EPA-600/5-74-030
September 1974

AN EVALUATION OF MARKETABLE EFFLUENT PERMIT SYSTEMS

By

Russell J. deLucia

Contract No. 68-01-1882
Program Element No. 1BA030
ROAP 21AXN06

Project Officer
Dr. Marshall Rose
Washington Environmental Research Center
Washington, D. C. 20460

Prepared for
Office of Research and Development
U. S. Environmental Protection Agency
Washington, D. C. 20460

ABSTRACT

This report is a study of the practical problems and prospects of using marketable effluent permits (MEP) as a water pollution control tool. Under such a system, pollution rights are contingent upon possession of permits; the permits are acquired and/or traded through an auction or market. This study details the requirements of MEP systems, discusses their theoretical advantages, and examines them through the use of industrial organization theory, comparisons with analogous markets, and a simulation model. The simulation model employs Mohawk River data to determine the effect of different system parameters on the operation of a MEP system. The legal and administrative aspects of the marketable permit system are also dealt with. The conclusion is that marketable permits are a promising control tool for many river basins.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLES

FIGURES

PREFACE

Water pollution legislation at the national level has reflected the increasing demand for clean water that is evident today in the United States. Water pollution control has progressed from a health-motivated activity to one directed at the enhancement of national water resources for recreational and aesthetic purposes. The most recent legislation, the 1972 Amendments to the Federal Water Pollution Control Act (hereafter referred to as the "Amendments" or the "1972 Amendments"), is designed to reduce significantly the discharge of pollutants into waterways with the complete elimination of discharges as the ultimate goal of the legislation.

The idea of establishing a market to assist in the control of pollution has been discussed by economists and others[1] as a possible alternative to non-market control measures, such as quantitative effluent standards. Under the economist's standard assumptions concerning the workings of the marketplace, a market in pollution discharge permits can be shown to have many desirable properties, including the ability to allocate waste treatment efficiently among polluters.

This report is a study of the practical problems and prospects of using marketable effluent permits as one method of implementing the 1972 Amendments. The purpose of the study is to examine the efficacy of a market-oriented system of water pollution control by raising and examining the important questions surrounding the use of such a system. This is done below. Ultimately, however, the ability to predict whether and how well a new market will perform depends on the assumptions that one makes. Indeed, the analysis here of the probable strengths and weaknesses of a market in pollutants depends critically on the relevance of the economist's paradigm and its implications about the behavior of market participants. Perhaps the strongest argument in favor of the use of a market in discharge rights is that the economist's allegations concerning the workings of the marketplace remain untested in pollution control in the United States, while many other ideas have been tried and found wanting.

NOTES

[1] E.g., J. H. Dales, Pollution, Property, and Prices (Toronto, 1968).

Section 1

Introduction

Framework for the Study

This study examines the possibility of using a marketable effluent permit (MEP) system as a water pollution control tool. A marketable effluent permit system is any one of a number of control schemes in which (1) waste discharges are prohibited unless the polluter holds permits providing the requisite authorization and (2) those permits are acquired through a market transaction. Stated somewhat differently, a MEP system is a control system in which (1) polluters can discharge wastes if and only if they hold a permit (or permits) from the regulatory authority and (2) the effluent permits are bought, sold, leased, rented, or in any way traded by the participants (polluters, regulatory agency, and others) of the system. This definition is a broad one which includes, for example, control systems in which the regulatory agency sells permits by auction to polluters, as well as systems in which buying and selling of permits among polluters is sanctioned. Several different MEP systems can be distinguished depending on the kinds of market transactions that are allowed, the pollutants that are covered, the participants included in the system (e.g., municipalities and industrial firms), etc. The primary question addressed in this report is whether a well-designed MEP system can be used to help implement the provisions of the Amendments to the Federal Water Pollution Control Act.

The first comprehensive national water quality legislation was the Federal Water Pollution Control Act of 1948. The Act has been amended several times, most recently with the Amendments of 1972. Under the 1965 Amendments states were required to establish water quality standards for interstate and coastal waters and to formulate implementation plans for achieving those standards. Any discharge which reduced the quality of the receiving water below the established standards or that was in violation of the implementation plan was subject to enforcement action. In 1970, difficulties in enforcing the provisions of the Act led the Department of the Interior (which was at that time responsible for administration of the water pollution control program) to invoke the Refuse Act of 1899 (Section 13 of the River and Harbor Act) as the legal mandate to control waste discharges.

The Refuse Act prohibits the discharge or deposit of wastes into navigable waters and their tributaries unless authorized by a permit from the Secretary of the Army. Enforcement measures including civil and criminal penalties are provided to help enforce the provisions of the Act. Starting in 1970 the Army Corps of Engineers received applications from dischargers for permits, determined the effect of the proposed discharges, and formally issued a permit to the polluter. The Environmental Protection Agency (EPA) reviewed applications and advised the Corps as to whether to issue a permit. This process proved cumbersome, and was slowed even further when the Corps was enjoined from issuing permits by a United States District Court judge. The injunction was based on two grounds: (1) the Refuse Act provides for permits only for navigable waters and not their tributaries (even though the Act prohibits waste discharges into both); and (2) the Corps was found to be in violation of the National Environmental Policy Act which requires an impact statement covering the water quality aspects of Refuse Act permits.

The stated goal of the 1972 Amendments is the elimination by 1985 of the discharge of pollutants into navigable waters. The emphasis of the new law is on effluent limitations, although stream standards are to continue to play a role in water quality management. At the time the 1972 Amendments became law, the Corps was still enjoined from using the Refuse Act permit program. The Amendments terminate the use of prior enforcement mechanisms, including the Refuse Act permit program and the use of enforcement conferences, and in their place establishes a National Pollutant Discharge Elimination System (NPDES).

The specific control goals set by the 1972 Amendments are:

1. the application by industrial sources of best practicable control technology currently available by 1977 and of best available technology economically achievable by 1983;

2. the application by municipalities of secondary treatment by 1977 and of the best practicable waste treatment technology by 1983;

3. the achievement of water quality standards by 1977.

Under the terms of the Act, the EPA is to identify the degree of effluent reduction attainable through the application of best practicable control and best available technology in terms of amounts of the chemical, physical, and biological constituents of pollutants. Best practicable treatment has been interpreted by the EPA to be a process providing percentage waste removals similar to those effected by the secondary treatment of biological wastes (approximately 85 percent). The goals of the Amendments for 1983 have yet to be translated by EPA into specific effluent limitations.

The 1972 Amendments do not ignore the concept of water quality standards in attempting to achieve the 1977 and 1983 goals. The water quality standards which were adopted under the prior versions of the Federal Water Pollution Control Act are continued in effect and can be updated by states. New standards are to be established where they were not previously adopted by the states. If water quality standards cannot be met by the 1977 effluent limitations, then more stringent limitations must be adopted by that date. Thus the effect of the Amendments is to require the achievement of best practicable technology and secondary treatment by 1977, plus further effluent limitations in those cases where water quality standards are endangered.

For this study the 1977 regulations concerning effluent limitations and water quality standards are assumed to be a requirement all polluters must meet. Thus, industries are constrained to achieve best practicable treatment levels (as defined by EPA) by 1977; similarly municipalities must achieve secondary treatment levels by that date and water quality standards must be met.

The evaluation in this study of the marketable effluent permit system is made on the basis of economic efficiency, administrative and enforcement requirements, equity, and legal and political feasibility. The MEP system is measured against these criteria and is compared with other control alternatives to determine its relative strengths and weaknesses for use as a tool to implement the 1972 Amendments.

Criteria for Evaluation of the MEP System

As stated above, the purpose of this study is to evaluate the effectiveness of the marketable effluent permit approach in achieving the goals of the 1972 Amendments. "Effectiveness" refers to the relative efficiency, the ease of administration and enforcement, the degree of equity, and the legal and political feasibility of the control method.

The efficiency of the MEP method is measured in terms of direct resource costs of waste treatment that are expended to attain the goals of the Amendments. Under these terms of reference, the most efficient method to achieve a stated goal, for example, a given ambient water quality standard, is to allocate treatment requirements among dischargers in a manner that minimizes the total resource costs of pollution control. This is the least cost configuration of waste treatment, and is used here as a standard against which to measure the efficiency of different control methods.

The administrative and enforcement properties of the MEP system are not as easily evaluated since there is no standard measure of performance. The best that we can do is to attempt to outline the administrative and enforcement requirements of the system's operation. Those requirements can then be compared with the corresponding requirements of other methods of water pollution control.

Equity is perhaps the most difficult of all of the criteria to define. One important factor is the equal treatment of equals--uniform regulations imposed on dischargers in similar situations. The difficulties, however, are in defining what is meant by "similar situations" and in comparing dischargers who are not in similar situations. The measures that we focus on in this report are the per capita costs for municipalities and the distribution of costs for different industries. This report draws conclusions based on these measures as well as on the subjective evaluation of the extent to which the control system presents the appearance of equity to participants.

The legal feasibility of the control method refers to matters regarding its constitutionality, the extent to which changes in legislation are required, and the legal difficulties likely to be encountered in implementing the control method. The political feasibility of the control system has to do with the likelihood of its being acceptable to the general public, the administrative and legislative bodies involved in its implementation, and the dischargers who will be under the regulations of the system. This is related to both the equity and the legal feasibility of the system and is perhaps the most subjective of the criteria that are used in this study.

Organization of the Report

The present introductory section of this report, Section 1, is followed by the detailed examination of the MEP system in Sections 2 through 7. In Section 8 the results from earlier sections are evaluated, the MEP system is compared with other control alternatives (in particular, the effluent charge system and the NPDES), and some aspects of implementation are discussed.

Section 2, which follows below, is a detailed look at the variants of the MEP system. For example, the question of what pollutants to include under this control system is discussed and tentative conclusions are presented. Wherever possible, logical choices among variants of the system are made in Section 2. In many cases the viability of the MEP system does not rise or fall on the basis of the resolution of such questions; nevertheless, their tentative resolution allows the discussion in the following parts of the report to be better focused.

In Section 3 the theory of the MEP system is discussed. The material in that section is based on the standard theorems of microeconomics theory. In addition, theoretical work on externalities and on systems of emission rights is reviewed.

Section 4 is drawn from the theory of industrial organization. The concepts of workable competition are applied to the MEP system to attempt to discover potential problems of the effluent permit market.

Markets and auctions analogous to the MEP system are described in Section 5. The Treasury bill market, the offshore oil leasing auction, and the market for taxi medallions are examined to find information relevant to the workings of the MEP system.

In Section 6 the results of the Mohawk River effluent permit system simulation are presented and analyzed. Variants of the MEP system were analyzed with a computer simulation model. The data base used for the model is the upper Mohawk River basin. Responses of the polluters in that basin to a MEP system are estimated with the computer simulation model.

The legal and administrative aspects of the MEP system are treated in Section 7. The discussion there includes constitutional, tax, and legislative issues, as well as related administrative matters. The costs of administering the MEP system are compared in Section 7 to those of other control systems.

Section 2

The Marketable Effluent Permit System

In the marketable effluent permit system a regulatory authority issues effluent permits authorizing the discharge of certain pollutants in amounts that depend on the receiving waterway and the desired stringency of pollution control. The key to the system is reliance on a market-related allocation method. As we elaborate below, several variants of the marketable effluent permit system are possible; for one to which we give prime consideration, permits are distributed to dischargers through a combination direct allocation system and a Dutch auction system. Subsequent to the initial distribution, holders of permits may buy and sell them through a regulated market. Permits can be bought and sold by industries, municipalities, and anyone else with an interest in obtaining the discharge rights inherent in the possession of the effluent permit.

An example is helpful in order to establish the nature of this control system. Suppose that there are fifteen different dischargers located along a given waterway. Under the MEP system, the regulatory authority determines the number of effluent permits to issue as a function of the nature of the waterway and the water quality goals. If the goal is to achieve a given level of dissolved oxygen concentration, then the permits are designed to meet that requirement. Each permit would authorize the holder to discharge one pound per day of BOD into the waterway, and the number of such permits issued by the authority would depend on the desired water quality. To account for the differential impact of different polluters on the water quality, permits would be worth different amounts (of waste discharges) to different polluters.

