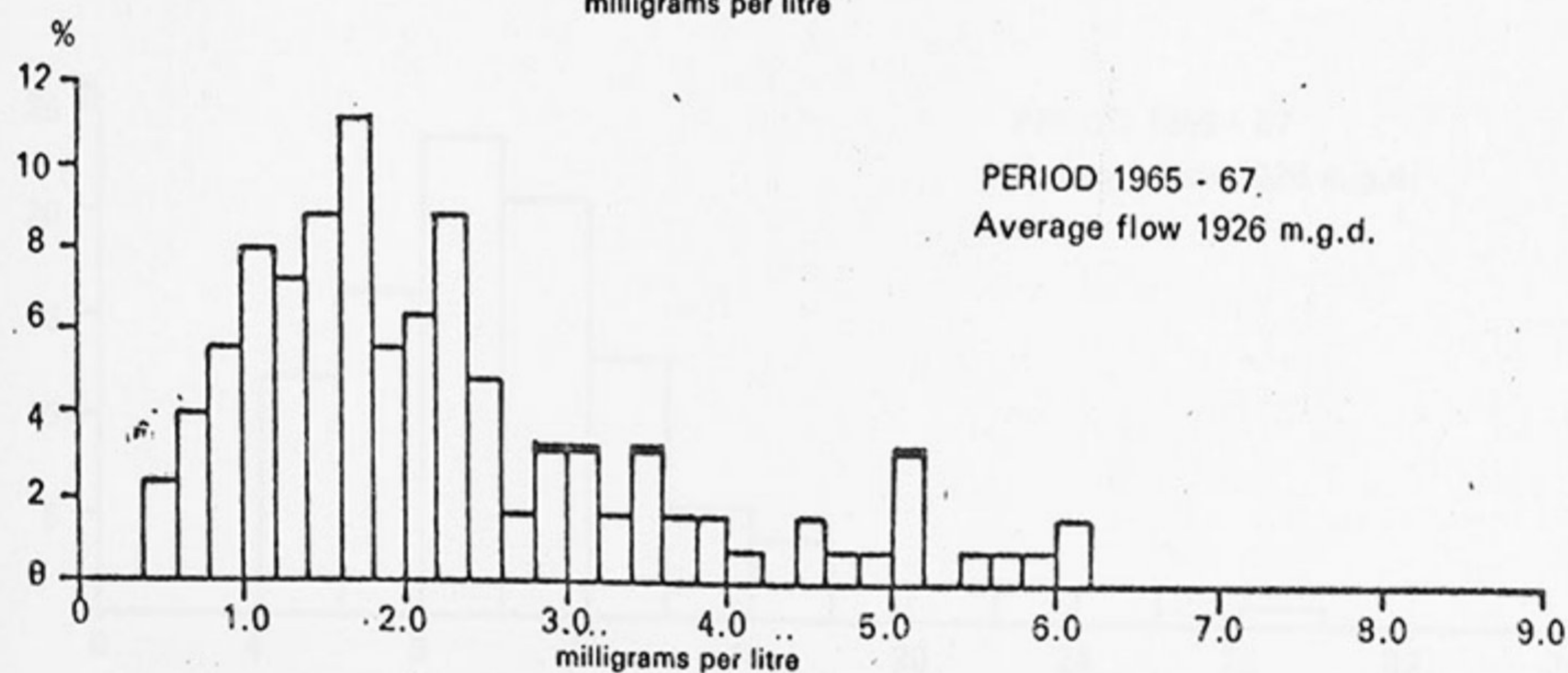
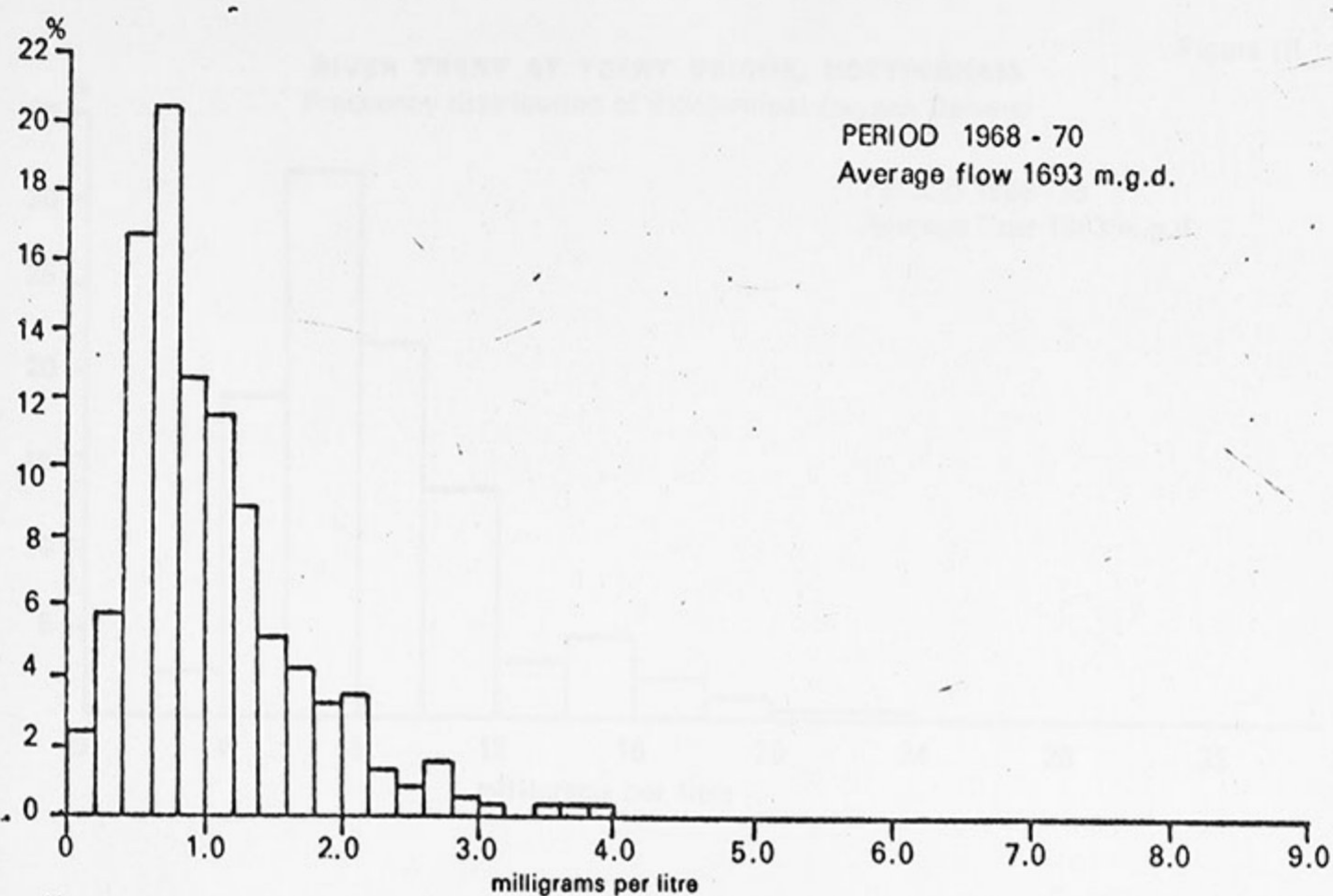
TABLE 1 (continued)

ANALYTICAL FIGURES AT KEY POINTS

River and Station Numbers	Period (Averages)	Flow m.g.d.	MILLIGRAMS PER LITRE							Temp. °C	pH	Biotic Index	Classification and Remarks
			P.V. (4 hour)	B.O.D. (5 days at 20°C)	Suspended Solids	Ammonia as N	Nitrate as N	Chlorides as Cl	Alkalinity as CaCO ₃	Dissolved Oxygen			
Trent DUNHAM No. 20	1970 (36) Range (1970) 1969 1968-70 1965-67 1962-64	890	6	7	40	0.7	8.0	101	165	7.2	7.5		Medium Approximate limit of fishery. Improvement in ammonia level continues.
			2-11	4-17	10-218	0.2-2.1	5.1-11.4	49-149	115-190	5.3-9.5	7.0-8.0		
			6	7	41	0.8	8.1	102	164	7.0	7.5		
			6	7	40	0.8	8.0	98	163	6.9	7.5		
			7	9	34	1.7	6.6	101	167	6.1	7.5		
Trent GAINSBOROUGH No. 21	1970 (40) Range (1970) 1969 1968-70 1965-67 1962-64		7	6	66	0.55	7.9	98	148	6.9	7.5		Medium High suspended solids due to tidal scouring effect
			4-25	3-12	15-392	0.1-1.0	0.1-11.0	47-156	112-168	1.8-10.1	7.2-7.9		
			7	7	124	0.8	7.8	96	165	6.1	7.5		
			7	7	92	0.7	7.6	95	159	6.0	7.5		
			8	8	117	1.5	6.7	97	167	5.3	7.5		
Trent KEADBY No. 23	1970 (40) Range (1970) 1969 1968-70 1965-67 1962-64	980	11	12	—	2.6	6.7	104	163	3.7	7.4		Medium Very high suspended solids ("warp") caused by strong tidal scouring effect. Very low dissolved oxygens sometimes recorded
			10	7	361	0.6	8.1	309	147	5.3	7.4		
			3-27	3-12	22-2,400	0.1-2.1	5.6-11.9	49-2,680	110-170	0.4-9.9	6.9-7.9		
			8	7	186	0.9	7.7	187	168	5.4	7.5		
			12	7	258	0.8	7.6	239	161	4.9	7.6		
Alfreton Brook TOADHOLE FURNACE No. 158	1970 (16) Range (1970) 1969 1968-70 1965-67 1962-64		6	8	126	1.2	8.3	516	238	7.7	7.4	V	Medium Polluted by sewage effluent and mine water
			3-19	2-28	14-1,210	0.3-2.5	4.5-13.6	135-1,470	100-490	3.6-11.4	7.0-7.8		
			5	12	30	1.6	6.9	290	248	6.1	7.3	IV	
			5	8	60	1.5	7.3	434	239	7.4	7.4	V	
			5	3	21	1.4	5.9	320	213	7.1	7.5	IV	
Amber AMBERGATE No. 89	1970 (17) Range (1970) 1969 1968-70 1965-67 1962-64	20	6	6	—	2.8	5.4	201	202	6.3	7.5	IV	Medium Some recent improvement resulting from better trade effluent treatment
			7	7	53	1.0	6.2	316	172	8.5	7.5	V	
			3-23	4-21	12-351	0.3-2.2	3.6-11.5	57-750	70-262	4.2-11.8	6.9-7.8		
			6	11	27	1.4	5.1	152	172	7.2	7.3	III	
			6	11	38	1.2	5.3	241	168	8.1	7.4	IV	
	1965-67		7	13	37	1.0	3.7	233	173	7.8	7.5	II	
			9	16	—	2.7	3.8	195	180	6.7	7.5	II	