The unique characteristic of the marketable effluent system is that the ultimate allocation of the permits depends on a market type transaction. For example, the permits may be originally sold to bidders in a Dutch auction (described below) or in an auction in which permits are distributed to the highest bidders until none remain. No matter what system is employed for the initial distribution of the permits, there still remains the possibility of employing a market for their subsequent allocation among participants in the system. A market, similar to markets for stocks and bonds, can be established in which participants can buy and sell them. Thus an industrial firm desiring to enter a river basin region would use the market to purchase the effluent permits necessary for the operation of its plant. The entering firm would be required to bid the price of the permits up enough to induce one or more of the permit holders to sell the requisite number of effluent permits.

The efficiency properties of markets are well-known. The use of a market for effluent permits presents each polluter with an option: reduce waste discharges or buy permits authorizing those discharges. The polluter is continually faced with the opportunity to increase waste discharges by purchasing additional permits or to reduce discharges by selling the excess permits. Thus, the price of the permit in the market creates an incentive for the polluter, just as the effluent charge does. A cost-minimizing polluter will treat wastes (and sell excess permits) up to the point at which the marginal cost of waste discharge reductions equals the price of a permit.

This has two desirable effects. The first is that each polluter has a continuing incentive to seek ways further to reduce discharges. The second is that the market assures that the marginal costs of waste control are the same for different dischargers. If the costs to each discharger of eliminating the last unit of wastes are the same, then there are no opportunities to achieve the same total (river basin effluent) discharge reduction at a lower total cost.

The MEP system has other desirable attributes including (1) indicator properties, (2) the ability to deal with the growth and entry of polluters, (3) adjustment simplicity, (4) effectiveness, and (5) equity properties. These can be quickly summarized.

The indicator properties of the MEP system arise as in any market: the price equals the marginal value of the commodity to the market participants. Thus, the price of the permit is an indicator of the marginal value of the permit to polluters; consequently, for cost-minimizing polluters, the price of a permit gives the marginal cost of reducing waste discharges.

The growth and entry of polluters is handled naturally and effectively in the MEP system. Increasing waste discharges, through either entry or growth, is allowed only upon the acquisition of effluent permits. Thus, the polluter (or aspiring polluter) must enter the market for effluent permits and induce other dischargers to relinquish some permits. This assures that the total discharges into the basin remain the same and, further, that the entering or growing polluter is forced to take account of the marginal costs of waste treatment that growth imposes on the river basin system.

As with the effluent charge, an adjustment in the control level for the river basin can be made simply and impersonally with the MEP system. When permits expire, the regulatory authority can reduce the total amount of outstanding permits by issuing fewer. More importantly, the regulatory authority has the opportunity to buy permits on the open market and to retire them. Neither of these procedures is excessively complicated administratively and either can be accomplished impersonally without devising different rules and procedures for different polluters.

By providing a continuing incentive for waste reduction, the effluent permit promises to speed waste discharge reductions. Additionally, the market provides an orderly and impersonal way in which discharge privileges are allocated. Since the alteration of the pattern of discharge reductions takes place through the actions of the market rather than through administrative procedures, there are fewer opportunities for polluters to postpone compliance.

Finally, the MEP system has two desirable equity characteristics. First, the allocation of permits and discharge privileges is made through the market. Each polluter must pay the same amount--the market price--for increasing waste discharges. Thus, in a very basic sense, equals are treated equally. Second, the MEP system provides a good deal of flexibility with regard to the distribution of the costs of pollution control. By subsidizing the purchase of permits (in a way that, as is discussed later, enhances the efficiency properties of the market) by municipalities, the costs to cities can be kept down. In addition, the initial allocation of discharge permits need not be made via the market. The MEP system can function effectively even if permits are initially given to polluters. This provides the regulatory authority a means of influencing the distribution of costs among polluters.

Many different variants of the MEP system are possible. The complete specification of a MEP system would include the following elements:

1. the method of initial distribution of the permits;
2. the pollutants or ambient conditions covered by the permits (permits could be issued with reference to particular pollutants or with reference to particular ambient conditions);
3. the term and amount of the permits, i.e., the specification of the time period during which they are valid and the rules for the issuance of additional permits or the retirement of extant ones;
4. the eligibility requirements for holders of permits and the kinds of pollution sources to be included;
5. the relation of the pollution controls to hydrologic and other seasonal variations in water conditions:
6. the trading rules and procedures of the market;
7. the methods of monitoring discharges, enforcing compliance to the discharge limitations, and enforcing compliance to the other rules of the market;
8. the relation of the permits to the NPDES and to the federal and state grant programs for wastewater treatment;
9. the choice of basins to be included on the system and the definition of the physical boundaries of the water basin:
10. the use of monies collected and the source of money for the administration of the system; and
11. the administrative machinery for the MEP system.

These aspects of the MEP system are discussed below.

The Method of Initial Distribution

The way in which the effluent permits are initially distributed is of crucial importance and, in fact, is the very crux of some MEP systems. The option is either to sell the permits or to give them away. If they are sold, the question remains how the sale is effected: if they are given away, the question is to whom and in what amounts.

Effluent permit systems can be categorized in accordance with the following matrix:

Initial Distribution.	Trading Permitted	Trading Prohibited
Sale	I	II
Direct Allocation	III	IV

Under our broad definition of the MEP system, regulatory methods of types I, II, and III are all marketable effluent permit systems. In each of these types of systems effluent permits are distributed and, in types I and III, are subsequently traded among participants using a market (an auction, trading procedure, or the like). Effluent permit systems of type IV are not MEP systems; NPDES is a type IV system.

Under type III effluent permit systems, the initial allocation of permits is determined on the basis of criteria other than market bids. One possible variant of this approach is to give permits to each discharger for a given proportion of the discharger's current waste load. For example, if the total waste load for the waterway is initially 200 units per day, and the authority determines that this load should be reduced to 100 units per day, then each of the existing dischargers might be issued permits authorizing discharges equal to one-half of their current loads. If subsequent trading of the permits is allowed through a market system, this control system will share most of the desirable efficiency properties of the MEP system. In that case as Montgomery[1] shows, the only effect of the direct allocation of effluent permits is to affect the allocation of costs among different dischargers.

In the type I and type II systems, the initial distribution of the effluent permits is through a sale or an auction. The two procedures that we consider here are the so-called Dutch auction system and an English auction system of the sort used by the government to sell Treasury bills. In both auction systems the regulatory authority first publicizes the characteristics of the permits--their term, the amount of pollution discharges authorized, and any other relevant facts. In the Dutch auction system the authority announces a relatively high price and invites orders for permits at that price. If the number of the orders is insufficient to absorb the entire issue, all orders are voided, a lower price is announced, and the process begins again from scratch. Ultimately, a price is reached at which all of the available permits are sold.

In the Dutch auction system the orders for permits submitted by individuals at the announced price are binding on those individuals; they are obligated to receive the number of permits they apply for and to pay the announced price. In contrast, the government has the right to cancel the offering price and void the extant orders if the total number of permits ordered falls short of the total number offered by the authority. In this case the authority lowers the price and repeats the auction procedure. The purchasers of the permits can have no complaints if this occurs. It is as though they are told that (1) their present order for permits will be filled at a price lower than the one they expected, and (2) if they want to order additional permits they may do so.

It is possible to operate the Dutch auction in a one-step procedure by asking for a schedule of orders rather than for one order at a time. Thus, for example, a polluter's order for permits received by the authority would state the total amount of permits that the individual wished to purchase at each of several different prices. Table 2-1 gives such a schedule. This particular order for permits would obligate the buyer to purchase 15,000 permits if the price is $10, 20,000 permits if the price is $8, and so on. Using this demand schedule along with all of the others submitted by potential buyers, the authority can determine the price at which the market clears, i.e., the price at which the prespecified

Table 2-1

Hypothetical Order for Permits for

a Dutch Auction

Price of Permits	No. of Permits Ordered
$ 2	50,000
$ 4	34,000
$ 6	26,000
$ 8	20,000
$10	15,000
$12	13,000

total number of permits can be sold. The permits are issued and distributed according to that price.

A second possibility for an auction market is the English auction similar to the one operated every Monday for the sale of United States Treasury bills. Under this system, blocks of permits are auctioned off one at a time until the total supply of permits is exhausted. For example, if 100,000 permits are to be sold, they could be sold in blocks of 100 at successively lower prices until all 100,000 are sold. This method appears to be inferior to the Dutch auction for at least two reasons.

First, under the Dutch auction, each of the participants in the market is assured of obtaining all of the permits ordered at the price that is finally established in the market. In contrast, there may be frustrated orders in the English-type auction. This can encourage the submission of bids that are based on gaming approaches to the auction, rather than bids that represent the true value of the permit to the polluter. For this reason the English auction may lead to a less efficient allocation of waste treatment than the Dutch auction.

Second, in the Dutch auction every bidder obtains the permits at the same price. This has the appearance of equity. In contrast, the English auction system discriminates among different buyers. Different buyers pay different amounts for the permits in accordance with their bids.

One of the supposed advantages of the English-type auction system is that the revenues from the sale of the permits are higher than under the Dutch system. This, however, may not be the case. Due to the expectations and bidding behavior of different market participants, revenues under the English system may actually turn out to be lower. This is discussed further in Section 5.

In the event that the regulatory authority wants to issue or retire some of the effluent permits, or in the case where a new or existing discharger makes increased demand for waste load discharges, a type I or III system is vastly superior to a type II MEP system. In both the type I and type III systems, there is a market for buying and selling permits that is maintained over time and that allows adjustments to changes in the river basin system or in the stringency of regulatory controls. The type II system performs the initial allocation chore among dischargers in an efficient manner, but it lacks the highly desirable dynamic qualities of the type I or type III system.

Suppose, for example, that a new industrial firm desires to enter the riverway. Under the type II MEP the authority must set aside some assimilative capacity for such a contingency. If this assimilative capacity is then sold to the entering firm, there is no assurance that the efficiency properties of the system are maintained. In contrast, in the type I and type III systems, the entering or growing discharger is required to participate in the market for effluent permits in order to increase waste discharges. This assures that the allocation of waste treatment chores among polluters is maintained in a reasonably efficient configuration. Provision for the automatic handling of the growth of the river basin is one of the most appealing and outstanding characteristics of the MEP system and is a compelling factor in the rejection of the type II system in favor of types I or III.

Pollutants Included in the MEP System

Several factors are relevant to the choice of pollutants to be managed by the MEP system. Advantages of the MEP system include its efficiency and dynamic properties. Such advantages are significant only if there are substantial amounts of money involved in the control of the pollutant. The likelihood of maintaining an efficient market is greater if the market is large in terms of both numbers of players and money. An active and on-going market with ample participants is necessary in order to assure that a buyer or a seller can complete a trade without radically altering the market price. This condition, which assures that the market price is meaningful and that the market is effective, is more likely if the number of market players is large. This suggests that the marketable effluent permit system will work best in instances where (1) there are many polluters and (2) significant expenditures are anticipated for the control of the pollutant. Additionally there is little sense in operating a market if the object is the immediate and complete prohibition of the discharge of the pollutant or if the amounts of the "commodity" traded in the market cannot be easily measured. These considerations suggest that (3) the pollutant cannot be one that is completely prohibited and (4) the pollutant, its amount and its source must be easily identifiable.

Two measures of pollution that meet these criteria are biochemical oxygen demand (BOD) and biomass potential (BP). The concept of biochemical oxygen demand and the oxygen-sag phenomenon are well known and need not be discussed here. For cases in which dissolved oxygen is the ambient measure of water quality, BOD is perhaps the appropriate measure of waste input to employ. In contrast, the concept of biomass potential used here is not well known. It has only recently been defined and elaborated in "Effluent Charges: Is the Price Right?", a report prepared by Meta Systems Inc for the Environmental Protection Agency. The argument for and details of the use of BP as the measure of pollution are presented in that report. Here we present a brief summary of the definition and use of BP as a measure of pollution.

Most existing biological quality criteria were designed originally with reference to water potability. They relate to the control of waterborne disease and of tastes and colors in drinking water. The intent of BP is to provide a surrogate for needed biological and ecological parameters to measure water quality for recreation and aesthetic purposes. A useful quantitative measure of stream loading from municipal and industrial sources would be a parameter that indicates the extent to which substances in waste water distort the biological activity of streams beyond natural levels. Excess productivity can be correlated with the increment of biomass above that of the natural aquatic ecosystem.

The biomass or decomposition potential of a wastewater effluent, measured in either concentration units, milligrams per liter, or in units of material flux, pounds per day, may be quantified as follows:

$$\alpha BOD_5 + \beta N + \gamma P.$$

Here BOD_5 is the five-day BOD measured under standard laboratory conditons; N is total (organic or nitrate) nitrogen; and P represents biologically available phosphorus. The coefficients α, β and γ reflect the relative contributions of each constituent. While further research is needed to delineate these parameters precisely for many streams and lakes they may for practical purposes be taken as simple fixed constants. In the numerical computations of this study, biomass potential has been defined with $\alpha = 1.47$, $\beta = 4.57$, and $\gamma = 30$.

The impairment of a stream, pond, or lake by the discharge of degradable organics and nutrients can be conceived as a function of the concentration of added biomass potential, the mean residence time of nutrients, and the stream geometry which affects the rate of recycling of nutrient elements. Unlike the oxygen-sag formulation for determining stream assimilative capacity for aerobic stabilization, the relation determining the effect of BP on a waterway is essentially distance independent. That is, the stream impairment from BP is largely independent of the point of outfall of the discharge within a given segment. Consequently, the transfer coefficients that relate the amounts of discharges to their effects on a given segment of a waterway are essentially constant among different polluters if BP is taken as the parameter of pollution.[2]

The marketable effluent permits can be geared either to the amount of the pollutant entering the waterway without regard to any differences in the effects on ambient quality among dischargers, or the system can be designed to maintain particular ambient conditions. (In some cases--notably when BP is used as the measure of pollution--these two approaches are equivalent.) To illustrate the latter approach, assume that minimum standards for dissolved oxygen concentration have been set for each section of a tidal estuary. Then in order to maintain the specified quality profile of the estuary, the regulatory authority issues permits that specify the amount that the holder is authorized to discharge into the waterway. The holder of the permit is given the option of discharging into any section of the estuary, but the amount of the allowable discharge is dependent on the effect of the discharge on water quality and thus on the point at which the discharge is made. For example, if the effects of discharges into section 1 are twice as deleterious as discharges into section 2, then a permit might give the polluter the option of discharging 1 lb/day of BOD into section 1 or, alternatively, 2 lb/day of BOD into section 2.

This procedure can be described more completely with another example. Using the oxygen-sag formulation, the regulatory authority estimates a set of transfer coefficients d_{ij} which indicate the relative effects of waste discharges at different points on the waterway. The coefficient d_{ij} indicates the effect on the quality of section j of a one-unit discharge into section i. In the case of BOD, d_{ij} is the reduction in the dissolved oxygen concentration of section j which would result from a 1 lb/day increase in BOD discharges into section i. Now, if the goal is to maintain a specified water quality profile, then the authority must recognize that the effects of discharges on water quality are different for different discharge locations and formulate the effluent permits accordingly.

Suppose that there is only one critical section of the waterway, i.e., one section in which the quality standard is endangered. Growing and entering polluters are most likely to push the dissolved oxygen level in the critical section below the established standard. Consequently, the trading of permits among sections must be related to the critical reach. Suppose, for example, that waste discharges into section 2 have twice the impact on stream quality in the critical section as waste discharges into section 8. Under this assumption if section 5 is the critical section, then d_{25} would be twice as large as d_{85}. To be more specific, suppose d_{25} = 0.0002 ppm/lb-per-day and d_{85} = 0.0001 ppm/lb-per-day. Thus, for every pound per day of discharges into section 2 the dissolved oxygen' concentration falls 0.0002 ppm, and every pound per day discharged into section 8 lowers the dissolved oxygen concentration by 0.0001 ppm.

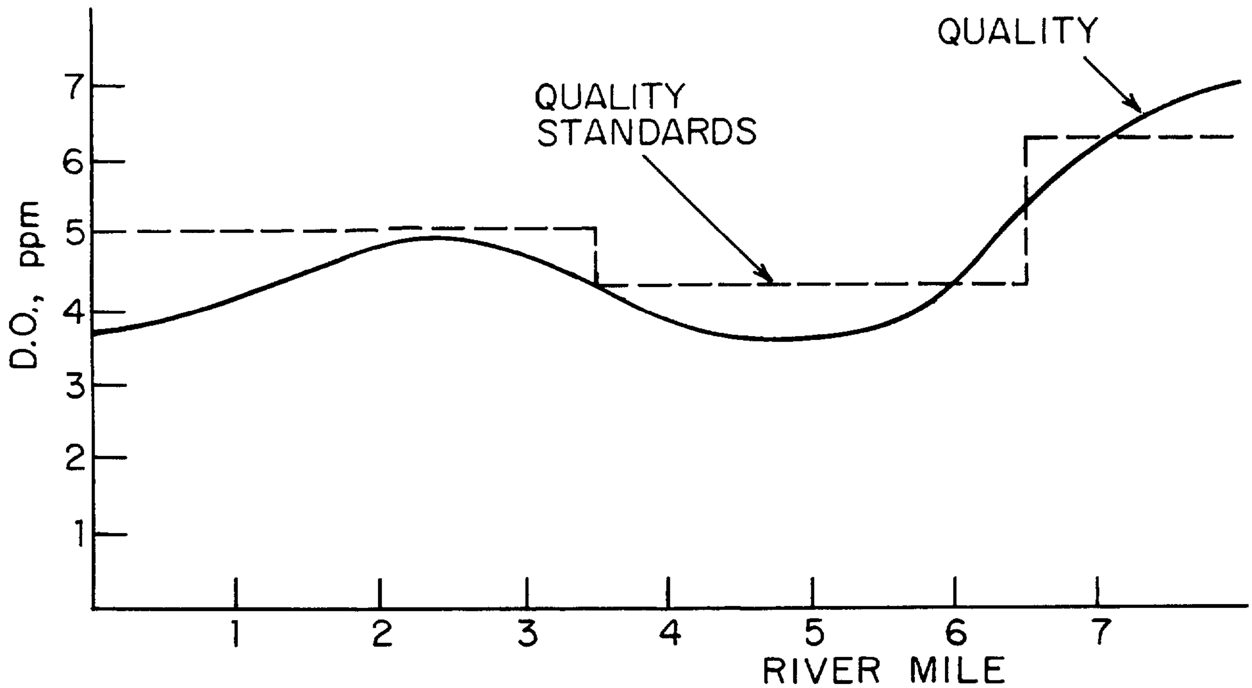
In the above example an exchange of discharge rights between sections 2 and 8 would alter the quality of the critical section 5. If one pound per day of waste discharges is transferred from section 8 to section 2, the increased discharge rate in section 2 will lower the section 5 DO level by 0.0002 ppm while the decreased discharge rate in section 8 will increase the section 5 DO level by 0.0001 ppm. The net effect is thus a 0.0001 ppm decrease in the DO concentration of the critical section. To avoid lowering the quality of the critical section, one-to-one trades of discharge rights must not be allowed. In this example an increase of one pound per day in the section 2 discharge rate must be accompanied by a decrease of two pounds per day in the section 8 discharge rate. The net effect on the DO level of section 5 is then nil.

A reformulation of the permit system can solve the problem of the differential effects on the critical section. Each permit can be designed to authorize different discharge rates for different discharge locations. In the above example, a permit would carry with it the right to discharge either one pound per day into section 2 or two pounds per day into section 8. Thus the transfer of the permit from section 8 to section 2 would not lower stream quality in section 5.

The most complicated case is one in which the permits are geared to the maintenance of ambient water quality, the transfer coefficients are not equal to one another, and there exists more than one critical section of the waterway. In this situation, the trade or sale of permits must account for more than one quality constraint. Such a case may arise if, as in Figure 2-1, the quality standards are different in different sections of the waterway. In such a system there exist market prices and permit supplies such that the different quality standards are met and the least cost situation is attained (see Section 3 of this report). For the situation of multiple quality constraints and multiple transfer coefficients, the permit system design is complicated. A system must be established to ensure that all trades and exchanges of permits maintain the water quality level at all critical sections of the

Figure 2-1

Quality Standards and Ambient Quality
for a Hypothetical River Basin



waterway. More than one quality constraint must sometimes be considered in setting the allowable trading ratios among dischargers.

Thus, gearing the MEP system to ambient standards results in a potentially more complicated system than if the goal is simply the control of a given amount of total discharges. In the presence of multiple trading ratio constraints the operation of the market by the regulatory authority in a fashion that would maintain stream quality standards may be so complicated as to obscure control from public scrutiny. This is not an insurmountable difficulty; indeed, it is possible to understand and to operate the system effectively in spite of multiple quality constraints and differential effects on water quality. However, the fact remains that the simpler the system, the better it is administratively as well as politically.

There are, however, other compelling arguments based on the intent and substance of the 1972 Amendments for the use of a control system geared only to the control of discharges and largely independent of the details of ambient water quality conditions. As is stated above in connection with the definition of biomass potential, new biological and ecological parameters are needed to measure water quality for recreation and aesthetic purposes. These parameters must, by the nature of the water quality goals, relate more to the total effects of the pollutants on the waterway system than to effects on specific quality parameters. Additionally, the emphasis of the 1972 Amendments is on effluent limitations, rather than ambient water quality. The goals of the bill clearly focus on the reduction and eventual elimination of discharges.

Within this context, it makes sense to design a control system that is centered on the reduction of discharges. This does not preclude the use of a MEP system prior to 1977, the date for which the water quality standards apply. Indeed, the use of such a control system can assist in the attainment of the quality goals. However, the system can best serve the attainment of the longer term goal of discharge elimination and should be designed with that in mind.

In the case of biomass potential the transfer coefficients are equal: d_{25} is the same as d_{85}. Thus the trading ratios among discharge locations are unity, and a market geared to the establishment of some specified level of ambient water quality is equivalent to a market in (effluent) BP units. Since each BP unit has the same effect on water quality, each permit can specify an allowable number of BP units without reference to the location of the discharge. This makes for a simpler market, and is an adventitious effect of the use of BP as the measure of pollution.

In sum, the MEP system is best confined to pollutants meeting the criteria presented above--BOD and BP are two prime candidates--and is best used without reference to different trading ratios. Thus the trading ratios among dischargers are unity and discharges in one end of the waterway are considered equivalent to discharges in the other end: permits trade on a one-to-one basis. In those river basins in which this approach endangers water quality standards, fewer total permits are issued.

It should be noted that although it is theoretically possible to operate different MEP systems for different pollutants within a given water basin, BP and BOD cannot be used simultaneously because BP relies on a measure of BOD. It would, however, be possible to establish separate markets in the same waterway for two pollutants such as BOD and heat discharges.

The Term of Permits

Subsequent to the original auction of permits the authority may want to increase or decrease the total number of permits in existence. To do so in an ad hoc manner would disrupt the functioning of the market and trust in the market as a mechanism for the allocation of waste discharges. Consequently, upon initial issuance of the permits provision should be made for limiting their term. If the term of the permits is limited, then a reduction in the number of outstanding permits can be made by reissuing fewer than expire. Issuance of new or additional permits can be easily accomplished through their sale in the market.

Limiting the term of the permits is desirable for other reasons, in particular to guard against the establishment of a permanent property right in polluting and to help assure that the MEP market functions relatively smoothly and continuously. Also, if initially the permit terms are staggered so that some of the permits expire each year, then there is the opportunity each year to reduce discharges, improve water quality and work toward the goals of the 1972 Amendments by reducing the number of outstanding permits. However, as is observed in Section 6, the number of outstanding permits can become politically difficult to alter. For this reason the intention to remove permits from circulation should be announced at the outset of the MEP system, and to the extent possible estimates of the schedule of permit retirement should be given. An alternative that is open to the regulatory authority in a type I or III system is to remove permits from circulation by purchasing them on the open market. This costs the authority money, but preserves the desirable properties of and confidence in the MEP system.

In a staggered-term MEP system, each permit authorizes a specified rate of discharge, say one lb/day of BOD, for a predetermined length of time. After the expiration of the permit, the holder must (assuming the permit is being used by a waste discharger) purchase another permit or restrict waste discharges. For the MEP systems we examine in Section 7 there are five different term permits. In one of those systems, permits are issued with one, two, three, four, and five year terms. Subsequently, any new permits would be issued with five-year terms. Thus if one-fifth of the permits expire after one year, the regulatory agency might choose to replace them through an auction with an equal number of five-year permits.