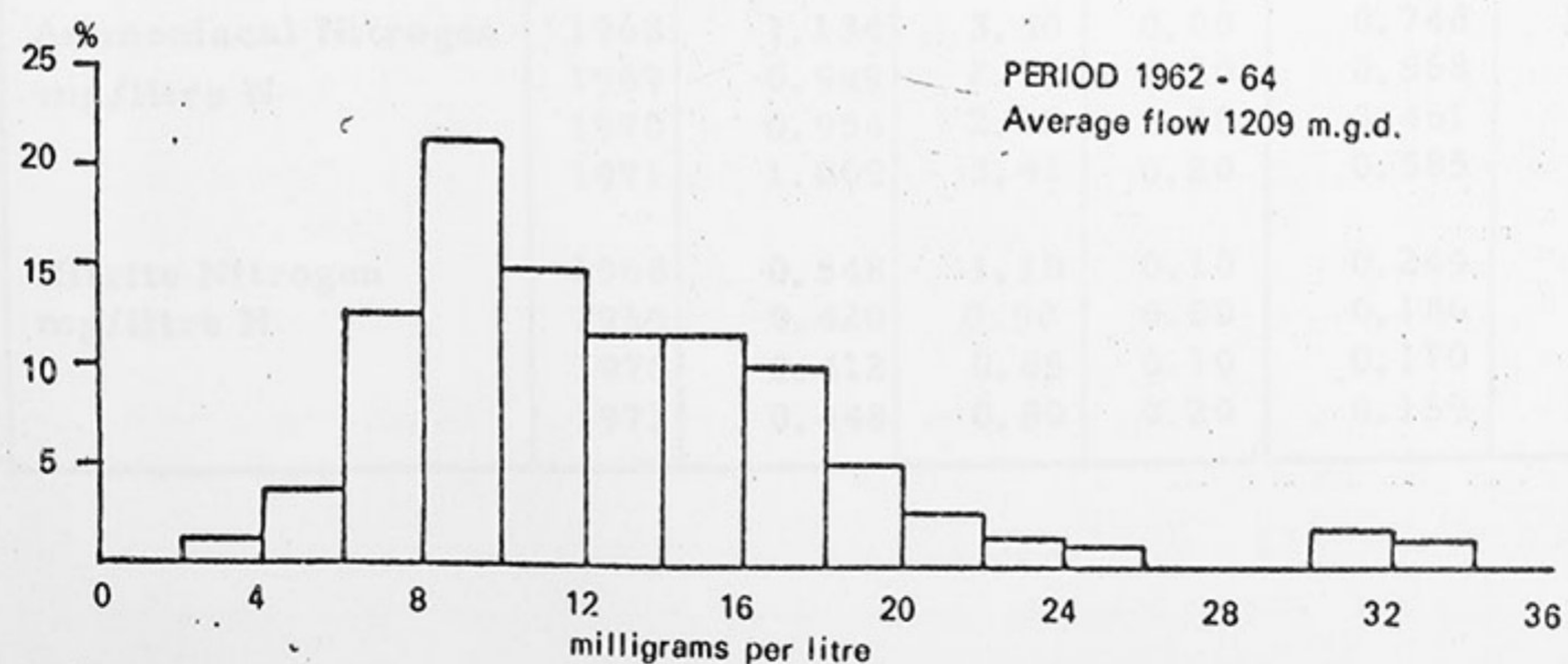
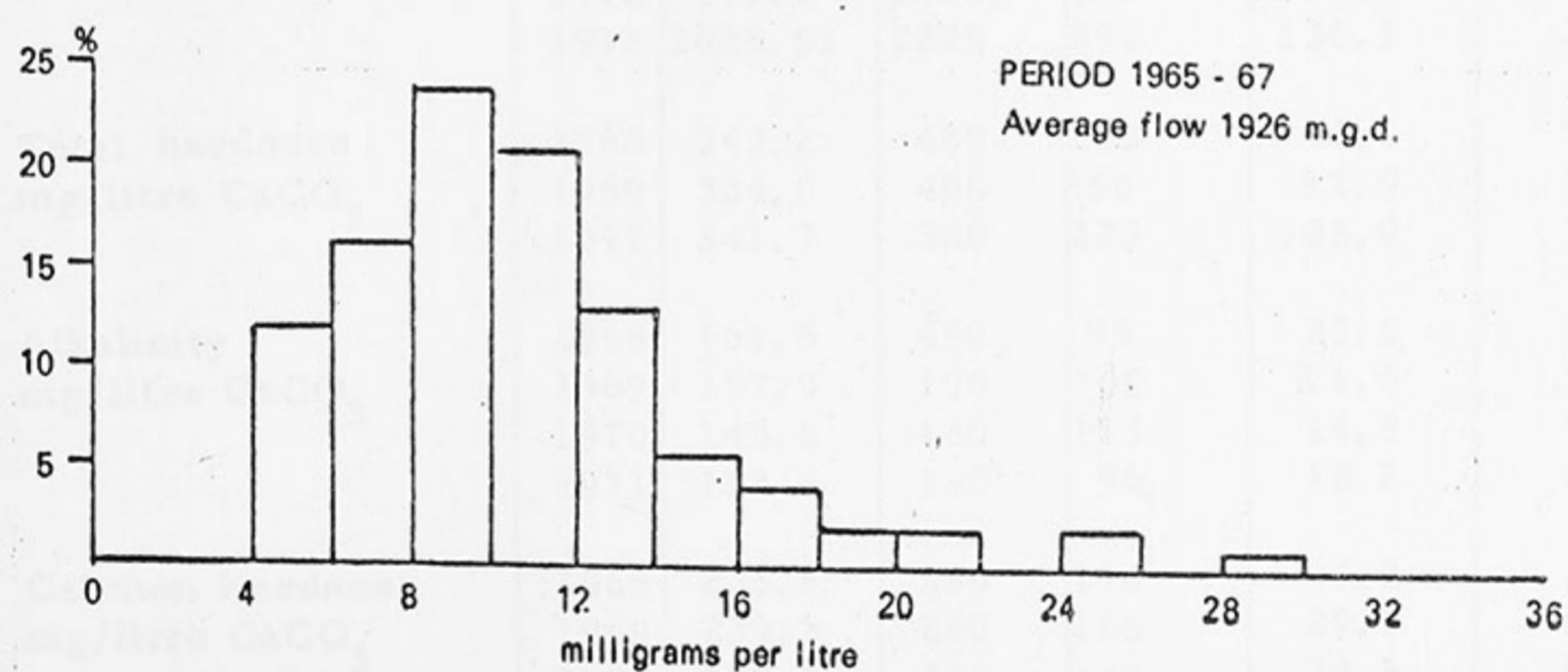
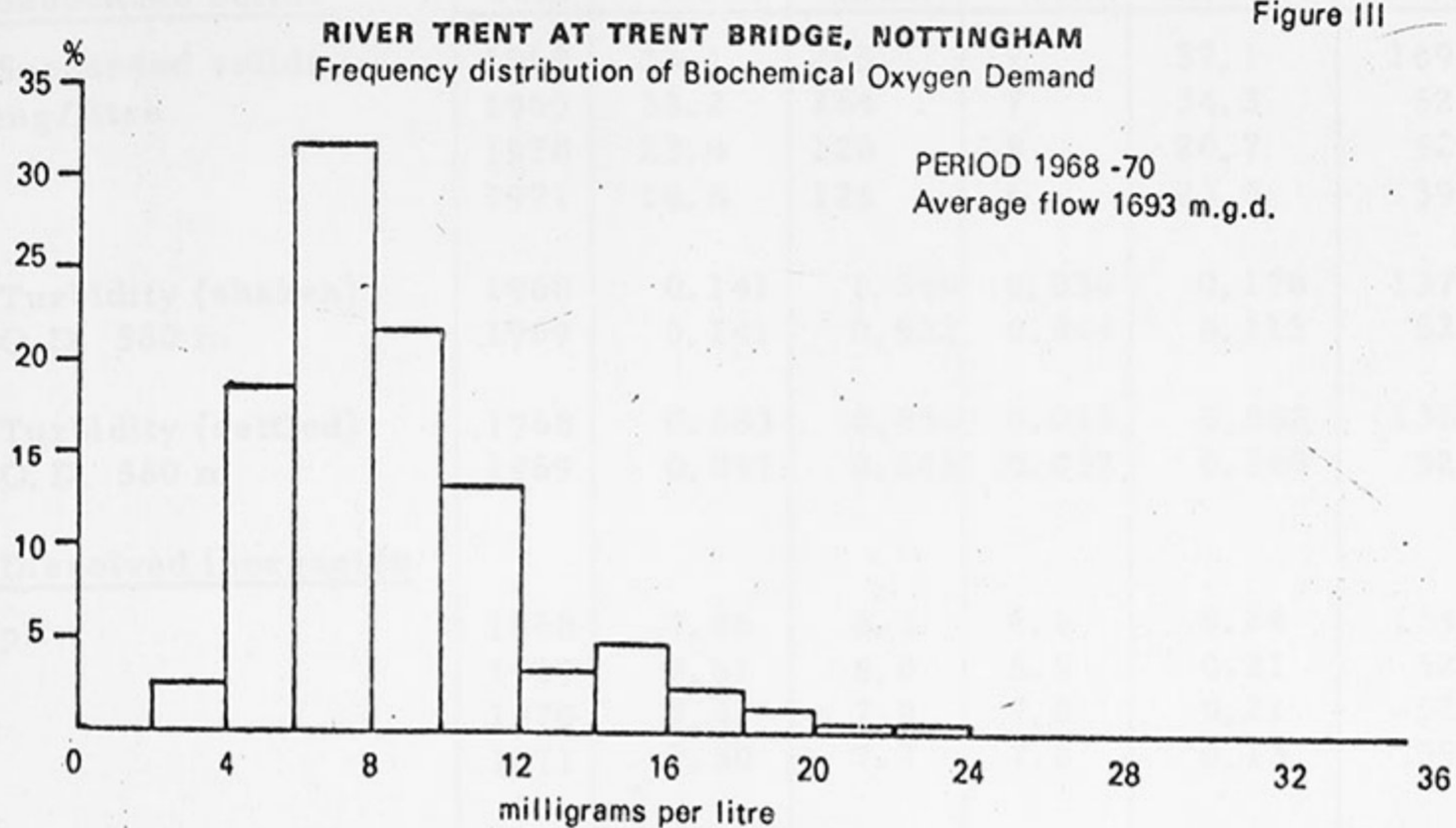
APPENDIX FIGURE A(b) (page 1)
 Source : Trent River Authority,
 Annual Report for the Year
 Ended 31st March, 1971

RIVER TRENT AT TRENT BRIDGE, NOTTINGHAM
 Frequency distribution of Ammoniacal Nitrogen



APPENDIX FIGURE A(b) (page 2)

Figure III



APPENDIX FIGURE A(c) (page 1)

Source: Water Research Association,
Trent Economic Model, Section 4,
Water Treatment, Final Report.

TABLE 10

SUMMARY OF RAW WATER DATA 1968-71 (AT COLWICK)

Suspended solids	Year	Mean	Max.	Min.	St. Dev.	Obs.
Suspended solids mg/litre	1968	33.1	265	7	37.1	169
	1969	33.2	164	7	34.3	52
	1970	23.4	120	8	20.7	52
	1971	18.8	125	6	23.5	39
Turbidity (shaken) O. D. 580 m	1968	0.141	1.340	0.036	0.176	137
	1969	0.141	0.522	0.044	0.113	52
Turbidity (settled) O. D. 580 m	1968	0.083	0.830	0.019	0.088	136
	1969	0.097	0.248	0.037	0.060	52
<u>Dissolved inorganics</u>						
pH	1968	7.46	8.3	6.6	0.24	184
	1969	7.51	8.0	6.9	0.21	52
	1970	7.47	7.9	7.0	0.21	52
	1971	7.50	7.7	7.2	0.13	39
Electrical Conductivity µmho/cm	1968	918.0	1200	565	146.1	169
	1969	953.0	1270	620	179.0	52
	1970	971.6	1250	700	155.1	52
	1971	1025.51	1225	590	136.1	39
Total hardness mg/litre CaCO ₃	1968	343.2	480	235	48.1	36
	1969	324.0	400	250	32.0	52
	1971	341.7	380	225	35.0	39
Alkalinity mg/litre CaCO ₃	1968	161.5	450	95	23.5	40
	1969	157.9	190	105	21.0	51
	1970	148.5	180	115	14.8	52
	1971	153.4	196	96	18.2	39
Calcium Hardness mg/litre CaCO ₃	1968	235.5	280	170	25.8	35
	1969	229.3	280	165	29.1	51
	1970	222.2	336	185	29.2	52
	1971	233.3	265	160	22.4	39
Ammoniacal Nitrogen mg/litre N	1968	1.134	3.30	0.00	0.748	188
	1969	0.949	2.30	0.20	0.568	51
	1970	0.954	2.23	0.20	0.461	52
	1971	1.069	3.41	0.20	0.585	39
Nitrite Nitrogen mg/litre N	1968	0.548	1.10	0.10	0.244	44
	1969	0.420	0.90	0.00	0.186	51
	1970	0.412	0.85	0.10	0.170	52
	1971	0.448	0.80	0.20	0.159	39

APPENDIX FIGURE A(c) (page 2)

TABLE 10 (CONTD)

	Year	Mean	Max.	Min.	St. Dev.	Obs.
Nitrate Nitrogen mg/litre N	1968	6.137	7.70	3.50	1.025	44
	1969	6.976	11.30	5.30	1.785	51
	1970	7.306	9.90	5.30	1.087	52
	1971	8.179	10.70	5.70	1.063	39
Chloride mg/litre Cl	1968	93.4	134	55	19.9	37
	1969	97.0	153	40	29.2	49
	1970	100.2	163	51	28.2	52
	1971	93.7	140	37	22.9	38
Sulphate mg/litre SO ₄	1968	178.6	225	126	25.6	29
	1969	184.6	247	99	35.5	29
	1970	184.2	233	136	28.8	52
	1971	181.8	216	116	22.8	37
Orthophosphate mg/litre P	1968	0.558	1.04	0.02	0.285	32
	1969	0.951	2.10	0.30	0.506	51
	1970	1.028	2.10	0.35	0.458	52
	1971	0.649	1.06	0.10	0.222	39
Reactive silica mg/litre SiO ₂	1968	6.16	11.0	4.0	2.03	30
	1969	4.17	7.1	0.2	1.49	52
	1970	4.34	6.8	1.5	1.25	52
	1971	3.88	6.4	1.5	1.17	39
Fluoride mg/litre F	1968	0.377	0.72	0.15	0.110	29
	1969	0.443	0.60	0.31	0.088	52
	1970	0.444	0.66	0.21	0.109	52
	1971	0.435	0.62	0.29	0.084	34
Sodium mg/litre Na	1968	61.59	98.0	32.0	17.34	30
	1969	64.58	116.0	20.8	23.52	52
	1970	153.5	250.0	57.0	96.50	2
	1971	76.4	76.7	76.4	0.00	1
Potassium mg/litre K	1968	9.80	25.0	7.2	3.01	30
	1969	8.19	13.3	4.2	2.04	52
	1970	7.40	7.40	7.40	0.000	1
	1971	12.00	12.00	12.00	0.000	1
Iron (total) mg/litre Fe	1968	1.167	4.74	0.00	1.049	32
	1969	1.361	6.00	0.31	1.205	52
	1970	0.200	0.300	0.100	0.070	11
	1971	0.174	0.320	0.080	0.057	39
Manganese (total) mg/litre Mn	1968	0.142	0.62	0.00	0.131	29
	1969	0.181	0.68	0.00	0.145	48
	1970	0.068	0.160	0.000	0.050	11
	1971	0.057	0.200	0.000	0.054	39