Staggering the permits is advisable for three primary reasons. The first is that it avoids a serious, major disruption in the market's functioning that would occur if all permits were to expire contemporaneously. The second reason is that a turnover of permits helps to assure that there is a market, i.e., that purchases and sales occur reasonably often. The third reason for staggering permit terms is mentioned above: it allows the regulatory authority to adjust in a continuous manner the number of outstanding permits. As permits expire, fewer can be issued in accordance with the goals of the 1972 Amendments. This allows a gradual attainment of those goals.

In all of the effluent permit systems considered here, the number of permits to be issued by the authority is fixed in accordance with the characteristics of the individual river basin system. Thus, there are a fixed number of permits to be allocated among the participants of the system. This is in contrast to systems in which the price of the permits or the information obtained in an auction is used to help determine the optimal number of permits to be issued or sold. Thus the MEP system analyzed here is based on effluent and/or ambient standards, rather than on a marginal damage function. This approach recognizes the fact that measures of damages are not available and, further, that the present legislation is based on standards.

Eligibility Requirements for Permit Holders

There are two questions concerning participation in a MEP system: first, who is required to hold permits, and, second, who is allowed to participate in the market? Stated differently, which classes of dischargers are to be regulated using the MEP system and which sets of individuals will be allowed to participate in the effluent permit market? The latter question arises because speculators and environmentalists may want to purchase permits.

In determining which sources should be controlled with the MEP system, consideration must be given to the nature of the discharge as well as the nature of the discharger. The types of pollutants are discussed in the above section. There is also the question of whether non-point pollution sources can be included in a MEP system. (A non-point source is one where the discharge into the waterway is distributed over a wide area rather than being collected and discharged at one location. An example is the runoff from agricultural fields.)

There are at least two arguments for excluding non-point sources from the MEP system. First, it is difficult accurately to identify and measure the amounts of wastes flowing into a waterway from a non-point source. Consequently, it can be argued that regulations should be in the form of specifying, for example, better agricultural practices rather than imposing effluent limitations of the sort implicit in a MEP system. Second, the control of non-point sources is difficult and attaining particular performance standards, say in terms of lb/day of BOD, is not possible.

Neither argument is compelling. It is in fact possible to estimate the effects of different control or process alternatives for the control of non-point sources. While the uncertainty in these estimates is likely to be greater than for the control of point sources, there is little rationale for not encouraging the development of more effective technology and measurement techniques. This development must of necessity occur no matter what the choice of control method.

There is the additional question of whether municipal dischargers should be required to participate in the MEP system. An alternative is to impose specific municipal treatment requirements with performance standards. We believe, however, that the MEP system should include municipal dischargers. There are efficiency gains to be made by including the municipal systems; uniform performance standards do not efficiently distribute treatment costs among dischargers.

The assumption that municipal dischargers act within the marketable effluent permit system as cost minimizers can be questioned. Municipalities are not organized as business firms, and decisions are often made on bureaucratic rather than economic grounds. However, unlike some public services, waste treatment is measurable and well defined. It lends itself to control and measurement better than police protection, education, and many other public services. At present many municipal plants are operated ineffectively because cities have little or no incentive to maximize the effectiveness of their pollution control facilities. The MEP system provides an incentive.

As is shown below, there need be limited additional financial burden on municipalities from a well-designed MEP system. Additionally, a permit system can be an added incentive for equitable cost sharing among the users of a municipal waste treatment system.

The second issue regarding participation in the MEP system is the question of who is to be eligible to buy and sell permits. Potential permit holders include the following. First, there are the dischargers required to hold the permits in order to operate their facilities. Second, environmentalists and conservationists may be interested in purchasing permits in order to prevent the dumping of wastes into the waterway. Third, speculators may be interested in buying and selling permits in order to make money on the transactions. These types of participants are not mutually exclusive. For example, a discharger may be in a good position to speculate on the value of the permits.

Under a type II MEP system the initial distribution of the permits is accomplished through a market-type device, such as an auction. Trading of the permits subsequent to the first distribution is not allowed. This type of MEP system precludes speculative activity, since the purchase and sale of permits is not allowed. For this type of MEP system there are compelling arguments not to limit market participation to dischargers. First, there is little guarantee that the dischargers will at all times use all of the permits that they hold. They may hold more than they need for reasons of advance planning or for speculative reasons having to do with potential growth of their operations. It would seem perverse to require that the dischargers use all of the permits they purchase, i.e., to require that they pollute. On the other hand, it would be discriminatory to allow speculative activities by potential producers of waste (who may not be using their effluent permits), yet prohibit others from speculating in the market.

Second, it is important to have a large number of market participants. Participation in the market by a diverse set of individuals places a check on dischargers who may try to manipulate the market for their own benefit. Speculative activity can help to assure that the market works reasonably well and that collusive activities by dischargers or other attempts to manipulate the market do not succeed.

The presence of speculative activity can help reduce problems of market manipulation. If speculators are in the market, a large discharger is unable to offer a particular low bid in the hopes of keeping the price of the permits down. To do so would risk losing the permits to a speculator who could then sell them to dischargers for a premium. Since the presence of speculative activity can help the market to operate efficiently, a type II MEP system may be less effective than a type I or a type III system. It is well known, however, that speculative activity can be detrimental in some cases. Panic buying or selling by speculators can disrupt a market, and speculators with large amounts of capital can sometimes manipulate markets. These possibilities must be weighed against the potential beneficial effects of speculative activity.

Hydrologic and Other Seasonal Variations

Changes in the flow of the receiving waters or in their temperature can alter significantly the assimilative capacity of the waterway. If the goal of a control system is to control the quality of the water, then these variations should be accounted for. They provide opportunities for a temporal allocation of the waste treatment capabilities of the receiving waters. It is possible to structure a permit program to take advantage of this fact. The permits can be designed on a seasonal basis by providing bonus discharges during high flow months or by varying authorized discharges in a prespecified manner with the conditions of the receiving water.

In spite of the possibility of exploiting the variation in stream conditions, we suggest a system of permits conferring unchanging discharge privileges with the number of permits determined in accordance with quality standards and based on the expectation of an extreme hydrological condition in the low flow season. A permit system structured to allow daily or weekly discharge variations in accordance with daily or weekly streamflow changes would entail prohibitive administrative requirements. A permit system could, however, be structured in accordance with the expected seasonal hydrologic changes, with adjustments in the discharge privileges keyed to some seasonal multiple of the expectation of an extreme hydrological condition. A system based on seasonal changes would introduce additional monitoring requirements and would make the permits more difficult for dischargers to evaluate. Our approach in this analysis has been based on a rationale that if a permit system is to be considered, it should be a simple one in order to promote the smooth operation of the market and to avoid administrative problems. Hence, this report does not examine seasonally variant permit schedules. It might also be argued that since the goal of the 1972 Amendments is to reduce the long-term amounts of waste load on waterways, control methods designed to even out the quality of water throughout the year are not in the spirit of this legislation.

The Trading Rules and Procedures for the Market

In the operation of an auction for permits or of a market for the purchase and sale of permits, certain ends are desired. In particular, the rationale for having such a market is that it can provide an efficient, orderly method for the allocation of waste treatment among dischargers. As with any market, however, certain things can inhibit its correct functioning. Market imperfections may prevent the MEP system from exhibiting the desirable efficiency properties theoretically inherent in it. Rules and regulations on the conduct of individuals can help to avoid market problems. Such rules can include limits on prices, limits on price movements, or limitations on the permit holdings of any one market participant.

The rationale behind such rules is to prevent market panics and market manipulation. A market panic might occur if everyone predicted a significant increase in the price of the marketable effluent permit. In their effort to buy permits (either for speculative purposes or in anticipation of a subsequent need for them) they force the price up and the prediction of an increase in price becomes a self-fulfilling prophecy. A daily limit on the amount by which the price can increase or decrease can de-fuse such a panic by allowing time for market participants to reassess the supply and demand situation. They can then respond to those factors rather than to the psychology of the market. Similarly, placing a limit on the number of permits that one participant can control helps to avoid the domination and manipulation of the market by large interests.

The Choice and Definition of Basins

The choice and definition of river basins suitable for a MEP system is fraught with subjective judgments. The best areas for this system of control--the ones in which the market will function best--are regions with many polluters and a large total discharge rate. This enhances the probability that the system will operate as a competitive market, rather than being dominated by one or a few dischargers.

Financial Aspects of the MEP System

It is expected that the regulatory authority will collect money from both the auction of permits and the administration of fines. There are several natural and immediate claims on these funds. The administration of the market, monitoring and surveillance procedures, and the collection and evaluation of data pertinent to the operation of the MEP system all require funds. Excess revenues that are collected should revert to the state treasury, perhaps for use in water quality control.

Monitoring and Enforcement

The monitoring of discharges and the enforcement of effluent limitations are necessary elements of the MEP system. It is necessary to determine whether dischargers are in compliance by comparing the amounts of discharges with the amounts specified by the permits that they hold. There must be suitable penalties for exceeding the allowable discharge rates and mechanisms for assessing and collecting those penalties.

The MEP system thus shares the enforcement and monitoring characteristics and problems of the NPDES system. There is an additional aspect to the MEP system: the permissible level of discharges can vary from time to time if permits are traded among dischargers. This, however, is merely an accounting problem and will in all likelihood not affect substantially the monitoring and enforcement methods of the system.

Monitoring and reporting of waste flows are not sufficient control measures. There must also be established a clearly defined administrative system of fines and penalties for non-compliance with the rules of the system. Compliance with the trading rules of the MEP market is easily obtained by requiring that all trades and transactions involving the permits be channeled through the central market which can be operated under the guidance of the EPA. No trade will be valid unless it occurs under the auspices of the central registry. Rules regarding prices or price movements and regulations concerned with the limitation of permit holdings can then be easily enforced. No fines or penalties need be imposed; instead, illegal transactions will not be allowed to occur.

Thus, the only enforcement measures necessary are those designed to ensure compliance with the effluent limitations implied by the pattern of permit holdings. For this purpose we suggest an administered fine related to the asking price of effluent permits in the MEP market. The fine should be greater than the price of an effluent permit in order to encourage the use of the effluent permit market to allocate discharges throughout a river basin. As the price of permits rises the incentive to discharge illegally grows; consequently, the penalty for non-compliance should increase.

The NPDES, Municipal Grant Programs, and the MEP System

Some of the details of how a MEP system might be meshed with the NPDES are examined in Section 7. Under the system suggested there, polluters are still required to apply for NPDES discharge permits for 1977. Essentially, the machinery of the NPDES would be retained with some major accommodations for the MEP system. The major alterations that must be made are (1) provision for trading the marketable effluent permits, and (2) provision for automatically altering the NPDES permits to account for the changes in waste discharge allocation occasioned by the MEP system.

Additionally, it is necessary to coordinate the MEP system with the wastewater treatment grant programs of the federal and state governments. These programs must be accounted for in the determination and predictions of the responses of dischargers to the MEP system as well as the evaluation of the system's contribution to the achievement of the legislative goals. On the industrial side of the ledger the federal and state corporate taxes must be considered.

The efficiency properties of the effluent permit system depend on the market transactions to equalize the marginal costs of waste treatment among polluters. If the price of the permit in the market is $1.00 it is argued that dischargers will reduce waste discharges up to the point at which the marginal costs of waste treatment are $1.00. To do more or less would be more costly.

Due to the municipal waste treatment grant programs the marginal resource costs of waste treatment are not entirely reflected in a municipality's expenditures on treatment. For example, if the subsidy rate is 40 percent, then a dollar spent on waste reduction activities represents only a 60 cents out-of-pocket cost for the municipality. Similarly, for industrial dischargers the opportunity cost of waste treatment expenditures is frequently less than 50 percent of the total resource costs of pollution control measures.

The problem here with regard to the MEP system is that dischargers facing different subsidy or tax schedules will not allocate costs in the most efficient manner. The intent of the MEP system is to lead to the equalization of the real resource costs of waste treatment. If the market price of the permit is $1.00 and the resulting effective marginal treatment costs to different dischargers is 40 cents and 60 cents respectively, the marginal costs are obviously not equalized. This problem is satisfactorily resolved by extending the municipal subsidies and the corporate taxes so that they apply to the marketable effluent permit. Thus, if the market price of the permit is $1.00 the following situation obtains. The actual cost of the permit to the polluter is (1-s) x $1.00, where s is the subsidy or tax rate. The cost-minimizing polluter treats wastes up to the point where the out-of-pocket marginal costs of waste reduction equal the out-of-pocket cost of the permit. Thus the marginal (out-of-pocket) costs of waste treatment are (1-s) x $1.00. Since the waste treatment is subsidized at the rate s, then the marginal costs in real resource terms can be found by adding the subsidy back into the expression for out-of-pocket costs:

$$(1-s) \cdot \$1.00 + s \cdot \$1.00$$

which equals $1.00. Thus, no matter what the subsidy rate, the marginal cost in real resource terms of the waste reduction is equated with the cost of the permit; consequently, the marginal costs of treatment for all polluters are equated. This solution to the subsidy-tax problem has the adventitious effect of reducing the cost of the permits to municipalities.

Under this system a question arises as to the proper subsidy rate to apply. In many cases the subsidy rates for capital and for operating costs will differ. In that situation the subsidy rate to be applied to the effluent permit should be a weighted sum of the two subsidy rates, where the weights are determined by the discount rate and the relative size of marginal capital and marginal operating costs. If s_k is the capital costs subsidy rate, s_o the operating costs subsidy rate, r is the discount rate, and z is the prevailing ratio of marginal operating and marginal capital costs, then the appropriate effluent permit subsidy rate is

$$s = \left(\frac{r}{r + z}\right) s_k + \left(\frac{z}{r + z}\right) s_o \ , \qquad (1)$$

where we have assumed that capital costs are incurred one time only and that the corresponding marginal annualized costs are rC_k, where C_k equals marginal capital costs.

The expression for s is derived as follows. If C_k and C_o are unsubsidized marginal capital and operating costs then total unsubsidized marginal costs are $rC_k + C_o$. Subsidized marginal treatment costs are

$$(1-s_k)rC_k + (1-s_o)C_o \; .$$

The effluent permit subsidy rate, s, is chosen so that marginal costs will be the same for both the subsidized and unsubsidized dischargers. The unsubsidized discharger will equate marginal costs with the permit price:

$$rC_k + C_o = p \; ;$$

and the subsidized discharger will equate marginal costs with the subsidized permit price:

$$(1-s_k)rC_k + (1-s_o)C_o = (1-s)p \; .$$

These two equations can be solved to find s. In equation 1 the result is given, where z is equal to C_o/C_k.

From equation 1 it can be seen that s approaches s_k as z approaches zero, and s approaches s_o as z approaches infinity. It is also apparent that in order to estimate s the discount rate and the ratio of marginal operating to marginal capital costs must be known. A practical approach would be to assume average representative values for these, and calculate the effluent permit subsidy rate, s, on that basis.

This concludes the preliminary analysis of the different aspects of a MEP system. The administrative aspects of the system are dealt with in Section 7, and consequently are not treated above. The remainder of the report is directed at the evaluation of the MEP system and a comparison of that system with other control options.

NOTES

[1] W. David Montgomery, "Market Systems for the Control of Air Pollution," Ph.D. dissertation (Harvard University: Cambridge, Massachusetts, 1971), and "Markets in Licenses and Efficient Pollution Control Programs," Journal of Economic Theory, Vol. 5, No. 3 (December, 1972).

[2] Within such a given "equivalent impairment" river segment a change in location of point sources is insignificant. They are all considered to cause an equivalent impairment per pound of BP discharged. The detrimental effect to the river of a BP discharge is modeled by the impairment function (Ref: "Effluent Charges, Is the Price Right?" Meta Systems Inc p. 48).

$$I = K(BP/Q)(\text{Flow Time})^{\delta} \left(\frac{\text{Volume of affected reaches}}{\text{Surface Area of affected reaches}}\right)^{\mu}$$

(Typically $K = 1.0$, $\delta = 0.4$ to 0.6, $\mu = 0.2$ to 0.4)

Q is the effective dilution flow during low-flow warm temperature months (Q = 1/2 of the sum of the river flow at the waste outfall and the basin outlet). For cases where the segment of concern is at a distance remote from the ocean, and the change in Q over the segment is relatively small compared to the flow at the basin outlet, then the impairment per pound of BP discharged will be essentially the same over the segment and such a reach can then be considered an "equivalent impairment" segment.

Section 3

Markets, Auctions, Externalities, and the MEP System

This section presents a useful digression into the theory of markets, auctions, and externalities, and the relation of those theories to the use of marketable effluent permits. The following three sections take a progressively more empirical look at markets and the issues associated with the use of a market mechanism to control water pollution.

The Theory of Markets[1]

The relation of competitive equilibrium in allocating resources is the subject of many of the important theorems of microeconomics. A perfectly competitive market satisfies several conditions: consumers and firms maximize utility and profits respectively under conditions of free entry and free exit, and perfect information; products are homogeneous; firms and consumers are numerous and small relative to the total size of the market; and choices of firms and consumers are made without regard to other market participants. The fulfillment of these conditions can be shown to lead to economic efficiency in the production and distribution of goods.[2] "Economic efficiency" is taken to be Pareto optimality: the allocation of resources is Pareto-optimal if no consumer's utility can be increased without reducing some other consumer's utility, and no firm's output can be increased without reducing some other firm's output or increasing some input.

Externalities--external effects in consumption and production--can interfere with the attainment of Pareto optimality. Pollution is the classic example of an externality. If the utility of one or a set of people is adversely affected by the actions of a polluter, and there is no market to mitigate those effects, then the outcome will often be a suboptimal distribution of resources. As Arrow shows, however, "by suitable and indeed not unnatural reinterpretation of the commodity space, externalities can be regarded as ordinary commodities, and all the formal theory of competitive equilibrium is valid, including its optimality."[3] The reinterpretation of the commodity space involves the inclusion of pollution as a commodity and the recognition that it enters into both production and utility functions. Unfortunately, as Arrow points out,

> Pricing demands the possibility of excluding nonbuyers from the use of the product, and this exclusion may be technically impossible or may require the use of considerable resources. Pollution is the key example: the supply of clear air or water to each individual would have to be treated as a separate commodity, and it would have to be possible in principle to supply to one and not the other (though the final equilibrium would involve equal supply to all). But this is technically impossible.[4]

And there is the further difficulty of small numbers:

> Each [newly-defined environmental] commodity . . . has precisely one buyer and one seller. Even if a competitive equilibrium could be defined, there would be no force driving the system to it; we are in the realm of imperfectly competitive equilibrium.[5]

Thus, the prospects for using a market in effluent permits to achieve economic efficiency is viewed pessimistically by Arrow for two classic reasons: the inability to exclude individuals from the benefits of pollution control and the limited size of the resulting market. Marketable effluent permits can, however, be used in a more limited fashion to assist in the attainment of efficiency.

The Theory of the MEP System

Several writers have discussed possible arrangements in which the use of a market can serve to implement pollution control goals.[6] Because of the public-good nature of water pollution control--the impossibility of properly excluding and charging the recipients of pollution control benefits--it is impossible to achieve overall Pareto optimality. Consequently, the level of overall water quality must be determined by society, through the determination of the value of water pollution control (a benefit function) or through the specification of water quality or effluent standards. The MEP system can then be used to achieve the specified degree of pollution control in an efficient manner.

The problem of market size--only one buyer and one seller --which accompanies Arrow's expansion of the commodity space is not necessarily a problem in the MEP market. Pollutants produced at one source are often perfect substitutes for pollutants produced at other sources; consequently there will often be many possible buyers and sellers in a market for effluent permits. This opens the possible use of the MEP system to meet overall water quality or effluent standards.

The theoretical basis for the use of effluent permits for the efficient achievement of environmental standards has been developed by Montgomery. He proves the existence of a competitive equilibrium, satisfying the condition of total cost minimization, in the market for effluent permits. In "Markets in Licenses and Efficient Pollution Control Programs," Montgomery first constructs cost functions relating each level of emissions to the polluters' costs.[7] He shows that under the standard assumptions concerning the cost function of firms, the emission cost function is convex. This is important in the demonstration that the total costs of emission control are minimized within a MEP system.

Montgomery defines a set of licenses which confer the right to emit pollutants at a certain rate. Each of the polluters is given some initial allocation of licenses. The polluter's problem is then to maximize profits by, among other things, minimizing the costs of emission control plus the cost of purchasing licenses, subject to the constraint that emissions be equal to or less than the amount of licenses held by the polluter. A market equilibrium exists if there is some set of prices of licenses such that when each polluter minimizes the sum of the cost of reducing emissions and the net cost of buying and selling licenses, excess demand for licenses is non-positive, and excess supply of a license results in a license price of zero. This definition covers (1) the condition whereby the prices of licenses be such that supply equals demand and (2) relevant corner conditions.

Montgomery differentiates between emission licenses and pollution licenses, licenses which relate respectively to emission standards and ambient standards. He establishes the existence and efficiency (total cost minimization) of equilibrium in systems of both emission and pollution licenses. The market for emission rights suffers from more restrictions than the market for pollution licenses. This is due to the fact (discussed above in Section 2) that it is not always desirable to allow the transfer of emission rights on a one-for-one basis. The exchange of licenses between polluters at different locations may adversely affect the quality of water due to spatially differential effects on quality. If, however, the transfer coefficients relating emissions to quality are the same for all polluters, or if environmental standards are in terms of total emissions, then the market for emission rights does not suffer this disadvantage.

A Dutch auction (of the type discussed in Section 2) for the distribution of effluent permits can achieve the same efficiency goals as the systems described by Montgomery. Under the same conditions concerning the motivation of firms and the convexity of cost functions, it is clear that a Dutch auction leads to an equilibrium with the desired efficiency properties. This is true because the definition of a market equilibrium for the Dutch auction as well as the functions and constraints governing the Dutch auction are identical to those in the Montgomery formulation.

Montgomery has served to provide the idea of market effluent permits with the theoretical underpinnings of microeconomics. His important contribution is the demonstration that the MEP system can provide the efficient achievement of environmental standards if the competitive conditions are met.

Problems of Imperfect Competition

The efficiency properties of the MEP system depend on the assumptions of a competitive equilibrium, in particular on the assumption of a sufficiently large number of market participants to inhibit market manipulation. As is discussed elsewhere in this report, the market for effluent permits will, for many river basins, suffer from the number or size distribution of polluters. Various theoretical solutions to the duopoly and oligopoly have been formulated which show the equilibria that result under different assumptions of imperfect competition. Since it is relevant to the Mohawk simulation study of Section 6, the Cournot solution[8] is described here, along with the market problems of effluent permit auctions as analyzed by Rose.[9]

Under the Cournot assumption each firm acts as though its actions do not affect those of other firms. Each firm does, however, incorporate the other firm's output decision into its planning process. In the case of marketable effluent permits, the Cournot assumption is that each polluter assumes that the other polluters will react to the price of a permit as cost-minimizing price-takers. In the Cournot solution, as the number of market participants is increased, the output of each represents a progressively smaller proportion of the industry total, and the effects of an individual on the other market participants is diminished. In the limit the Cournot solution approaches the perfectly competitive result. With a small number of market participants, however, the competitive results will not be approximated. In that case, imperfect competition results in a loss in efficiency, and is one of the main problems anticipated in the use of a MEP system.

Rose analyzes the problem of the manipulation of an auction-type bidding process. The auction is designed to achieve the optimal amount and distribution of emission rights. Rose assumes that the public authority knows the marginal pollution damage function, but not the treatment cost functions, and seeks to find the optimal treatment configuration. The problem of the regulatory authority is to infer the polluters' marginal cost of treatment functions from the polluters' bidding. Rose illustrates the problems that occur when purchasers of the effluent permits perceive themselves as having some measure of control over the permit prices through their bids:

> In these circumstances a strategy of underbidding, in which, at any price, fewer rights are requested than would be called for in a perfectly competitive situation, may be advantageous to these firms. However, these "non-truthful" bids, i.e., not reflective of marginal abatement costs, result in the generation of false signals to the central authority and ultimately excess expenditures for clean-up activities.[10]

Rose's paper demonstrates that the regulatory authority can infer the polluters' marginal treatment cost functions from their bidding behavior even under some conditions of imperfect competition. The most important point of the paper as it relates to this study is the illustration by Rose how problems of market manipulation can interfere with the distribution of effluent permits in an auction.

The problem of market manipulation, both for the ongoing permit market and the initial permit auction, is a significant one for the MEP system. It is treated further in the sections below.