APPENDIX FIGURE A(c) (page 3)

TABLE 10 (CONTD)

	Year	Mean	Max.	Min.	St. Dev.	Obs.
Aluminium (total) mg/litre Al	1968	0.050	0.25	0.00	0.066	25
	1969	0.143	0.52	0.00	0.108	52
	1970	0.200	0.200	0.000	0.200	1
Cadmium mg/litre Cd	1969	0.000	0.000	0.000	0.000	52
	1970	0.002	0.008	0.000	0.002	52
	1971	0.003	0.012	0.000	0.002	36
Chromium mg/litre Cr	1969	0.000	0.00	0.00	0.000	52
	1970	0.004	0.03	0.00	0.007	52
	1971	0.010	0.02	0.00	0.004	36
Nickel mg/litre Ni	1969	0.050	0.02	0.00	0.032	50
	1970	0.051	0.15	0.00	0.028	52
	1971	0.057	0.09	0.02	0.017	36
Copper mg/litre Cu	1969	0.039	0.08	0.00	0.040	52
	1970	0.045	0.12	0.00	0.022	52
	1971	0.041	0.11	0.01	0.017	36
Lead mg/litre Pb	1969	0.001	0.030	0.000	0.003	51
	1970	0.008	0.040	0.000	0.011	52
	1971	0.019	0.050	0.000	0.011	36
Zinc mg/litre Zn	1969	0.119	0.21	0.01	0.050	52
	1970	0.138	0.54	0.04	0.101	52
	1971	0.112	0.30	0.03	0.064	36
Cyanide mg/litre CN	1968	0.005	0.070	0.000	0.013	29
	1969	0.002	0.013	0.000	0.002	52
	1970	0.001	0.004	0.000	0.001	52
	1971	0.001	0.004	0.000	0.001	36
Arsenic mg/litre As	1970	0.002	0.010	0.000	0.004	12
	1971	0.000	0.000	0.000	0.000	11
Selenium mg/litre Se	1970	0.000	0.000	0.000	0.000	9
	1971	0.000	0.000	0.000	0.000	8
Boron mg/litre B	1970	0.464	0.750	0.200	0.167	12
	1971	0.456	0.630	0.230	0.113	11
Dissolved oxygen mg/litre O ₂	1968	7.94	57.0	4.0	4.53	140
	1969	7.43	10.8	4.7	1.71	51
Free carbon dioxide mg/litre CO ₂	1968	14.06	33.0	6.5	6.06	24
	1969	11.07	32.0	3.4	5.81	52

APPENDIX FIGURE A(c) (page 4)

TABLE 10 (CONTD)

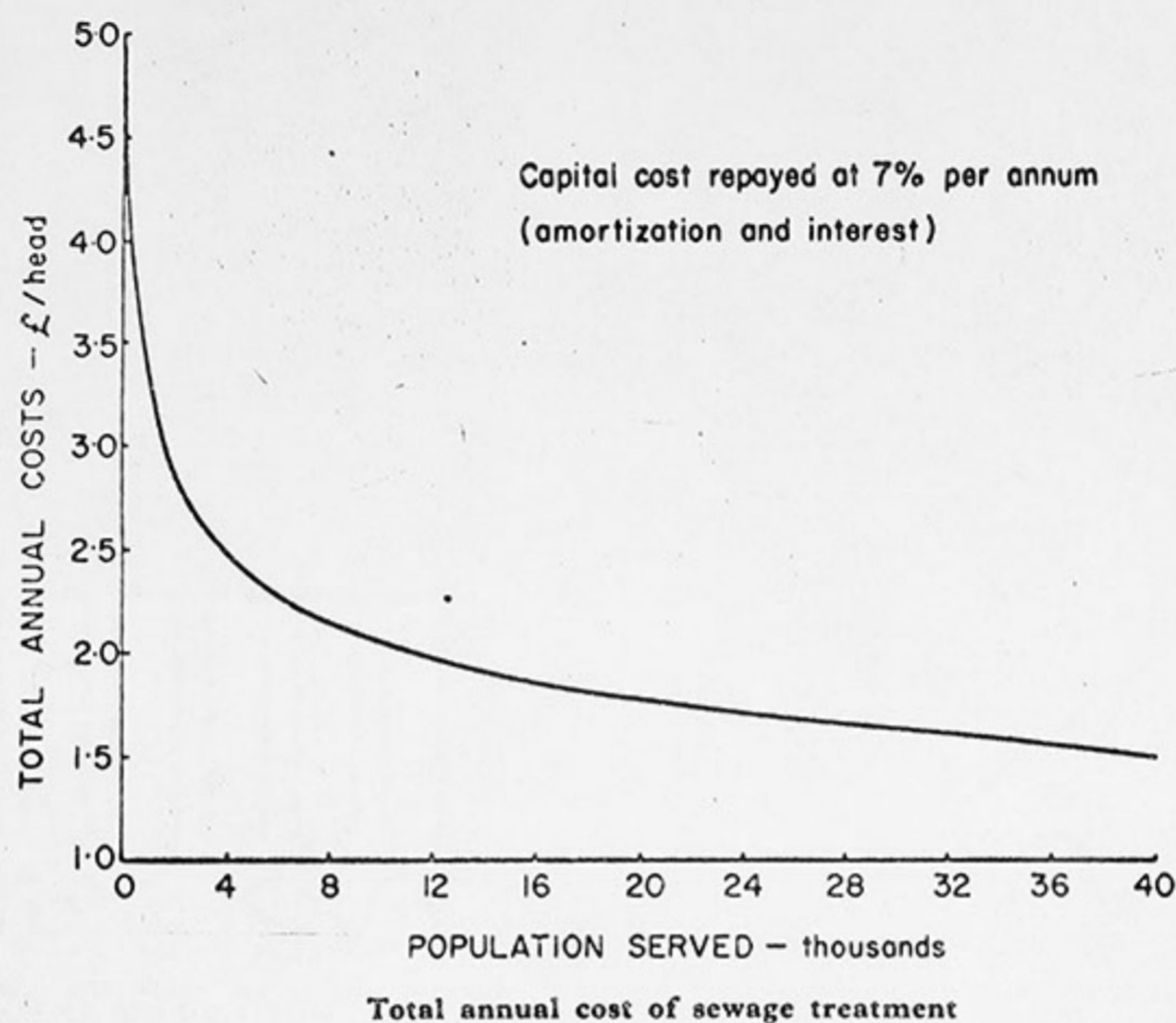
	Year	Mean	Max.	Min.	St. Dev.	Obs.
<u>Dissolved organics</u>						
Colour	1968	0.063	0.212	0.028	0.022	139
O.D. 400 m.	1969	0.056	0.092	0.033	0.014	52
	1970	0.048	0.076	0.028	0.011	52
	1971	0.053	0.122	0.034	0.014	39
Total organic carbon mg/litre C	1969	9.0	19.0	3.0	3.0	32
	1970	8.2	13.0	2.0	2.9	29
	1971	7.8	11.0	4.0	2.1	29
Permanganate value mg/litre O ₂	1968	6.83	15.6	3.6	2.95	40
	1969	6.27	13.8	3.6	2.14	51
	1970	5.70	10.4	3.6	1.44	51
	1971	5.47	10.4	3.6	1.54	32
Biochemical Oxygen demand (BOD) mg/litre O ₂	1968	8.73	18.8	3.3	4.51	41
	1969	8.29	19.0	4.4	3.08	49
	1970	8.00	17.1	4.2	2.44	50
	1971	6.88	13.2	3.8	2.36	37
Anionic detergents mg/litre Manoxol	1968	0.195	0.40	0.03	0.088	33
	1969	0.296	0.93	0.03	0.153	52
	1970	0.307	0.63	0.05	0.123	52
	1971	0.268	0.50	0.12	0.096	39
Non-ionic detergents mg/litre Lissapol	1968	0.090	0.20	0.02	0.048	25
	1969	0.077	0.40	0.00	0.078	52
	1970	0.031	0.20	0.00	0.040	50
	1971	0.028	0.15	0.00	0.037	34
Phenol mg/litre	1968	0.006	0.016	0.000	0.003	26
	1969	0.005	0.013	0.000	0.003	50
	1970	0.004	0.016	0.001	0.003	51
	1971	0.003	0.007	0.001	0.002	38
Threshold odour number	1968	41.0	60	40	4.4	20
	1969	41.2	100	7	15.3	52
	1970	29.7	80	7	17.6	52
	1971	41.0	158	10	31.2	39
Organo chlorine pesticides µg/litre	1968	0.273	0.542	0.043	0.124	28
	1969	0.173	0.460	0.066	0.084	48
	1970	0.101	0.295	0.000	0.068	47
	1971	0.056	0.160	0.000	0.048	34
Carbon chloroform extract mg/litre	1968	0.415	0.490	0.340	-	2
	1971	0.349	0.450	0.280	0.071	7

APPENDIX FIGURE A(c) (page 5)

TABLE 10 (CONTD.)

	Year	Mean	Max.	Min.	St. Dev.	Obs.
<u>Biological</u>						
Total algal count, clumps/ml	1968	2477.917	14440.000	120.000	2953.444	24
	1969	3247.000	21840.000	0.000	4944.717	40
	1970	2628.636	18680.00	60.000	3528.498	44
	1971	8669.333	69480.00	0.00	14047.796	30
Chlorophyll, mg/litre	1968	0.026	0.150	0.000	0.035	31
	1969	0.024	0.093	0.000	0.023	50
	1970	0.026	0.170	0.002	0.031	47
	1971	0.019	0.062	0.003	0.012	39
Coliforms, $10^3/100$ ml	1968	240.413	3000.000	10.000	563.958	31
	1969	148.763	700.000	6.000	159.165	32
	1970	176.422	840.000	6.000	191.975	45
	1971	168.605	1200.000	7.000	237.591	38
E. Coli, $10^3/100$ ml	1968	14.595	210.000	0.002	40.224	28
	1969	4.446	13.000	0.140	3.370	30
	1970	7.716	48.000	0.100	8.581	44
	1971	7.657	58.000	0.200	12.246	37
Plate Count (22°C) $10^3/\text{ml}$	1968	1054.003	17000.000	0.006	2757.476	25
	1969	229.393	1300.000	2.500	322.256	14
	1970	85.916	850.000	0.100	175.729	31
	1971	142.025	2500.000	0.300	412.328	36
<u>Temperature and River Flow</u>						
Temperature $^\circ\text{C}$	1968	15.48	28.0	2.2	6.14	183
	1969	12.17	26.0	5.0	5.31	52
	1970	15.11	27.0	7.5	5.50	52
	1971	15.15	25.5	5.0	5.28	39
Average daily flow, cumecs	1968	89.260	396.200	28.329	88.49	356
	1969	88.238	438.650	45.280	87.58	364
	1970	79.137	212.960	29.170	57.485	48
	1971	67.735	385.020	27.300	71.969	39

APPENDIX FIGURE B(a)



APPENDIX FIGURE B(b)

PERCENTAGES OF TOTAL ANNUAL COSTS
ACCOUNTED FOR BY DEBT CHARGES

Population served (thousands)	Operating cost* (£/head)	Debt charges† at 7 per cent (£/head)	Total annual cost‡ (£/head)	Debt charges as per cent of total
0.2	1.62	3.325	4.945	67.4
0.25	1.50	3.115	4.615	67.5
0.5	1.20	2.695	3.895	69.2
0.7	1.12	2.520	3.640	69.3
0.8	1.10	2.450	3.550	69.1
1	1.03	2.310	3.340	69.2
1.5	0.93	2.135	3.065	69.7
2	0.88	1.995	2.875	69.3
3	0.80	1.820	2.620	69.5
4	0.75	1.715	2.465	69.6
5	0.72	1.645	2.365	69.5
6	0.69	1.575	2.265	69.6
7	0.67	1.540	2.210	69.7
8	0.65	1.482	2.132	69.7
9	0.63	1.455	2.085	69.9
10	0.62	1.435	2.055	69.8
20	0.55	1.225	1.775	69.2
40	0.45	1.050	1.500	70.3

Source of appendix figures B(a) and B(b):
R. M. Bradley and Peter C. G. Isaac, "The Cost of
Sewage Treatment," Institute of Water Pollution Control,
Conference Paper No. 4, October 25, 1968, Figure 35
and Table 12, p. 27.