NOTES

[1] This discussion relies on Kenneth J. Arrow, "The Organization of Economic Activity: Issues Pertinent to the Choice of Market Versus Nonmarket Allocation," in Joint Economic Committee, The Analysis and Evaluation of Public Expenditure: The P.P.B. System (Washington, D.C., 1969), and James M. Henderson and Richard E. Quandt, 'Market Equilibrium," Chapter 4 in Microeconomic Theory (McGraw-Hill; New York, 1958), pp. 85-125.

[2] For discussions of competitive equilibrium and its relation to Pareto optimality and welfare maximization see F. M. Bator, "The Simple Analytics of Welfare Maximization," American Economic Review, Vol. 47 (March, 1957), pp. 22-59; J. de V. Graaff, Theoretical Welfare Economics (Cambridge University, 1957), Chapter IV; and Paul A. Samuelson, Foundations of Economic Analysis (Harvard University; Cambridge, Massachusetts, 1948), Chapter VIII.

[3] Arrow, "The Organization of Economic Activity. . . ,'p. 57.

[4] Ibid., pp. 57-58.

[5] Ibid., p. 58.

[6] For example, J. H. Dales, Pollution, Property, and Prices (University of Toronto; Toronto, 1968) and H. D. Jacoby and G. W. Schaumburg, 'Marketable, Fixed Term Discharge Effluent Permits," unpublished, reported in Effluent Charges on Air and Water Pollution: A Conference Report, Edward I. Selig, reporter (Environmental Law Institute; Cambridge, Massachusetts, 1973), pp. 36-43.

[7] W. David Montgomery, 'Market Systems for the Control of Air Pollution," Ph.D. dissertation (Harvard University; Cambridge, Massachusetts, 1971); "Markets in Licenses and Efficient Pollution Control Programs," Journal of Economic Theory, Vol. 5, No. 3 (December, 1972), pp. 395-418; and "Artificial Markets and the Theory of Games," Social Science Working Paper No. 8 (California Institute of Technology; March 1972).

[8] Descriptions of different oligopoly solutions are given in Tun Thin, Theory of Markets (Harvard University; Cambridge, Massachusetts, 1960) and Robert L. Gustafson, "Firm Price Output Behavior in Imperfectly Competitive Markets," in Agricultural Market Analysis, Vernon L. Sorenson, editor (Michigan State University; East Lansing, Michigan, 1964).

NOTES (continued)

[9] Marshall Rose, "Market Problems in the Distribution of Emission Rights," *Water Resources Research*, Vol. 9, No. 5 (October, 1973), pp. 1132-44.

[10] *Ibid*., p. 1138.

Section 4

Industrial Organization Theory and the MEP System

Within the field of industrial organization, the theory of workable competition has been developed as an attempt to indicate how the structure of a market and the conduct of individual firms within a market affects its performance. It is an attempt to indicate the practically attainable desirable standards for individual markets.[1] The theory of industrial organization and the concept of workable competition are useful in the examination of the marketable effluent permit system. They provide both a language with which to discuss the practical evaluation of the workings of the market as well as guides for the assessment of those aspects of the market that have the greatest bearing on the goals of the MEP approach.

For convenience in analysis the various characteristics of a market have been traditionally divided into three mutually dependent categories: performance, conduct, and structure. Market performance is the end result of market actions --prices, output levels, production cost levels, etc.--arrived at in the course of the workings of the marketplace.

Market conduct refers to the actions and tactics of the different buyers and sellers within the marketplace--for example, whether firms collude in the establishment of price or output levels. Market structure is described by the organizational characteristics of the market, such as the degree of seller and buyer concentration and the extent of product differentiation. The elements of performance, conduct and structure provide useful categories in which to discuss the norms that should be applied to the workings of the marketplace. In the case of effluent permits, generalized performance norms have been discussed above. They are efficiency, equity, and administrative and political feasibility. The literature and theory of workable competition can be used to develop more specific norms of workable competition that can be applied to the MEP system in order to determine whether the goals of the system are likely to be achieved.

Economists dealing with the formulation of norms of market behavior have had to move beyond the concept of perfect competition (requiring an infinite or very large number of relatively small buyers and sellers of a standardized product, etc.) and make an effort to establish standards sufficient for judging the workability of actual markets. It is clear that they have not been successful in determining quantitative normative standards that can be applied in all instances to determine the workability of markets. For example, they have failed to specify the number and distribution of sellers and buyers needed to preclude market collusion. Their efforts are helpful, nevertheless, in setting out guidelines and in flagging the important variables that should be considered in the evaluation of any market.

Many of the norms for structure, conduct, and performance that are dealt with in the industrial organization literature are not relevant to the special regulatory character of the MEP system. For example, the level of profits is an important performance norm for many markets, but is not applicable in the evaluation of the marketable permit system. The criteria of workability for a market depend on the goals of that market. For the effluent permit system those goals are somewhat more narrowly circumscribed than for typical industrial markets: they are to achieve the aims of the 1972 Federal Water Pollution Act in an efficient, equitable, and politically feasible manner. The standard of comparison for the MEP system is provided by other alternative control measures and the extent to which they meet the criteria of efficiency, equity and feasibility.

In this section the important elements of structure and conduct that are relevant to the MEP system are isolated and discussed.

Conduct Norms

Many of the elements of market conduct that are important determinants of market performance are automatically accounted for in the design of the MEP system. For example, discriminatory buying and selling, the use of illegitimate pricing methods, unwanted collaboration between buyers and sellers, and other potential market problems are avoided in the MEP system by the use of a regulated central market. There are, however, at least four areas of conduct that are potentially troublesome and worthy of discussion.

The first is the basic question of the response of dischargers to the system: Is it true that they will act to minimize costs or will some other motivations (perhaps bureaucratic) govern their response? This is an important question since many of the efficiency properties of the MEP system are based on the cost-minimizing response of dischargers.

With regard to industrial dischargers, it seems safe to assume that they will pursue a cost-minimizing path in response to the MEP system. Indeed, under a wide variety of motivational assumptions--including profit maximization, cost minimization, and growth maximization--firms will minimize the costs of waste treatment and disposal. A more important question arises with regard to the municipalities. Since they are not business firms with profit-oriented accounting systems they are in a less advantageous position to minimize costs. However, waste treatment is measurable and well defined and cities have had long experience enlisting the aid of competent engineers to design waste control systems that minimize costs to taxpayers. It is definitely easier for a city to respond as a cost-minimizer in the area of waste control than for any other public services such as education.

The second potential conduct problem has to do with the financial power and motivations of market participants. The market will not function as desired if predatory buying and/or no selling of permits occurs. If a buyer or a set of buyers has the financial power to monopolize the use of the permits and does so in order to exclude competitors from the region then the market will not serve its purpose in the manner intended. Several ways to discourage such behavior have been presented above. These include the staggering and reissuance of permits on a regular basis to provide a source of permits to entering or growing dischargers, the limitation of the amount of permits any one discharger can purchase and hold, and other rules designed to encourage the orderly operation of the market.

In some cases not selling permits (even in the face of large increases in the permit price) is a legitimate response of a discharger to future uncertainties in the growth of the firm or municipality or uncertainties in the policy of the regulatory agency. In these cases the worth of the permits to the dischargers may legitimately be higher than the bid price. In other cases the withholding of permits from the market may result from the attempt by a discharger to increase the price of the permits and/or to exclude others from the market. These are not legitimate uses of the market power of the discharger and must be discouraged by, for example, the use of staggered-term permits. In some cases the market structure will prevent these possible adverse effects automatically. If the number of market participants is great enough and the distribution of permits wide enough, then one buyer or seller will be unable to affect the market price significantly through independent action. Such a happy situation will prevent market manipulations of the type mentioned here.

This raises the third problem of market conduct, the collaboration of different market participants. There are two sides to this issue. First, it is desirable for different dischargers to take advantage of the economies of scale inherent in the treatment of wastes. This often requires a good deal of collaboration on the design, construction and operation of treatment facilities. In a MEP system such collaboration might also require coordination in the procurement of permits. On the other side of the coin, however, collaboration of market participants for the sole purpose of market manipulation is contrary to the workings of the market and should be prevented. Consequently, there must be rules prohibiting the cooperative buying or holding of permits by dischargers unless such buying is accompanied by plans to use joint facilities for the treatment of wastes.

The fourth and final problem of market conduct is related to the other three: the MEP system must not disrupt the orderly exiting, entering, growth and attrition of industrial firms and municipalities from the river basin system. One way to assure that participants enter and exit from the market in a reasonable fashion is to assure that the potential three problems outlined above are avoided. Barriers to entry and the failure of businesses that can be associated with the MEP system will be kept at a minimum if the exclusionary tactics and illicit collaboration of market participants are avoided. However, even if these problems are avoided, one of the natural effects of a well-functioning MEP system will be to slow the growth of municipalities and firms, and, in a few marginal cases, prevent the entry of a business concern or precipitate its demise. These effects are more a result of the 1972 Amendments than the control tool used for their implementation. Pollution control requirements are going to cause some dislocations simply because that is part of the cost of meeting the goals of the legislation. The beauty of the MEP system is that these costs are distributed in a reasonably efficient manner.

Structure Norms

The elements of conduct and structure of markets overlap; as with market conduct many of the important elements of market structure that determine market performance are automatically accounted for in the design of the MEP system. For example, the regulatory authority can assure that there is a standardized "product" on the market (homogeneous certificates conferring a specific privilege), trading procedures can be regulated to assure arms-length transactions, and the dissemination of adequate information concerning bid and sell prices can be assured by regulatory actions. There are, nevertheless, areas of market structure that are likely to entail difficulties in a MEP system.

The first, and the most pervasive, problem is that of market concentration, and the second is the problem of market size. The concentration of the market--the distribution of the relative sizes of buyers and sellers--is important because it bears on the problems discussed with respect to market conduct. Predatory practices, price fixing, and the like are much more likely to occur in situations where one or a few market participants control the major share of the market. This is a recurring market problem in the literature of industrial organization, as the extent of the literature on the effects of market concentration on market performance attests.[2]

MEP markets are likely in many cases to be dominated by one or two large dischargers, principally municipalities wherein most of the smaller dischargers are using the municipal treatment system. The extent of this problem can be assessed by looking at a representative sample of river basins and computing concentration ratios in terms of the present and projected waste discharge of polluters. If, for example, 95 percent of the BOD discharges in a given river basin are from one discharger, then the likelihood of the market's being dominated by that discharger is great, as is the probability of market problems.

For the portion of the Mohawk River Basin examined below in Section 6, approximately 45 percent of the total waste discharges in the basin are attributable to one city (Utica), and the two cities (Utica and Rome) account for about 58 percent of the total discharges. As is shown in Section 6, this appears to present no real threat to the MEP market. Utica is unable to dominate the market even when assumed to have perfect information regarding the responses of other polluters. An example in Section 6 does demonstrate, however, that the problems of market domination are real in a case where two dischargers comprise the market.

A related problem is the size of the market in terms of the number of buyers and sellers actively engaged in market transactions. The stock markets in the United States work reasonably well in spite of the fact that a low percentage (approximately 1 percent in the New York Stock Exchange) of the total number of outstanding shares is traded on any given day. Other markets function with smaller numbers of shares, however, and this may not be a problem for typical river basins.

A second important structural problem in the MEP system is the presence of taxes and subsidies. These have distorting effects and can prevent the market from achieving any degree of efficiency. Ways of dealing with the distortions in incentives that are engendered by taxes and subsidies are considered in Section 2. The suggestions there were (1) equalize capital and operating subsidy rates, (2) subsidize the purchase of permits by municipalities, (3) enforce cost-sharing requirements for joint industrial-municipal treatment, and (4) for the purposes of corporate taxation treat the purchase of a permit just as the purchase of any other asset.

Conclusions

As Sosnick states, "no practicable set of structure or conduct requirements, and especially the incomplete set usually mentioned, can assure that performance will be satisfactory. Whether performance is favorable can be inferred only with data on performance."[3]

In the final analysis it is impossible to predict that a market such as the MEP system will function as desired. However, it is apparent from an examination of the MEP systems in light of the industrial organization literature that the primary problems of conduct and structure have to do with the size and distribution of dischargers and the conduct of large dischargers. The market cannot be expected to function effectively if the size of the market is too small or if the market is heavily concentrated and under the direct influence of a small number of participants.