APPENDIX FIGURE B(c)

Population	Annual expenditure per head: shillings		
	Operation cost	Loan charges	Total
1,000	20.0	21.9	41.9
10,000	12.0	14.5	26.5
50,000	8.0	12.0	20.0
100,000	6.5	11.0	17.5
200,000	5.5	10.0	15.5
500,000	4.0	9.0	13.0
1,000,000	3.0	7.9	10.9
1,500,000	2.5	7.5	10.0

Source: C. B. Townend, "The Economics of Waste-water Treatment," Proceedings of the Institute of Civil Engineers, Vol. 15 (1960), Table 1, p. 216. The figures are for 1959 prices and a 6½% interest rate.

APPENDIX FIGURE C

ASSUMED QUALITY OF EFFLUENTS AND THE CORRESPONDING MEAN CONCENTRATIONS FOR EACH PARAMETER

The concentrations of oxidized nitrogen for all specified qualities of effluent, and the concentrations of ammoniacal nitrogen for ET2, were obtained from summaries of data collected from questionnaires; the mean concentrations were estimated from given average values, and the 95 percentiles from corresponding maximum values.

Parameter of effluent quality	Effluent quality (mg/l)					
	ET2		ET3		ET4	
	Mean	95 percentile	Mean	95 percentile	Mean	95 percentile
BOD	11	20	11	20	5	10
Suspended solids	17	30	17	30	4	10
Ammoniacal nitrogen	20	30	1.6	3.5	1.0	3.5
Oxidized nitrogen	5	15	19	28	19	28
Range of mean concentration for each standard of effluent						
Phenols	0 - 0.95		0 - 0.95		0 - 0.15	
Cadmium	0 - 0.0075		0 - 0.0075		0 - 0.0013	
Chromium	0 - 0.12		0 - 0.12		0 - 0.02	
Copper	0 - 0.35		0 - 0.35		0 - 0.1	
Lead	-		-		-	
Nickel	0 - 0.3		0 - 0.3		0 - 0.1	
Zinc	0 - 0.475		0 - 0.475		0 - 0.11	
Chloride	-		-		-	

Source: K. S. Porter and A. G. Boon, "Cost of Treatment of Waste Water with Particular Reference to the River System of the Trent Area," in Institute of Water Pollution Control, The Trent Research Programme: Proceedings of Symposium (15-16 April 1971), Table 3, p. 59.

APPENDIX FIGURE D	No Treatment	WT 1	WT 2	WT 3	WT 4	WT 5	WT 6	WT 7	WT 8
Total Organic Carbon	0-1 0-3 0-5 0-∞ 0-0.5 0-20 0-300 0-1 0-100 0-200 0-300 0-∞ 0-25 7-8 0-800 0-0.01 0-0.002 0-0.01 0-0.05 0-1.5 0-0.05 0-1.0 0-1.5 0-0.5 0-1.1 0-500 0 0-0.001 0-0.026 0-1	1-1.7 3-5 5-8.3 0-∞ 0.5-1.0 0-20 0-300 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 0-800 0-0.01 0-0.002 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0-0.5 0-1.1 0-500 0 0-0.001 0.026-0.052 1-500	1-1.7 3-5 5-8.3 0-∞ 1.0-2.0 0-20 0-300 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 0-800 0-0.01 0-0.002 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0-0.5 0-1.1 0-500 0 0-0.001 0.026-0.052 1-500	1.7-5.7 5-16.7 8.3-28.0 0-∞ 0.5-1.0 0-20 0-300 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 0-800 0-0.01 0.002-0.02 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0.5-5.0 0-1.1 0-500 0 0.001-0.01 0.052-0.174 1-500	1.7-5.7 5-16.7 8.3-28.0 0-∞ 1.0-2.0 0-20 0-300 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 0-800 0-0.01 0.002-0.02 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0.5-5.0 0-1.1 0-500 0 0.001-0.01 0.052-0.174 1-500	1-1.7 3-5 5-8.3 0-∞ 0.5-1.0 20-25 300-375 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 800-1050 0-0.01 0-0.002 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0-0.5 0-1.1 500-625 0 0-0.001 0.026-0.052 1-500	1-1.7 3-5 5-8.3 0-∞ 1.0-2.0 20-25 300-375 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 800-1050 0-0.01 0-0.002 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0-0.5 0-1.1 500-625 0 0-0.001 0.026-0.052 1-500	1.7-5.7 5-16.7 8.3-28.0 0-∞ 0.5-1.0 20-25 300-375 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 800-1050 0-0.01 0.002-0.02 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0.5-5.0 0-1.1 500-625 0 0.001-0.01 0.052-0.174 1-500	1.7-5.7 5-16.7 8.3-28.0 0-∞ 1.0-2.0 20-25 300-375 1-500 100-500 200-500 300-500 0-∞ 0-25 2-9 800-1050 0-0.01 0.002-0.02 0.01-0.02 0.05-0.10 1.5-3.0 0.05-0.10 1.0-5.0 1.5-7.5 0.5-5.0 0-1.1 500-625 0 0.001-0.01 0.052-0.174 1-500

Source: Water Research Association, Trent Economic Model, Section 4, Water Treatment, Final Report, December, 1971. Figures in body of table refer to mean values, in mg/litre unless otherwise stated.

APPENDIX FIGURE D (page 2)

NOTES TO TABLE D - ACTION LEVELS FOR WATER TREATMENT

TOC	WT1	-	40% removal
	Carbon	-	70% removal
Ammonia	WT1	-	0.5 mg/litre by breakpoint chlorination
			Biological sedimentation - 75% removal
Suspended solids	WT1	-	99.8% removal
Total hardness	WT1	-	200 to 400 mg/litre removal
pH	WT1	-	pH correction
Total dissolved Solids	Desalination - (Electrodialysis)		250 mg/litre removal
Phenols	Carbon	-	90% removal
Cadmium	WT1	-	50% removal
Chromium	WT1	-	50% removal
Copper	WT1	-	50% removal
Lead	WT1	-	50% removal
Nickel	WT1	-	80% removal
Zinc	WT1	-	80% removal
Detergents	Carbon	-	90% removal
Sulphate	Desalination	-	125 mg/litre removal
Pesticides	Carbon	-	90% removal
Colour	WT1	-	50% removal
	Carbon	-	70% removal
Turbidity	WT1	-	99.8% removal

APPENDIX FIGURE E

TABLE C
STANDARDS FOR DRINKING WATER

mg/litre except where stated otherwise

Constituent	WHO European Standards (6)	US Public Health Service(7)	
		Recommended*	Reject
Lead	0.1		0.05
Arsenic	0.05	0.01	0.05
Selenium	0.01		0.01
Chromium (Hexavalent)	0.05		0.05
Cadmium	0.01		0.01
Cyanide	0.05	0.01	0.2
Polycyclic Aromatic Hydrocarbons	0.2 µg/l		
Fluoride	0.9-1.7	0.9-1.7	
Nitrate Nitrogen (as N)	11-22	10	
Sulphate	250	250	
Carbon Chloroform Extract	0.2-0.5	0.2	
Barium	1.0		1.0
Copper	0.05	1.0	
Iron	0.1	0.3	
Phenols	0.001	0.001	
Manganese	0.05	0.05	
Zinc	5.0	5.0	
Magnesium	30, if $SO_4 > 250$ 125, if $SO_4 < 250$		
Hydrogen Sulphide	0.05		
Chloride	200-600	250	
Total Dissolved Solids		500	
Threshold Odour Number		3	
Anionic Detergents	0.2	0.5 ABS	
Ammonia	0.05		
Total Hardness (As $CaCO_3$)	100-500		
Silver			0.05
Turbidity		5	
Colour		15	

* Reject, if above level, where alternatives are available.

Source: Water Research Association, Trent Economic Model,
Section 4, Water Treatment, Final Report, December, 1971.

APPENDIX FIGURE F

TABLE E

COST OF WATER TREATMENT PLANTS FOR THE TRENT AT
NOTTINGHAM p/m³ (1972)

	mgd. 4.75	mgd 9.51	mgd 19.01	47.53
Throughput m ³ /s	0.25	0.50	1.00	2.50
River intake	0.078	0.075	0.071	0.064
Storage reservoir	0.284	0.191	0.133	0.086
Biological sedimentation	0.016	0.016	0.019	0.017
Sedimentation, filtration, disinfection, sludge treatment	0.496	0.425	0.352	0.301
Activated carbon adsorption	0.285	0.252	0.234	0.222
Total Fixed Charges	1.159	0.959	0.809	0.690
Operating Cost	2.020	1.980	1.970	1.940
Total Water Cost	3.18	2.94	2.78	2.63

Source of Appendix Figures F through S:

Water Research Association, Trent Economic Model,
 Section 4, Water Treatment, Final Report, December, 1971.

APPENDIX FIGURE G
CAPITAL COSTS OF WATER TREATMENT £000's

Throughput (m^3/s)	0.25	0.50	1.00	2.50
River Intakes (1967)	55	105	200	450
Storage reservoirs (1967)	230	310	430	700
Conventional treatment plant (1962)	280	480	800	1700
Biological sedimentation (1972)	16	32	72	168
Activated carbon adsorption (1971)	196	347	644	1524
Desalination-electrodialysis (1971)	300	570	1100	2500

APPENDIX FIGURE H
SUMMATION OF CAPITAL COSTS FOR ECONOMIC
 MODEL PLANTS

WT ₁	River intake Storage reservoir Conventional treatment plant
WT2	WT1 + Biological sedimentation
WT3	WT1 + Activated carbon adsorption
WT4	WT2 + Activated carbon adsorption
* WT5	WT1 x 1.25 + desalination
* WT6	WT2 x 1.25 + desalination
* WT7	WT3 x 1.25 + desalination
* WT8	WT4 x 1.25 + desalination

*Assume reject ratio in electrodialysis = 20%

i.e. Product/Input = 0.8

APPENDIX FIGURE I
OPERATING COSTS OF ECONOMIC MODEL PLANTS p/m³(1971)

Throughput m ³ /s		0.25	0.50	1.00	2.50
WT1	1.429+0.024 for 5 mg/litre chlorine to breakpoint 0.5 mg/litre of ammonia	1.453	1.453 1.56	1.453	1.453
WT2	WT1-0.024 as chlorine for breakpoint not required	1.429	1.429	1.429	1.429
WT3	WT1 + carbon operating cost	1.903	1.863	1.843	1.823
WT4	WT2 + carbon operating cost	1.879	1.829	1.819	1.799
WT5	WT1 + desalination operating cost	3.453	3.353	3.253	3.153
WT6	WT2 + " "	3.429	3.329	3.229	3.129
WT7	WT3 + " "	3.903	3.763	3.643	3.523
WT8	WT4 + " "	3.879	3.729	3.619	3.499

APPENDIX FIGURE J

COST OF STORAGE RESERVOIRS

Plant throughput, m ³ /s	0.25	0.50	1.00	2.50
Storage volume m ³	151 000	302 000	604 000	1.510 000
Capital Cost £ (1967)	230 000	310 000	430 000	700 000

APPENDIX FIGURE K

BIOLOGICAL FILTRATION COSTS

Throughput m ³ /s	0.25	0.50	1.00	2.50
Filter volume m ³	1 125	2 250	4 500	11 250
Media Cost £	2 700	5 400	10 800	2 700
Cost of filter + Media £ (1967)	12 700	22 350	39 400	87 600
Cost of pump + driver £	450	630	865	1 535
Total cost £ (1967)	13 150	22 980	40 265	89 135

Operating cost: 0.014 p/m³ (1971)

APPENDIX FIGURE L

BIOLOGICAL SEDIMENTATION COSTS

Throughput m ³ /s	0.25	0.50	1.00	2.50
Size and no. of tanks	1 x 10m	2 x 10m	3 x 12m	7 x 12m
Tank volume m ³	633	1 266	2 880	6 720
Upflow rate m/h	9	9	8.3	8.9
Residence time min.	42	42	48	45
Cost £ (1972)	15 800	31 600	72 000	168 000

Operating cost: Included in overall operating cost

APPENDIX FIGURE M

CONVENTIONAL TREATMENT PLANT COSTS

Throughput m ³ /s	0.25	0.50	1.00	2.50
Capital Cost £ (av. 1962) (Fig. 60 TP.60)	280 000	480 000	800 000	1 700 000

APPENDIX FIGURE N

CHEMICAL TREATMENT - OPERATING COSTS

Chemical	Application	Unit Cost	Average dose mg/litre	Cost (1971) p/m ³
Ferric sulphate	Coagulation	£14.5/tonne (40% w/w)	30 as Fe ₂ (SO ₄) ₃	0.109
Polyelectrolyte	Coagulant aid	£ 1.1/kg	0.1	0.011
Caustic soda	Softening	£15.5/tonne (47% w/w)	Depends on degree of softening required (see Table 37a)	0.66 0.99 1.32
Chlorine	Disinfection	£48/tonne	4	0.019
Totals p/m ³				0.799 1.129 1.459
Final hardness				300 200 100

APPENDIX FIGURE O

COST OF SOFTENING

Maximum raw water hardness mg/litre CaCO ₃ - 500			
Final hardness mg/litre CaCO ₃	300	200	100
Softening cost p/m ³	0.66	0.99	1.32

APPENDIX FIGURE P

CAPITAL COSTS OF ACTIVATED CARBON SYSTEMS £ (1971)

Flow m ³ /s	0.25	0.50	1.00	2.50
Equipment cost	50.000	85 120	145 300	325 550
Erection cost	37 600	56 550	102 000	230 000
Direct cost	87 600	141 670	247 300	555 550
Bare price	109 500	177 000	309 000	694 000
Total without Carbon	120 400	194 800	340 000	764 000
Carbon	76 000	152 000	304 000	760 000
Total	196 400	346 800	644 000	1524 000

APPENDIX FIGURE Q

OPERATING COSTS OF ACTIVATED CARBON SYSTEMS p/m³ (1971)

Flow m ³ /s	0.25	0.50	1.00	2.50
Carbon make-up	0.11	0.11	0.11	0.11
Labour	0.06	0.03	0.03	0.01
Maintenance	0.14	0.12	0.11	0.11
Fuel	0.01	0.01	0.01	0.01
Steam	0.01	0.01	0.01	0.01
Electricity	0.12	0.12	0.12	0.12
Total	0.45	0.40	0.39	0.37

APPENDIX FIGURE R

DESALINATION COSTS (ELECTRODIALYSIS)

Throughput m ³ /s	0.25	0.50	1.00	2.50
Total capital cost including building £ (1971)	300 000	570 000	1100 000	2500 000
Operating costs p/m ³ (1971)	2.0	1.9	1.8	1.7

APPENDIX FIGURE S

COSTS OF RIVER INTAKES

Throughput m ³ /s	0.25	0.50	1.00	2.50
Capital cost £ 1967 (from Fig. 37, TP 60)	55 000	105 000	200 000	450 000

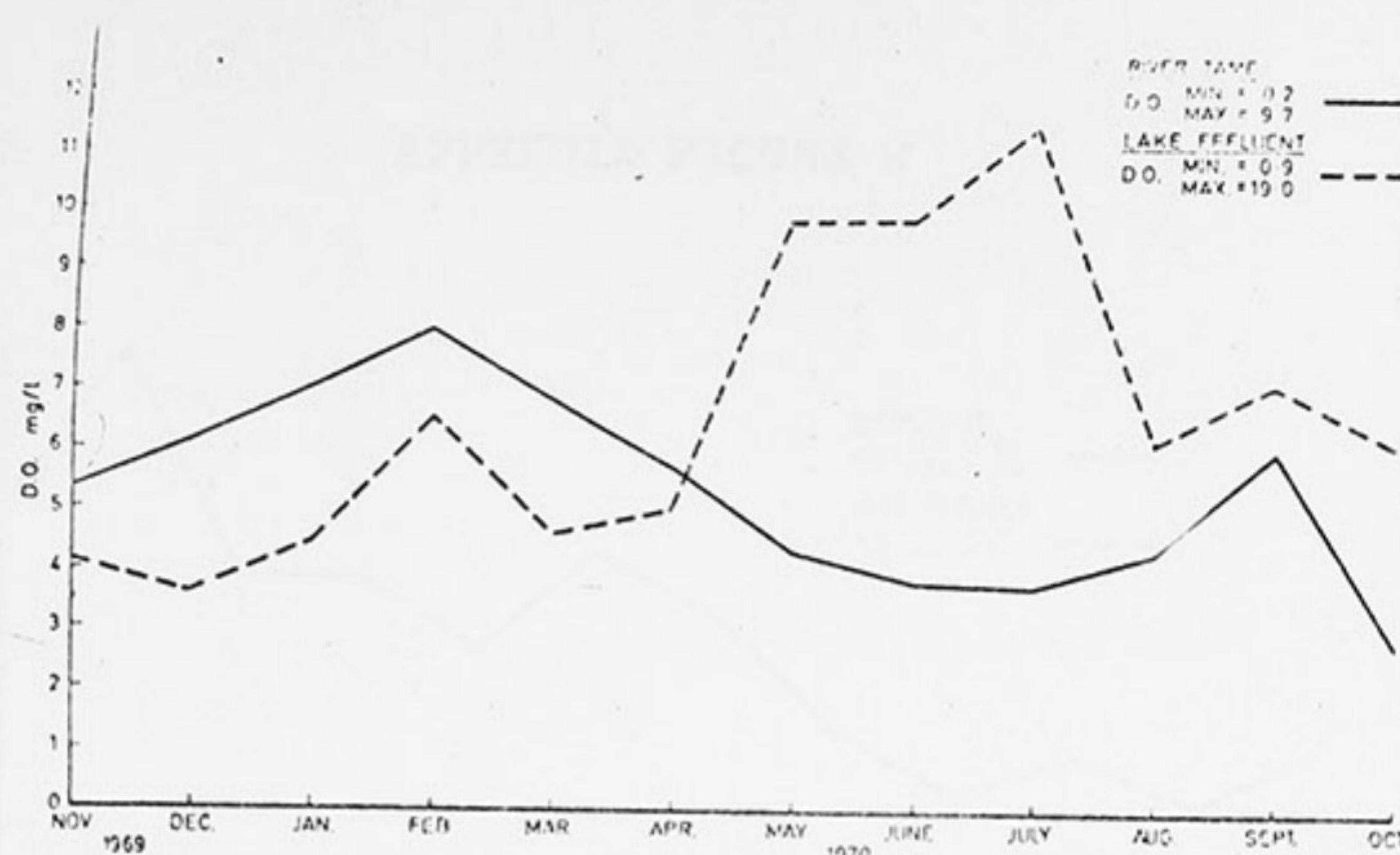
APPENDIX FIGURE T

ASSUMED EFFECT OF A RIVER RETENTION LAKE ON
THE ANNUAL MEAN QUALITY OF THE RIVER TAME.

Water Quality Parameter	Level of Parameter after the lake as a fraction of that before
BOD	0.60
Am.N	0.90
Ox.N	0.92
DO	1.14
SS	0.26
Temp	0.94
TDS	0.97
PhOH	0.50
Cr	0.25
Cu	0.86
Ni	0.88
Zn	0.70
Pb	0.50
Cd	0.50
TOC	0.65
Cl	0.97

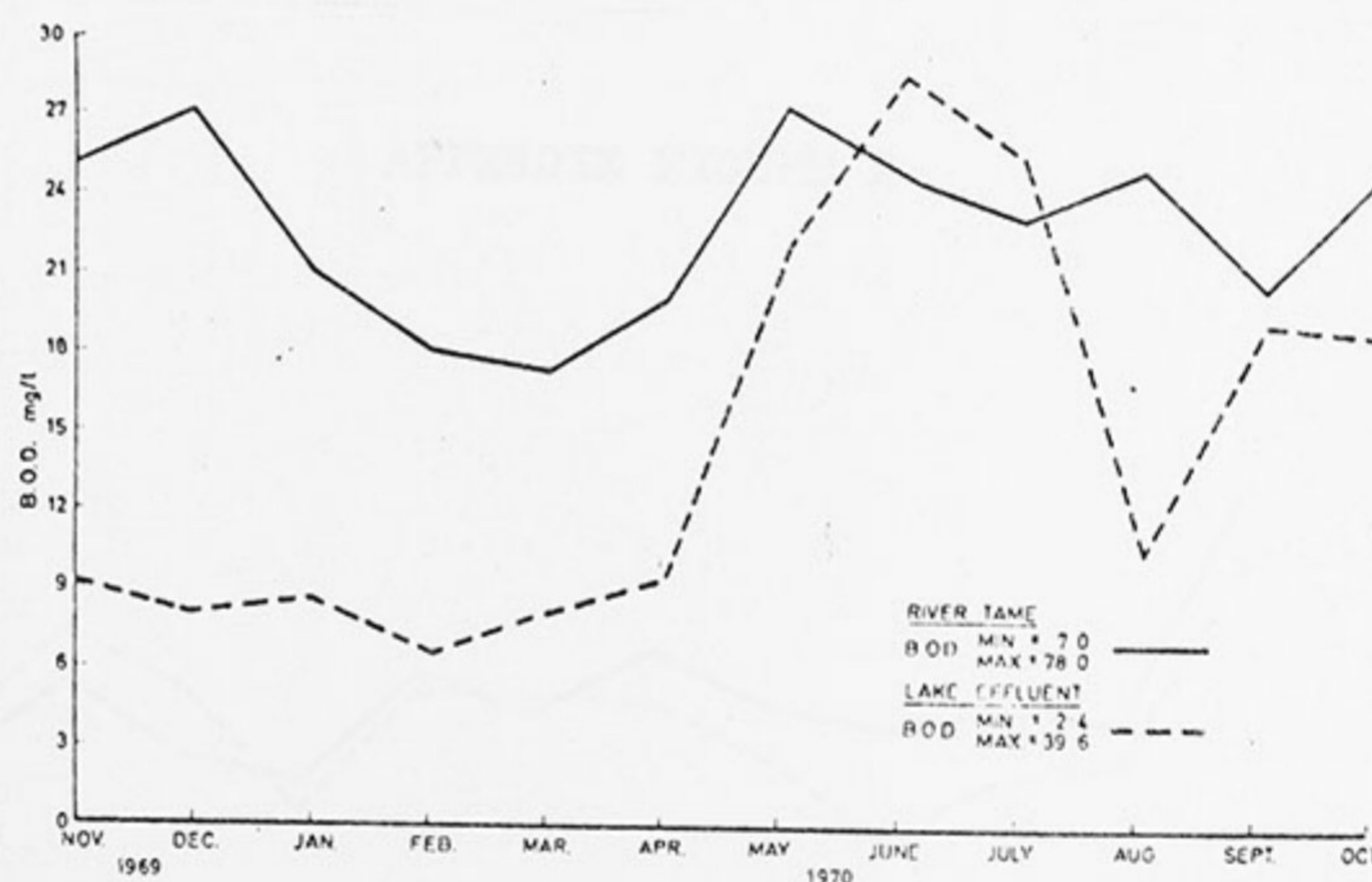
Source: Water Research Association
Trent Research Programme