The industrial organization literature does not provide specific, definitive guides as to how small or concentrated markets can be without encountering significant market problems. As we saw in Section 3, the Cournot solutions to the oligopoly problem suggest that in a simple situation the price with ten sellers in the market does not differ too much from the price with 1,000 sellers. In one study[4] Bain concludes that a "critical level" of concentration occurs roughly when 70 percent or more of the market is controlled by the eight largest firms. Thus we have some assurance that if more than ten dischargers with equally distributed shares of the total discharges are present in the river basin, the MEP system is likely to function effectively. Beyond that, we cannot speak with any confidence. With regard to the size of the market, it seems safe to assume that the amount of money involved in waste treatment and the significant amounts of wastes that are discharged into the nation's waterways are a guarantee that the market will be large enough to provide for orderly buying and selling of permits.

NOTES

[1] The concepts of industrial organization and workable competition are discussed in Joe S. Bain, Industrial Organization (Wiley, New York, 1967) and Stephen H. Sosnick, "A Critique of Concepts of Workable Competition" in the Quarterly Journal of Economics, LXXII (Cambridge, Massachusetts, August 1958), pp. 380-423.

[2] See, for example, N. L. Collins and L. E. Preston, Concentration and Price-Cost Margins in Manufacturing Industries (University of California Press, Los Angeles, 1968) and William G. Shepherd, "The Elements of Market Structure," in Review of Economics and Statistics, 54(1) (February 1972), pp. 25-37.

[3] Op. cit., p. 397.

[4] Joe S. Bain, Barriers to New Competition (Harvard University, Cambridge, Massachusetts, 1956).

Section 5

Analogous Auctions and Markets

There have been many studies of industrial markets and some of the work on the questions of concentration are relevant to this study. An example is Bain's work that is mentioned in the previous section. In addition, there are many markets and auctions that are in one way or another closely analogous to the MEP system. Examples include the market for liquor licenses, the taxi medallion market, the Treasury bill auction, and the federal funds market. The taxi medallion license, for example, shares many of the characteristics of the market for effluent permits: a fixed number of permits conferring specific rights on the holder are traded among market participants.

This section reviews some studies of specific markets and auctions in an attempt to gain insight to their workings and to learn the extent to which they meet the criteria of efficiency and equity. Information relevant to the evaluation of the MEP system is highlighted. Unfortunately, those markets--the markets for taxi medallions and for liquor licenses--that are most nearly parallel to the MEP market are the ones that have been studied least. Others, such as the Treasury bill auction, are the subject of numerous papers.

United States Treasury Bill Market

The weekly Treasury bill auction has been studied extensively[1] and its organization and functioning are known in detail. At present the Treasury releases an announcement each week inviting tenders for a specified amount of 91-day and 182-day issues. Bids are normally tendered Monday and delivery is made to the successful bidders on the following Thursday. Bidders submit one or more bids for chosen amounts of a bill issue at various prices. The Treasury arrays the bids in order of decreasing price and, beginning with the highest bid, accepts as many bids (at successively lower prices) as is necessary to cover the amount of bills issued.

Since each of the successful bids is filled at the price submitted, the Treasury is effectively practicing price discrimination against the purchasers of the bills. This is in contrast with a competitive auction procedure in which all bids are filled at the market clearing price. Friedman has proposed that the Treasury discontinue the use of price discrimination in the Treasury bill market by making all sales at the "stopout price."[2] (The "stopout price" is the lowest successful bid.) He contends that this would actually increase the Treasury's receipts for a given volume of bills for two reasons.

First, under the discriminatory system a bidder is penalized if he pays more than the stopout price. Consequently, effective bidding requires the accurate assessment of the probable bids of other market participants in order to be able to submit a bid only high enough to insure that the bidder is fairly likely to have his order filled. This results in the submission of bids below those that would be submitted if no bidder were concerned about the possibility of paying a higher price than other market participants.

To illustrate, suppose that a bidder anticipates a market clearing price of $10, but is willing to pay as much as $12 if necessary. In the competitive bidding system the bidder could bid $12 and be certain of obtaining the item at or below his demand price. If the market clearing price turns out to be $11 then the bidder receives the item for $11 and is satisfied. In contrast, the bidder would be reluctant to bid $12 in a discriminatory bidding system. Since his estimate of the market clearing price is $10 he will bid at or slightly above that amount. A bid of $12 will end up costing $12, while a successful bid at a price closer to $10 will save him money. Thus, the incentive to bid $12 is countered by the desire to save part or all of the excess over $10. This results in lower bids and, consequently, a lower market price.

Second, Friedman contends that the discriminatory system places a high premium on knowing the workings of the bill market. Consequently, investors without the necessary resources or time cannot compete effectively. This narrows the market to a degree that can lead to collusive activities.

The first of these contentions has been tentatively confirmed by the market experiments of Smith.[3] The implication in terms of the revenues from auctioning effluent permits is not significant. However, Smith's results do imply that the use of a competitive market as opposed to a discriminatory bidding system is potentially more useful in obtaining information about bidders' true demand schedules. Thus in the MEP system, competitive bidding is likely to provide better information about the marginal costs of waste treatment. The Dutch auction, which is suggested in Section 2 as a possible means of effluent permit distribution, is a competitive bidding system slightly different operationally from the one suggested by Friedman, but equivalent in terms of the end results. This result also suggests that the efficiency properties of the market are more likely to be realized in a competitive bid than in a discriminatory bid. Since bidders are more likely to bid in accordance with their true demand schedules, the competitive form of bidding is more likely to lead to the efficient allocation of marketable permits.

Smith also reaches the interesting conclusion that the outcome of a discriminatory auction may depend crucially on the number of bidders, whereas the outcome of the same offering under competition may be relatively independent of the number of bidders. Stated differently, the market clearing price in a competitive bid is less dependent on the number of market participants than in a discriminatory bid. Smaller numbers are more likely to lead to market distortions in a discriminatory bid. This is another point in favor of the use of a competitive market in the distribution of effluent permits.[4]

Taxi Medallion Markets[5]

The market for taxi medallions is similar in many respects to the market for effluent permits. Taxi medallions confer on the holder a specified privilege--to operate a taxi under a given set of regulations--and are traded among participants in the taxi business. The number of medallions is often limited by statute to an absolute number or to a number based on the population of the area of service. The restriction can be on the number of cabs in a city, on the number within given zones of a city, etc.

In Boston and New York City the right to operate a taxi is limited to holders of medallions. The number of medallions in New York is limited by a 1937 law to 13,566. However, during the depression and war nearly 2,000 medallions were surrendered and were never reissued. The remaining medallions are split approximately 8 to 5 between fleet and independent owners. Transfers between the two classes of owners is prohibited in the New York market. Boston also limits the number of taxi medallions by statute. There are 1,525 taxi medallions of which 737 are fleet-owned and 788 are owned by independents. Although trading is not prohibited between the two classes of owners, the fleet owners do not sell medallions to individuals.

In both Boston and New York City the medallion markets provide evidence that a relatively small market can operate reasonably well in terms of providing a ready opportunity to buyers and sellers (at the going price). In Boston, 1970 medallion prices were in the neighborhood of $30,000; in New York City independent medallions sold in 1970 for around $23,000 while fleet medallions were about $1,000 less.

While providing evidence that markets with limited numbers of a homogeneous product can function, the market for taxi medallions also exhibits some of the market problems that pose probable barriers to the effective working of the MEP system. In Boston the fleet owners, through their refusal to sell medallions to independents, are essentially acting as monopolists. They realize that it is in their joint long-term interest to control a large share of the market in order to keep cab fares up and, more importantly, to maintain the power to prevent the issuance of more medallions. The latter has been suggested many times since the law limiting the number of medallions to 1,525 was passed in 1930.

The last point--the difficulty in altering the number of medallions--is pertinent to the formulation of a MEP system. It is politically difficult to alter the number of rights, whether they be taxi medallions or effluent permits, once they are issued. For this reason, the market for effluent permits should be established as far as is possible with the effluent permits bearing definite expiration dates and with specific provisions regarding the reissuance of the permits.

The problem of one class of sellers, say industrial polluters, refusing to sell to a specific class of buyers, say environmentalists, can be avoided in the MEP market by requiring all trades to take place with the central registry acting as the middleman.

Offshore Oil Leasing Market

Many theoretical and empirical studies of bidding strategies have been conducted.[6] Empirical studies of competitive sealed bidding covering many years of data and different situations show that the bids tend to be lognormally distributed.[7] One market that has been the object of many studies is the auction for offshore oil leases. The Department of the Interior conducts the auction for leasing rights to specified offshore plots on the continental shelf. Sealed bids are submitted which have historically tended to be lognormally distributed for any given tract.[8] Theoretical justification of the empirical results is found in the concept of multiplicative errors that naturally arise in the evaluation of (uncertain) offshore oil drilling prospects. If multiplicative errors are involved in the process of estimating the worth of a tract, then bids for tracts would tend to be lognormally distributed.[9]

The implications for the evaluation of the MEP system are not profound. They are simply that (1) a working market can be devised and operated for allocation of a resource by the government and (2) the behavior of market participants appears to conform to reasonably "good" market behavior, i.e., behavior consistent with rational, independent bidding behavior.

Conclusions

Information on markets that would be useful for the evaluation of the MEP system is sparse. A prime example is the lack of information on the market for liquor licenses which is analogous in many ways to the MEP system. Even for the three markets discussed above, facts useful for the evaluation of the MEP system are few and far between. Nevertheless, some relevant conclusions from the Treasury bill, taxi medallion, and oil leasing market studies are presented above.

NOTES

[1] Examples are Andrew Brimmer, "Price Determination in the United States Treasury Bill Market," Review of Economics and Statistics, Vol. XLIV, No. 2 (May, 1962); Deane Carson, "Treasury Open Market Operations," Review of Economics and Statistics, Vol. XLI, No. 4 (November, 1959); Henry Goldstein, "The Friedman Proposal for Auctioning Treasury Bills," Journal of Political Economy, LXX, No. 4 (August, 1962); and Milton Friedman, A Program for Monetary Stability (Fordham University; New York, 1960).

[2] Hearings Before the Joint Economic Committee on Employment, Growth, and Price Levels, Part 6A (Washington, D.C., 1959), pp. 1148-1153.

[3] Vernon L. Smith, "Experimental Studies of Discrimination Versus Competition in Sealed-Bid Auction Markets,' Journal of Business, Vol. 40 (1967), pp. 56-84.

[4] Ibid., p. 70.

[5] This section relies primarily on the following sources: Sandi Rosenbloom, "Taxis, Jitneys, and Poverty," Transaction (February, 1970), pp. 47-54; William A. Strauss, "The City of Boston and its Taxicabs," unpublished paper, Harvard University Public Policy Program (May, 1970); Edmund W. Kitch, Marc Isaacson, and Daniel Kasper, "The Regulation of Taxicabs in Chicago," The Journal of Law and Economics (October, 1971), pp. 285-350; and M. E. Beasley, "Regulation of Taxis," The Economic Journal (March, 1973), pp. 150-172.

[6] Examples are Michael H. Rothkoff, "A Model of Rational Competitive Bidding," Management Science, Vol. 15, No. 7 (March, 1969), pp. 362-73; R. B. Wilson, "Competitive Bidding with Asymmetric Information," Management Science, Vol. 13 (July, 1967), pp. 816-20; and F. Edelman, "Art and Science of Competitive Bidding," Harvard Business Review, Vol. 43 (July-August, 1965), pp. 53-66.

[7] For examples see J. Aitchison and J. A. C. Brown, The Lognormal Distribution (Cambridge University; Cambridge, England, 1957); and John J. Arps, "A Strategy for Sealed Bidding," Journal of Petroleum Technology, Vol. 17 (September, 1965), pp. 1003-1009.

[8] Arps, "A Strategy for Sealed Bidding"; Chester R. Pelto, "The Statistical Structure of Bidding for Oil and Mineral Rights," Journal of the American Statistical Association, Vol. 66 (September, 1971), pp. 456-60; and P. B. Crawford, "Texas Offshore Bidding Patterns," Journal of Petroleum Technology, Vol. 22 (March, 1970), pp. 283-89.

[9] See Keith C. Brown, "The Distribution of Louisiana Outer Continental Shelf Lease Bids," Land Economics, Vol. 43 (August, 1967), pp. 354-57; and Crawford, "Texas Offshore Bidding Patterns."

Section 6

Mohawk River Simulation Model

To help examine the workings of the marketable effluent permit system a computer simulation model was developed using data from the Mohawk River Basin. The model provides estimates of the important cost, emission, and control parameters that would be assoicated with a MEP system. Consequently, the results of the model can be used to discover and illustrate possible consequences of using this type of pollution control instrument.