APPENDIX FIGURE U



Graph of monthly averages of dissolved oxygen at Lea Marston

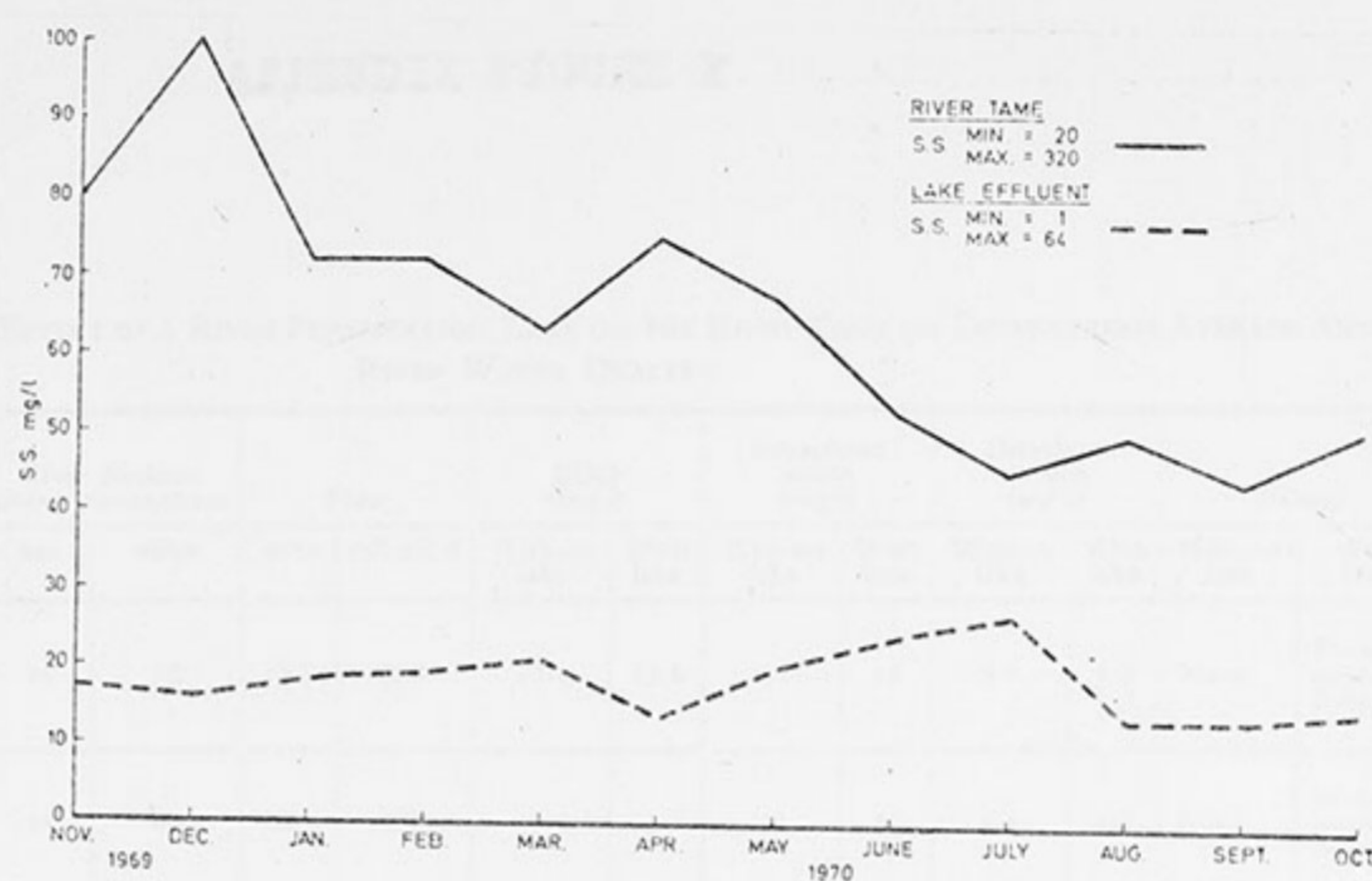
APPENDIX FIGURE V



Graph of monthly averages of BOD at Lea Marston

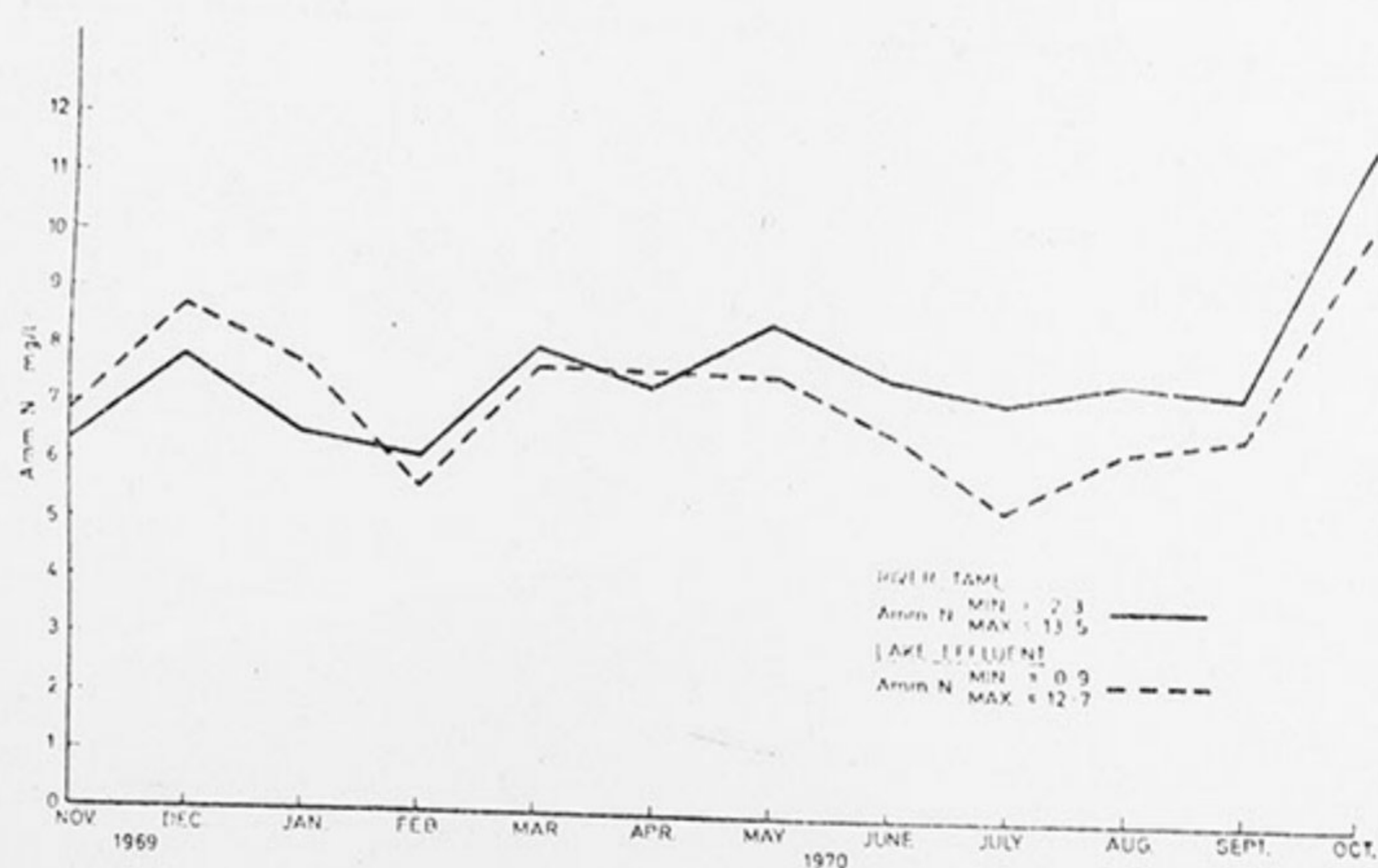
Source of Appendix Figures U, V, W, X, and Y: W. F. Lester et al., "The Effect and Cost of River Purification Lakes," in Institute of Water Pollution Control, The Trent Research Programme: Proceedings of Symposium (15-16 April, 1971), Figures 1, 3, 4, 5, and Table 13, pp. 79-81, 86.

APPENDIX FIGURE W



Graph of monthly averages of suspended solids at Lea Marston

APPENDIX FIGURE X



Graph of monthly averages of ammoniacal nitrogen at Lea Marston

APPENDIX FIGURE Y

ESTIMATED EFFECT OF A RIVER PURIFICATION LAKE ON THE RIVER TAME ON DOWNSTREAM AVERAGE ANNUAL RIVER WATER QUALITY

Observation point	River distance above Nottingham		Flow		BOD (mg/l)		Suspended solids (mg/l)		Dissolved oxygen (mg/l)		Fishery	
	km	miles	m ³ /s	mil gal/d	Without lake	With lake	Without lake	With lake	Without lake	With lake	Without lake	With lake
River Tame at Purification Lake (Lea Marston) ..	94	59	13.1	250	22.6	13.6	64	19	5.6	6.2	None	Possible coarse fishery
River Tame at Tame/Trent confluence (Chetwynd) ..	64	40	18.4	350	18.9	12.4	68	35	4.1	4.5	None	Probable coarse fishery
River Trent below Tame/Trent confluence (Walton) ..	58	36	31.6	600	14.1	10.3	47	28	5.0	5.3	None	Coarse fishery
River Trent at Nottingham ..	0		81.5	1550	8.2	6.7	28	21	7.2	7.3	Coarse fishery	Coarse fishery

APPENDIX ON TRADE EFFLUENT REGULATION BY
THE UPPER TAME MAIN DRAINAGE AUTHORITY

provided by

N. Harkness, Ph. D., Chief Chemist

- (c) Total amounts of insoluble and soluble compounds of the above metals not to exceed 30 mg/l.
- (d) Suspended solids not to exceed 400 mg/l.
- (e) Class 1 limits where organic materials are discharged.

Class 3. Non-Ferrous metallic wastes and cyanides

Permissible standards:—

- (a) Cyanide not to exceed 10 mg/l.
- (b) Class 2 limits.
- (c) Class 1 limits where applicable.

Class 4. Cyanides

Permissible standards:—

- (a) pH Value 6-12.
- (b) Cyanide not to exceed 10 mg/l.
- (c) Suspended solids not to exceed 400 mg/l.
- (d) Class 1 limits where applicable.

Class 5. Ferrous and Non-Ferrous metallic wastes

Permissible standards:—

- (a) pH Value 8-12.
- (b) Suspended solids not to exceed 400 mg/l.
- (c) Class 3 limits where applicable.

Class 6. Wastes to which special limits will be applied.

General

Oil

Trade effluent to be free from physically separable, dispersed or emulsified oils.

Temperature

The temperature of trade effluent not to be in excess of 43.5 degrees Celsius (110 degrees Fahrenheit).

Condensing Water

Condensing water not to be discharged.

Injurious Substances

Attention is drawn to Section 27 of the Public Health Act 1936 which provides that certain matters shall not be passed into public sewers.

UPPER TAME MAIN DRAINAGE AUTHORITY

TRADE EFFLUENT

TREATMENT AND DISPOSAL COSTS and CLASSIFICATION FOR PURPOSES OF CONTROL

June 1970

156/170 Newhall Street
BIRMINGHAM. B3 1SE

1. Cost of the reception and disposal of sewage

(1) Definition of Annual Expenditure and Flow

"Annual Expenditure" means the amount by which the Authority's expenditure on revenue account in the relevant year is estimated by them for Precept purposes to exceed income other than trade effluent income.

"Annual Flow" means the flow to all of the Authority's Works in the relevant year, as estimated by the Authority.

(2) Definition of Costs

"Annual Cost" means quotient of the annual expenditure divided by the annual flow expressed in terms of cost per 1,000 gallons.

"Oxidation Cost" means that part of the annual cost apportioned to oxidation processes, as hereinafter stated.

"Sludge Cost" means that part of the annual cost apportioned to the processing and disposal of sludge, as hereinafter stated.

"Volume Cost" means that part of the annual cost apportioned to sewerage, settlement, distribution and other processes designed on a volumetric basis, as hereinafter stated.

(3) Apportionment of Cost

The basis of the apportionment of the annual cost as aforesaid shall be as follows:—

Volume Cost	...	...	47.6%
Oxidation Cost	...	...	28.1%
Sludge Cost	...	...	24.3%

provided that the said basis may be altered by the Authority to accord with changes in the incidence of expenditure by the Authority.

2. Cost of the reception and disposal of trade effluent

(1) For the purpose of calculating the cost to the Authority of the reception and disposal of trade effluent, the following factors shall be applied:—

- The cost attributable to processes designed on a volumetric basis shall be the same as that for sewage.
- The cost of oxidation shall be related to settled sewage (i.e. after primary sedimentation) having a Chemical Oxygen Demand (C.O.D.) of 418 mg/l or, where there is interference with the C.O.D. test, an Organic Carbon Value (O.C.V.) of 150 mg/l.

(c) The cost of sludge treatment and disposal shall be related to sewage having a Suspended Solids (S.S.) content of 344 mg/l.

provided that the said C.O.D. or O.C.V. and the said S.S. may be varied by the Authority to accord with any changes in the relevant strength of settled sewage or sewage respectively.

(2) The cost to the Authority for the reception and disposal of a trade effluent (T.E.) by the Authority is as follows:—

(a) Volume	...	Volume Cost
(b) Oxidation	...	Either
		Oxidation Cost $\times$ C.O.D. of settled T.E.
		C.O.D. of settled sewage
	Or	Oxidation Cost $\times$ O.C.V. of settled T.E.
		O.C.V. of settled sewage
		PLUS, in the case of a trade effluent containing soluble metals (excluding zinc) 50% of oxidation cost for each 5 mg/l or pro rata, after the first 5 mg/l.
(c) Sludge	...	Sludge Cost $\times$ S.S. of T.E.
		S.S. of sewage

(3) Where the cost to the Authority of the reception and disposal of a trade effluent is not reflected by the application of the parameters referred to in sub-paragraphs (1) and (2) of this paragraph, the Authority will apply such other parameters as they consider appropriate.

Classification of Trade Effluents

Class 1. Organic wastes and wastes not involving discharges containing metallic constituents

Permissible standards:—

- pH Value not limited except where chemicals are used and then 6–12.
- The C.O.D. will normally be expected not to exceed 600 mg/l, although local circumstances may require a lower limit. Applications for relaxation will be judged individually and transferred to Class 6.

(c) Suspended solids not to exceed 400 ppm.

Class 2. Non-Ferrous metallic wastes

Permissible standards:—

- pH Value 6–12.
- Total amount of soluble metals of Chromium, Copper, Nickel, Cadmium, Zinc, Lead and Tin not to exceed 10 mg/l.

UPPER TAME MAIN DRAINAGE AUTHORITY

Trade Effluent Charges 1970-71

Cost of sewage treatment per 1,000 gallons 18.00d (7.50p)

Volume	47.6%	8.57d (3.57p)
Oxidation	28.1%	5.06d (2.11p)
Sludge	24.3%	4.37d (1.82p)

Extension of the sewage treatment cost of trade effluent

Consent Limits

		p/1000	Maximum charge p/1000
Volume		3.57	8.72
Oxidation	2.11 x $\frac{600}{418}$	3.03	
Sludge	1.82 x $\frac{400}{344}$	2.12	
Metals	2.11 x $\frac{5}{10}$	1.05	9.77

Unit Charges

<u>Factor</u>	1 ppm C.O.D.	<u>Factor</u>	1 ppm S.S.
3.03	.00505	2.12	.0053

UPPER TAME MAIN DRAINAGE AUTHORITY

Trade Effluent Charges 1971-72

Precept	£4,333,838
Estimated Trade Effluent Income	<u>400,000</u>
	<u>£4,733,838</u>

Average Daily Flow 146 million gallons per day

Cost of sewage treatment per 1,000 gallons

$$\frac{473383800}{146000 \times 366} = 8.858p$$

		p/1000	p/1000
Volume	47.6%	4.216	4.22
Oxidation	28.1%	2.489	2.49
Sludge	24.3%	<u>2.152</u>	<u>2.15</u>
		<u>8.857</u>	<u>8.86 -</u>

Extension of the Sewage treatment cost to trade effluent

Consent Limits

		p/1000	Max. charge p/1000	
Volume		4.22		61ms
Oxidation	2.49 x $\frac{600}{418}$	3.57	10.29	144
Sludge	2.15 x $\frac{400}{344}$	2.50		
Metals	2.49 x $\frac{5}{10}$	1.25	11.54	2.3 & 5

1969 to 1971
**PROGRESS REPORT ON THE CONTROL OF
 TRADE EFFLUENTS**

The Authority acts as an agent in the control of trade discharges to the sewers of constituent local authorities in the case of all areas except Birmingham and Wolverhampton.

The agency agreements negotiated with these authorities provide for:

- (a) Control of the quality, nature and composition of all discharges made under a form of consent or direction or within the terms of agreements.
- (b) Bringing under control all unauthorised discharges and any which were formerly exempt under Section 4 of the Public Health (Drainage of Trade Premises) Act 1937.
- (c) The investigation of sources of pollution reported by the local authority or River Authority in surface water sewers, canals, rivers and streams.
- (d) Observing the requirements of the constituent authorities interested bodies and obtaining approval of other interested bodies.
- (e) Producing evidence for appeals and prosecutions.
- (f) Charging traders for reception and disposal of wastes under the charging scheme.

Progress has been maintained in the inspection and control of trade wastes by visits to premises, taking and analysing samples and examination of discharge points, pretreatment plants, metering and monitoring equipment. Premises where no notification of discharge has been made are being progressively visited and surveyed. The work is summarised in the following table:—

Constituent Authority	Number of Premises Visited			Total Number of Visits			Number of Samples Obtained			Number of Premises Surveyed		
	68/69	69/70	70/71	68/69	69/70	70/71	68/69	69/70	70/71	68/69	69/70	70/71
Aldridge/Brownhills	63	47	54	289	347	584	141	123	300	32	15	19
Meriden	27	23	18	67	57	73	26	15	30	17	14	9
Solihull	38	56	39	133	251	308	93	142	185	9	27	10
Sutton Coldfield	37	50	37	135	238	315	59	87	104	10	20	9
Walsall	306	222	289	1,542	1,565	2,327	755	794	1,199	160	64	122
Warley West	161	272	205	847	1,213	1,513	1,053	499	1,129	76	179	110
Bromwich	170	195	204	984	1,299	1,723	437	654	830	73	92	87
Dudley	28	16	24	181	240	300	47	83	133	21	6	9
Wolverhampton	3	5	8	3	10	9	—	1	74	1	—	—
Direct	5	5	5	14	15	59	11	8	51	—	—	—
Other Areas	14	1	3	14	5	12	—	4	8	9	—	—
TOTALS	852	892	886	4,209	5,240	7,223	2,622	2,410	4,043	408	417	375

The present volume of industrial effluent brought under control throughout the entire drainage area and discharged to the various Authority sewage works, amounts to 45,348,959 gallons per day. There are probably additional volumes of trade effluent that have yet to be brought under control. The progressive state of controlled volumes which the Authority has approved in successive years since 1966 is as follows:—

Year	Date	Total Volume Approved-gallons	Net Annual Volume brought under control
1966-67	1.4.66	40,726,660	2,263,176
1967-68	1.4.67	42,989,836	4,278,925
1968-69	1.4.68	47,268,761	— 63,590
1969-70	1.4.69	47,205,171	— 2,122,470
1970-71	1.4.70	45,082,701	266,258
	1.4.71	45,348,959	

Any negative net annual volumes shown are due to annulled consents resulting from demolition or change of use of premises or cessation of discharge. The larger cancelled volumes relate to premises within the City of Birmingham. During the calendar year 1970 the following ceased discharges were reported:—

Constituent Authority	Number of ceased discharges	Volume of ceased discharges gallons per day	Sewage Works affected
Birmingham	46	902,588	Minworth-Yardley
Solihull	4	176,200	Coleshill
Sutton Coldfield	2	16,000	Minworth
Walsall	3	19,800	Brockhurst
Warley	1	4,800	Walsall Road
Wolverhampton	3	5,316	Minworth
	1	6,000	Watery Lane

Trade Effluent Notices served during 1970-71 resulted in 146 applications being approved for the issue of consents. Applications may be in respect of existing previously uncontrolled discharges, new discharges or enhanced volumes in excess of existing consents (super-seding applications). The numbers of each type of application are given together with the additional volume of effluent resulting. The additional flows to sewage works affected are also given. (Table given below).

Constituent Authority	Number of Applications			Additional Volume galls. per day	Sewage Works	Additional Volume galls. per day
	Exist-ing Uncon-trolled	New	Super-seding applica-tions			
Birmingham	22	42	6	421,253	Minworth	495,983
Sutton	3	2	1	61,725	Yardley	13,340
Coldfield	9	6	1	55,060	Roway Lane	15,000
Warley	1	3		17,600	Coleshill	32,550
Meriden	1			250	Barston	250
Solihull	12	9	2	92,055	Ray Hall	66,695
West				500	Toll End	25,200
Bromwich	1				Tivdale	1,000
Dudley					Barns Lane	6,640
Aldridge	1	2		10,480	Brockhurst	54,935
Brownhills	11	9		158,030	Bescot	2,540
Walsall					Goscote	20
					Walsall Road	102,560*
					Bentley Road	240

* This volume includes an approval for 90,000 gallons per day for a new discharge which will replace an existing equivalent volume during 1971-72. The old consent will be surrendered after the transfer.

Constituent Local Authority (L.A.)	Variable Charges—£				Minimum Charges £		Total Charges		Chargeable Volume 1,000's gallons			Average Cost per 1,000 gallons		
	Transferred to L.A.		Treatment Charge Retain by U.T.M.D.A.		1969-70		1970-71		1969-70		1970-71		New Pence	
	1969-70 Period 1	1970-71 Period 2	1969-70 Period 1	1970-71 Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Aldridge/	300	397	1,477	1,751	55	60	65	1,832	2,208	24,638	36,203	31,218	7-44	6-07
Bromsgrove	—	2	—	55	—	—	—	—	57	12,601	119	25	47-90	36-00
Direct Discharge	916	935	4,804	364	20	20	15	5,740	369	71,517	16,563	13,830	2-23	2-73
Dudley	—	—	—	4,829	20	20	15	—	5,784	472	73,358	58,471	8-03	6-47
Meriden	5	4	26	19	20	20	15	51	43	111,710	427	170	10-07	12-35
Solihull	1,127	659	6,133	6,359	95	85	80	7,355	7,103	97,151	100,003	100,003	6-58	7-31
Sutton Coldfield	328	281	3,167	2,334	105	100	100	3,600	2,915	30,731	26,501	44,083	11-71	10-49
Walsall	3,180	3,362	19,611	20,751	315	345	355	23,106	24,458	214,015	294,280	254,254	10-80	8-31
Warley	4,470	4,740	29,150	32,428	165	160	175	33,785	37,328	433,086	458,508	485,390	7-80	8-24
West Bromwich	1,427	1,594	11,999	13,028	175	190	215	13,601	14,812	129,117	142,279	117,314	10-53	15-14
Wolverhampton	—	—	3,100	2,712	—	—	—	3,100	2,712	74,956	71,194	65,453	4-14	5-13
TOTALS	11,753	11,974	79,922	84,830	955	985	1,025	92,630	97,789	1,102,843	1,216,583	1,170,211	8-40	8-48

SUMMARY OF TRADE EFFLUENT CHARGES FOR

(a) Period 2 - 1970/71 (1.10.70.-31.3.71.)

(b) Period 1 - 1971/72 (1.4.71.-30.9.71.)

Constituent Local Authority	Variable Charges				Minimum Charges		Average Cost	
	Volume (1000 gals)		£		£		p/1000 galls	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Aldridge-Brownhills	36479	34420	2405	3521	71	65	6.59	10.23
Bromsgrove	28	22	12	9			42.86	40.91
Direct Discharge	13061	10529	607	507		5	4.65	4.82
Dudley	65415	24965	5485	2489	15	15	8.38	9.97
Meriden	328	506	19	29	20	21	5.80	5.73
Solihull	113084	112266	10111	10199	85	80	8.94	9.09
Sutton Coldfield	42090	41949	2244	2698	80	95	5.33	6.43
Walsall	242435	255384	21899	22847	377	340	9.03	8.93
Warley	483995	430078	54382	53021	175	240	11.24	12.33
West Bromwich	138609	127053	17833	16684	216	190	12.14	13.13
TOTAL	1135524	1037672	114997	112004	1039	1051	10.13	10.79

Average Daily Flow of Trade Effluent

The following statistics are derived from information collected from traders at the end of each 6-monthly charging period. The total quantity of effluent discharged during the period is divided by the actual number of days worked. An average figure provided by the constituent authority is used in the case of the non-agency areas.

Sewage Works	Average Daily Flow of Trade Effluent—1,000's gallons		Trade Effluent-Percentage of Average Sewage Flow	
	Period 1 1969-70	Period 2 1970-71	Period 1 1969-70	Period 2 1970-71
Minworth-Birmingham Agency	20,607	3,079	28.0	4.2
Yardley-Birmingham Agency	3,432	3,319	4.7	4.6
Coleshill-Birmingham Agency	1,599	0.1	14.2	—
Ray Hall	528	567	4.2	4.5
Brockhurst	740	617	5.8	9.8
Barston	592	1,245	9.4	17.9
Toll End	1,687	62	19.9	2.3
Roway Lane	90	421	3.1	21.5
Walsall Road	594	405	29.8	13.1
Goscote	352	409	11.3	17.8
Lunt Road	361	415	15.8	2.8
Barns Lane	66	80	2.3	11.3
Watery Lane	376	340	12.5	13.0
Bentley Lane	163	144	14.8	10.7
Tividale	165	178	9.2	9.9
Tipton Rd.	152	150	13.9	13.6
Foxyards	13	15	1.6	1.9
Walsall Wood	391	283	54.5	39.3
Bescot	42	31	5.3	4.0
	135	112	11.3	13.2
		152	4.0	4.5

Trade Effluent Charges

A charge for reception and conveyance of the trade effluent in the local authority sewer and for its treatment and disposal in admixture with sewage at the Authority's works is made. The charge is related to the basic cost of treating sewage at the date of issue of a Consent or Direction and to the average analysis of the trade effluent in the particular period. In some cases where the calculated charge is low a minimum charge is levied.

The table on page 7 gives the proportion of the total charges levied on behalf of the constituent authorities and the Authority in the agency areas for three consecutive 6-monthly periods up to 30th September 1971. The total volumes charged and the average charge levied per 1,000 gallons are also shown.

Other useful statistical information is derived from the 6-monthly charging period returns for the agency areas. Actual flows of trade effluent can be compared with the maximum consented volume. Each is expressed as a percentage of the average sewage works flow. The actual volume excludes minimum charge firms for which volume

information is not available. However in view of the rising cost of trade effluent treatment there is a progressively less significant daily volume falling within the minimum charge schedule. This insignificance is enhanced by the intermittent nature of such discharges. The daily consented volume includes the minimum charge consents in the most recent period quoted.

The charging classification facilitates the allocation of numbers of discharges and the consented and actual volumes in the main groups of effluent. In the tables this is shown in classes 1-7 appropriate to the original charging scheme which was effective for most discharges in the agency areas until 1st October 1970.

Individual discharges are also compared on average against the permitted maximum daily consented volume. The number of discharges exceeding volumetric limits is shown for each category of effluent. The excess volume is offset by discharges made within the volumetric limits of consents and only in the case of three sewage works is the total consented volume exceeded on average. Special circumstances account for these cases.

In the following table summarising the consented and actual flows of trade effluent to the various Authority sewage works in three successive 6-monthly periods all flow rates are given in 1,000's of gallons per day and volume in 1,000's of gallons:

Sewage Works		Consented Daily Trade Effluent						Actual Daily Trade Effluent					
		Period 1		Period 2		Period 3		Period 1		Period 2		Period 3	
		Vol.	%	Vol.	%	Vol.	%	Vol.	%	Vol.	%	Vol.	%
Name	Average Daily Flow	3,870	5.3	3,870	5.3	3,984	5.4	3,432	4.7	3,319	4.6	3,079	4.2
Minworth	73,500	490	3.9	489	3.9	493	3.9	740	5.8	567	4.5	692	5.0
Coleshill	12,700	684	10.9	669	10.6	731	13.2	592	9.4	617	9.8	618	9.8
Ray Hall	6,300	2,061	24.0	2,030	24.0	2,107	24.8	1,687	19.9	1,522	17.9	1,245	14.7
Brockhurst	8,500	201	7.0	201	7.0	273	9.4	90	3.1	67	2.3	62	2.1
Barston	2,900	905	45.2	919	46.0	965	48.3	594	29.8	536	26.8	421	21.5
Toll End	2,000												
Roway Lane	3,100	595	19.2	597	19.2	885	28.5	352	11.3	405	13.1	669	21.6
Walsall Rd.	2,300	406	17.8	424	18.2	435	18.9	361	15.8	409	17.8	415	18.0
Goscote	2,900	67	2.3	68	2.3	85	2.9	66	2.3	80	2.8	67	2.3
Lunt Rd.	3,000	425	14.2	425	14.2	445	14.8	375	12.5	340	11.3	327	10.9
Barns Lane	11,000	340	30.9	346	31.5	223	20.3	163	14.8	144	13.0	118	11.7
Watery Lane	1,800	362	20.1	386	21.4	386	21.4	165	9.2	178	9.9	160	8.9
Bentley Lane	1,100	51	4.6	51	4.6	51	4.6	152	13.9	150	13.6	143	13.0
Tividale	800	60	7.5	60	7.5	68	21.0	13	1.6	15	1.9	23	2.9
Tipton Rd.	720	110	15.3	110	15.3	71	9.9	391	54.5	391	54.5	283	39.3
Foxyards	800	42	5.3	42	5.3	42	5.3	42	5.3	31	3.9	32	4.0
Walsall													
Wood	850	145	17.1	145	17.1	161	19.0	96	11.3	134	15.8	112	13.2
Bescot	3,400	149	4.4	149	4.4	163	4.8	135	4.0	119	3.5	151	4.5

Period 1 — April 1969 to September 1969
 " 2 — October 1969 to March 1970
 " 3 — April 1970 to September 1970

In the following table the previous total consented and discharged volumes are subdivided into volumes attributable to classes 1-7 in the 3 successive periods. The total number of discharges giving rise to the flows are shown together with the number of discharges exceeding volumetric limits on average.

Sewage Works	Class 1			Class 2			Class 3			Class 4			Class 5			Class 6			Class 7			
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	
Minworth	333	261	201	227	272	230	1,611	1,499	1,683							6.4	9	—	1,255	1,278	965	A
	114	105	134	187	196	160	2,178	2,178	2,225							15	15	—	1,376	1,376	1,366	B
	13	13	15	11	11	13	18	18	16							1	1	—	6	6	7	C
	9	9	7	5	5	2	7	6	4							0	0	—	0	1	1	D
Coleshill	328	207	233	380	335	377	14	14	11										18	16	11	A
	210	190	120	230	260	330	18	2.9	14										32	25	25	B
	1	3	3	2	2	2	2	1	1										2	1	1	C
	1	1	1	2	2	1	0	0	0										0	0	0	D
Ray Hall	66	79	79	25	24	38	285	303	290			15	37	43	38	11	7	4	168	161	156	A
	77	75	75	33	33	57	279	271	227			21	99	94	50	35	35	35	161	161	146	B
	6	5	6	8	6	8	17	15	13			1	6	5	6	1	1	1	15	16	16	C
	3	3	4	2	0	2	7	7	5			0	0	0	1	0	0	0	4	4	7	D
Brockhurst	450	399	266	45.1	51	36	890	787	769				5	2	122	122	127	9	175	156	43	A
	582	535	443	43	47	46	1,106	1,083	1,076				4	5	205	155	195	7	171	164	141	B
	9	9	10	7	8	8	28	26	26				2	2	3	4	4	3	18	16	15	C
	4	3	5	4	5	1	8	10	8				0	0	1	1	3	1	5	5	4	D
Barston	50	40	51	6	2	2	31	21	3										3	4	6	A
	88	88	89	10	10	10	100	100	114										3	3	3	B
	4	4	5	1	1	1	1	1	2										3	3	3	C
	0	0	0	0	0	0	0	0	0										0	2	2	D

(Continued overleaf.)

Sewage Works	Class 1			Class 2			Class 3			Class 4			Class 5			Class 6			Class 7			
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	
Toll End	102	168	122	166	86		206	181	188				17	17	21	14	15	10	89	69	80	A
	426	475	483	161	161	161	191	189	184				51	51	51	8	4	4	68	68	73	B
	4	7	7	2	1	1	6	6	6				1	1	1	1	1	1	7	8	8	C
	3	3	4	2	0	0	4	3	4				0	0	0	1	1	1	3	2	4	D
Roway Lane	71	64	66	19	15	13	131	146	489				59	82		20	22	31	52	76	70	A
	60	62	64	11	11	11	237	237	723				200	200		17	17	17	70	70	64	B
	9	10	9	2	2	2	5	5	8				1	1		1	1	1	4	4	4	C
	4	6	4	2	1	1	2	2	4				0	0		1	1	1	1	3	2	D
Walsall Road	4	6	4	22	17	24	274	342	293				4	1	19	50	34	32	7	9	2	A
	11	17	8	23	23	42	313	335	311				5	5	5	48	49	48	6	6	1	B
	2	3	3	4	4	5	16	17	13				1	1	1	2	2	1	1	2	1	C
	0	0	1	2	2	1	5	6	7				0	0	1	2	0	0	1	1	1	D
Goscote	28	40	27	26	26	28	4	5	6							7	8	4	1	1	2	A
	42	40	41	13	13	13	3	3	3							9	9	9	2	2	2	B
	3	3	3	1	1	1	1	1	1							1	1	1	2	2	2	C
	1	2	0	1	1	1	1	1	1							0	0	0	0	0	0	D
Lunt Road	20	21	24	11	10	10	236	202	178				42	34	51	30	44	47	37	29	17	A
	22	22	22	12	12	12	241	241	262				48	48	48	74	74	74	28	28	19	B
	3	3	3	4	4	4	3	3	4				1	1	1	2	2	2	7	7	5	C
	2	1	2	1	1	1	2	2	1				0	0	1	1	1	1	4	3	1	D
Barns Lane	76	65	46	53	46	32	27	26	32										7	7	8	A
	229	233	90	75	75	73	31	33	48										5	5	6	B
	1	2	1	2	4	3	4	5	6										2	2	2	C
	0	1	0	2	2	1	2	2	4										1	2	2	D

(Continued overleaf.)

Sewage Works	Class 1			Class 2			Class 3			Class 4			Class 5			Class 6			Class 7			
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	
Watery Lane	6	5	—	3	2	8	—	—	12	3	18	3	—	3	—	153	150	137	—	—	—	A
	6	6	—	10	10	34	—	—	35	3	3	3	—	3	—	216	216	216	—	—	—	E
	1	1	—	1	1	2	—	—	1	1	1	1	—	1	—	1	1	1	—	—	—	C
	0	0	—	0	0	0	—	—	0	0	1	0	—	0	—	0	0	0	—	—	—	D
Bentley Road	3	4	5	148	142	135	1	4	3													A
	3	3	3	47	47	47	2	2	2													B
	1	1	1	2	2	2	1	1	1													C
	0	1	1	1	1	1	0	1	1													D
Tivendale				—	—	—	13	15	14				—	—	9							A
				—	—	100	60	60	60				—	—	5							B
				—	—	1	1	1	1				—	—	1							C
				—	—	0	0	0	0				—	—	1							D
Tipton Road							372	372	260										19	19	23	A
							100	100	100										10	10	11	B
							2	2	2										1	1	3	C
							2	2	2										1	1	3	D
Walsall Wood				11	9	7	81	123	102										3	2	3	A
				5	5	5	138	138	137										2	2	2	B
				1	1	1	4	4	3										1	1	1	C
				1	1	1	1	2	1										1	0	1	D
Foxyards	12	11	7																30	20	25	A
	25	25	25																17	17	17	B
	1	1	1																2	2	2	C
	0	0	0																2	2	1	D

(Continued overleaf.)

Sewage Works	Class 1			Class 2			Class 3			Class 4			Class 5			Class 6			Class 7			
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	
Hescot	13	11	11	37	22	38	39	42	64				8	9	9				38	35	30	A
	17	17	22	20	20	20	50	50	51				11	11	11				52	52	47	B
	2	2	2	1	1	1	1	1	2				3	3	3				2	2	2	C
	0	0	0	1	1	1	0	0	2				0	0	0				0	0	0	D

KEY

- A — Trade Effluent—Actual Average Daily Discharge 1,000 ga ls.
 B — Trade Effluent—Consented 1,000 galls.
 C — Total Nos. of Discharges.
 D — Nos. exceeding Consent.

CLASS KEY

1. Organic discharges of lower strength than average sewage. e.g. food, milk and brewery wastes.
 2. Non-ferrous metal wastes. e.g. Acid Pickling, Anodising, metal pretreatment.
 3. Non-ferrous metals and cyanides. e.g. Electroplating.
 4. Cyanide wastes. e.g. Cyanide hardening, chemical industry.
 5. Ferrous Pickling.
 6. Galvanizing.
 7. Waste where special limits are applied. e.g. Strong organic wastes, toxic chemicals.

Pretreatment of Effluents

A most important part of trade effluent control is that of bringing to the notice of management the importance of pretreating effluents so as to conform with consent conditions.

This may involve the installation of very elaborate and costly equipment and much negotiation takes place to ensure that the industrialist makes adequate provision and deals with all aspects of the problem.

The range of plant already installed varies according to its age. Since this is a rapidly expanding field of technology, new techniques and equipment are constantly being developed and introduced.

It is considered that the older plant, adequate perhaps to minimise the effects of strong discharges may not now be capable of the precise control which besides ensuring continuous compliance with standards ought to have economic importance for management in helping to minimise the waste disposal problem.

Where new premises are proposed the provision of appropriate drainage and plant is negotiated at the planning stage and in conjunction with an application for consent.

The following table gives the position regarding pretreatment plant within the agency areas.

Details of Plant	Constituent Authority Areas										
	a	b	c	d	e	f	g	h	i	j	Total
Full Treatment Plant capable of meeting standards	6	1	3	3	3	4	4	15	14	19	65
Partial Pretreatment Plants upgraded to meet standards				1							
Partial Treatment Plants meeting standards ..	4	1			2	4	4	17	13	16	61
Partial Treatment Plants not meeting standards ..	2			2		1	1	4	3	12	25
Schemes in Negotiation	1			2		1		13	2	3	22
Water Recycling schemes introduced ..	2			1		1	1	4	3	1	13
Pretreatment to protect sewer or optionally reducing strength ..	1	1		1	1	2	1	7	3	10	27

KEY (a) Aldridge-Brownhills (b) Bromsgrove (c) Direct Discharge (d) Dudley (e) Meriden (f) Solihull (g) Sutton Coldfield (h) Walsall (i) Warley (j) West Bromwich

Composition of Trade Effluents

Samples of trade effluent discharges are taken at intervals throughout the year either by or on behalf of all constituent local authorities within the drainage area and submitted for analysis at the Authority's Newhall Street laboratories.

The following schedules give a statistical summary of the analysis carried out in two complete years. All the Birmingham samples relate to the Minworth-Yardley Works. In each of the other areas samples are allocated to sewage works drainage areas and a works summary is also given.

During the two year period under review legal proceedings were taken on the recommendation of the Authority, against 3 firms in respect of 42 offences. Convictions were obtained in all cases.

TRADE EFFLUENT ANALYSES

Authority	Total Number of Samples		Number of Trade Discharges	
	Period 'A'	Period 'B'	Period 'A'	Period 'B'
Birmingham	13,456	13,502	818	833
Aldridge/Brownhills U.D.	130	219	34	36
Dudley County Borough	72	123	12	16
Solihull County Borough	125	177	31	31
Meriden Rural District	16	27	10	13
Sutton Coldfield Borough	76	99	32	32
Walsall County Borough	827	924	174	187
Warley County Borough	440	677	97	107
West Bromwich County Borough	648	820	116	140
Bromsgrove R.D.C.	4	8	1	1
Direct Discharge	12	15	5	5
Wolverhampton County Borough	117	131	32	32
TOTAL	15,923	16,722	1,362	1,433

Sewage Works	Percentage of Samples Classified as Satisfactory	
	Period 'A'	Period 'B'
Minworth-Birmingham Area	71.0	70.1
Minworth-Agency Areas	61.2	66.9
Yardley	75.0	80.0
Coleshill	54.1	70.7
Ray Hall	63.3	66.9
Brockhurst	52.5	55.1
Barston...	80.6	77.7
Toll End	60.7	64.2
Roway Lane	60.0	70.9
Walsall Road	44.4	31.6
Goscote	45.2	54.8
Lunt Road	50.0	88.9
Barns Lane	32.3	51.0

(Continued Overleaf)

The colours show the stream water quality in terms of the average ammoniacal nitrogen content. Other data given includes the biochemical oxygen demand, the minimum recorded dissolved oxygen, the biotic index and the character of the fishery at selected sampling points.