The inputs to the model include treatment cost and waste reduction data for eight Mohawk River municipalities. These are used to generate outputs based on the following assumptions:

1. municipalities, when faced with the requirement to buy effluent permits, will act so as to minimize their total costs, i.e., they will buy the number of permits and treat the amount of wastes consistent with the minimization of the present value of the sum of waste treatment costs and effluent permit costs;

2. the effluent permit price will be the market-clearing price, i.e., the price that equates the given supply with the sum of the municipalities' demands:

3. the alternative to buying permits is to reduce waste discharges as much as is technically possible (as indicated by the treatment cost data);

4. all quantities--costs, effluent quantities, etc.--are known with certainty.

Using these general assumptions, and others that are specific to the different model formulations, the model is used to generate outputs. The most interesting of these are the costs to polluters for waste treatment and permit purchases, the real resource costs of waste treatment, the number of permits purchased by municipalities, and the permit price. The inputs, assumptions, and outputs of the simulation model are discussed further below.

The Mohawk Data

This part of the study focuses on the Mohawk River Basin, in central New York State.[1] The Mohawk is a tributary of the Hudson, originating in the Adirondacks north of Rome. Uses of the river and its tributaries include navigation (April - December), power generation, municipal water supply (the lower Mohawk, below Schenectady only), flood control, and recreation (boating and fishing, although the latter use is declining because of increasing pollution). Flow is systematically regulated by means of locks and dams, because of navigation requirements. In the upper Mohawk, summer flow varies from 130 cubic feet per second (cfs) at Rome (milepoint 130) to 300 cfs at Herkimer (milepoint 87); below Herkimer, it is about 560 cfs. The pollution control history of the Mohawk Valley has been one of municipal irresponsibility. Before 1971, no town had secondary treatment, and many had none at all. Utica, for example, with a population of 150,000, discharged raw sewage to the river prior to 1971.

The simulation centers on eight municipalities on the upper Mohawk. Table 6-1 presents pertinent information concerning these cities,[2] and Table 6-2 gives, for each municipality, estimate costs and associated waste removal for seven waste treatment processes. The cost data which are described in more detail in Appendix B, were derived from data on typical municipal treatment plants with design flows of 1, 10, and 100 million gallons per day, with an average pollutant concentration of 200 mg/1.[3] The economic life of the equipment is assumed to be 25 years. As Table 6-1 shows, pollutant loads for the eight cities studied actually vary from 56 mg/l to 625 mg/l, while design flows of existing or proposed plants run from 1 to 27 million gallons per day. To provide the individual cost schedules, the basic cost data were adjusted according to the following approximations. Cost is assumed to be a function of flow: $C = kQ^{\alpha}$, where C = cost, Q = design flow, and k and α are constants. Values for k and α are found for each city by substitution in the following equations:

$$\alpha = \frac{\log_{10}C_1 - \log_{10}C_2}{\log_{10}Q_1 - \log_{10}Q_2},$$

with Q_1 and Q_2 taken as the high and low flow values nearest to that of the plant, and C_1 and C_2 the costs corresponding to those flow designs. Then, $k = \frac{C}{Q^{\alpha}}$. Further adjustments

Table 6-1

Mohawk River Basin Cities

City	River Milepoint	1970 Census Population	Design* flow,mgd	BOD load mg/1	Raw BOD lbs/day	Raw BP lbs/day	Assumed treatment level
Rome	123	50,148	16.5	56	7,790	31,052	Primary
Utica	104	150,700	27.0	127	28,830	105,389	Secondary
Ilion	87	9,808	4.0	151	5,000	19,048	None
Herkimer	87	8,960	1.7	156	2,210	7,713	Secondary
Little Falls	80	7,629	5.6	93	4,330	14,618	None
St. Johnsville	70	2,089	2.0	258	4,280	14,211	None
Ft. Plain	64	4,126	1.0	625	5,180	17,289	None
Canajohaire	61	2,686	2.6	278	6,000	19,559	None

*for existing or proposed treatment plants

Table 6-2

Wastewater Treatment Costs

Removal Scheme*	BOD Removed lbs/day	BP Removed lbs/day	Capital Cost ($)	Maintenance & Operation Cost ($/yr)
		Rome		
1	2,781	6,872	2,343,000	184,371
2	5,009	12,920	4,498,500	253,000
3	6,123	15,806	4,967,000	327,770
4	6,536	22,513	6,499,000	557,400
5	6,536	25,345	7,185,600	620,700
6	6,957	26,073	8,150,000	663,800
7	7,650	27,269	9,746,000	759,000
		Utica		
1	10,091	22,961	4,974,900	388,360
2	23,064	51,307	9,334,000	526,000
3	24,930	57,802	10,296,000	672,700
4	26,235	86,091	13,706,000	1,119,500
5	26,235	94,926	15,246,000	1,259,000
6	27,100	96,577	17,452,000	1,324,000
7	28,542	99,265	20,794,000	1,515,800

Table 6-2 (continued)

Removal Scheme*	BOD Removed lbs/day	BP Removed lbs/day	Capital Cost ($)	Maintenance & Operation Cost ($/yr)
		Ilion		
1	1,750	4,340	1,326,000	102,830
2	4,000	9,235	2,698,000	165,400
3	4,400	10,408	2,959,000	216,800
4	4,550	15,334	3,716,000	376,000
5	4,550	17,191	4,053,000	393,200
6	4,700	17,493	4,544,100	446,000
7	4,950	17,989	5,307,000	514,826
		Herkimer		
1	774	1,137	736,300	55,920
2	1,768	3,814	1,546,000	102,900
3	1,945	4,294	1,683,000	134,810
4	2,011	6,436	2,089,100	233,200
5	2,011	6,933	2,240,700	244,840
6	2,077	7,053	2,507,400	272,500
7	2,188	7,248	2,855,200	319,200

Table 6-2 (continued)

Removal Scheme*	BOD Removed lbs/day	BP Removed lbs/day	Capital Cost ($)	Maintenance & Operation cost ($/yr)
		Little Falls		
1	1,303	2,846	1,341,620	104,839
2	3,166	6,951	2,695,000	159,950
3	3,399	7,650	2,963,800	209,790
4	3,585	11,662	3,769,000	364,000
5	3,585	12,100	4,105,000	380,100
6	4,051	12,847	4,607,000	434,500
7	4,283	13,229	5,435,000	498,600
		St. Johnsville		
1	1,498	3,099	1,010,570	76,978
2	3,424	7,047	2,130,000	139,416
3	3,766	8,030	2,321,000	182,700
4	3,895	12,278	2,887,000	316,239
5	3,895	12,845	3,106,000	331,800
6	4,023	13,045	3,476,000	370,600
7	4,237	13,411	3,978,000	432,900

Table 6-2 (continued)

Removal Scheme*	BOD Removed lbs/day	BP Removed lbs/day	Capital Cost ($)	Maintenance & Operation Cost ($/yr)
		Ft. Plain		
1	1,807	4,107	952,000	71,400
2	4,765	9,871	2,040,000	142,800
3	4,931	10,579	2,210,000	187,000
4	5,014	15,294	2,720,000	323,000
5	5,014	16,094	2,890,000	340,000
6	5,097	16,327	3,230,000	374,000
7	5,139	16,544	3,620,000	442,000
		Canajohaire		
1	2,100	4,343	1,329,600	102,000
2	4,800	9,932	2,749,200	175,600
3	5,280	11,175	3,002,800	230,200
4	5,460	16,908	3,752,100	398,600
5	5,460	17,692	4,054,000	417,600
6	5,640	17,992	4,542,000	469,300
7	5,940	18,487	5,237,000	545,600

*Scheme descriptions:

Scheme No.	Process
1	Primary treatment
2	Secondary treatment (primary and activated sludge)
3	Super secondary (above processes, and polishing filter)
4	Above processes, and phosphorus removal and recarbonation
5	Above processes, and nitrogen stripping
6	Above processes, and pressure filtration
7	Above processes, and activated carbon adsorption

were made for concentration variance by application of the factor, $f_c = \frac{BOD_5 mg/l^{.467}}{200}$, derived from a general regression equation for the cost of secondary treatment.[4]

The Simulation Model

The simulation programs are designed to anticipate possible actions of polluters and different approaches by the regulatory authority. Several variants of the MEP approach were examined, but all can be classified as either one-term or staggered-term systems. The one-term MEP system is straightforward. One permit gives the right to discharge a fixed amount for a fixed number of years, In these systems, all permits are good for the same number of years. In the staggered-term systems, the expiration date of permits is staggered so that some permits are good for two years, some for three years, and so on. As we have seen above, each of these two types of systems has several rationale behind it.

In order to obtain the desired information through the use of the simulation model without making the model excessively complicated and expensive, simplifying assumptions must be made. In the case of the one-term permit model, the assumption is that the permits are issued at a given date, are effective for a given number of years, and then expire. Thereafter, polluters must reduce dis-

discharges as much as is technologically feasible, i.e., as much as the data in Table 6-2 indicate is possible. This allows us to examine the effects of changing the length of term of the permits, the subsidy rates, and other variables without becoming ensnarled in the complex issues of expectations and term structure. For example, questions about the response of polluters under uncertainty arise if the number and prices of effluent permits in future time periods are unknown. While these are important issues to consider, they are too complex to deal with in a model the purpose of which is merely to examine the magnitude of the effects of varying the cost and control parameters.

In the case of the staggered-term permit systems similar simplifying assumptions are made. All of the permits are issued on one given date and although they expire at different dates, no more permits are issued. After the expiration of all permits, polluters must reduce discharges as much as is technologically feasible. A further simplifying assumption is that the permits must be purchased initially in mixed blocks. For example, if there are one, two, three, four, and five year permits, then a polluter buys a package containing an equal number of each term permits. Once again, this is done to avoid the extremely difficult problems of term structure and expectations.

In all variants of the model the assumption of progress toward best practical technology is made. All dischargers are assumed not to decrease their treatment of wastes over time. This assumption is justifiable based on the mandate of the legislation, but is also necessary as a simplifying assumption for our model. Without that assumption it would be necessary to analyze the reduction in costs from reducing treatment levels and from undertaking the attendant disinvestment program. This is too difficult to attempt with the available data.

Other variations are made between different runs of the simulation model. One variant is a constraint on the lower level of treatment that each polluter is permitted to provide. These constraints tend to limit the demand for permits and correspond to the use of quantitative effluent standards in conjunction with the MEP system. The permit's worth to its holder is influenced by its length of term, the applicable discount rate, and the subsidy rates for capital and maintenance and operation costs; all of these factors are also allowed to vary. The pollutant to be covered by the permits must also be specified and two possibilities are tested: permits correspond to units of either BOD_5 (5-day biochemical oxygen demand) or biomass potential[5] (a weighted summarization of BOD_5, and nitrogen and phosphorous concentrations) of the wastes discharged.

The computer program simulated the proposed system and predicts the effect on the river basin system in terms of the above options. The minor options enter the routine as input variables; the cost data for each polluter (Table 6-2) are also input.

The value of a permit to a polluter is assumed to be the marginal costs of waste treatment that are avoided by not having to treat the wastes covered by the permit. Thus, for the one-term permits, the discounted costs of treating an additional unit of wastes for the number of years of the permit's term is the value of a permit to the polluter. Similarly, the value of the staggered-term permit is the discounted sum of the incremental treatment cost units that are avoided by owning the permit.

The first step in the simulation is to annualize the capital costs over the life of the equipment:

$$A_c = rC/[1 - (1+r)^{-n}],$$

where A_c is the annualized capital cost ($/year), C is total capital costs, r is the discount rate, and n the life of the equipment. These costs can then be added to the annual maintenance and operation costs to obtain total annual costs:

$$A_t = A_c + A_m ,$$

where A_t and A_m are respectively the annualized total and operating costs. This must be done for each of the treatment levels of the cost data. Thus, A_t is actually a function, $A_t(x)$ of the amount of wastes treated, x. The units of x are either pounds per day of BOD_5 or pounds per day of biomass potential.

The resulting stream of yearly total costs applies to the duration of the equipment; and if one makes the convenient assumption that the equipment will always be replaced by more of the same, one then has an infinite stream of annual costs. Then, the worth of a permit of any length is the present value of that portion of the treatment cost expenditure stream that is avoided by holding the permits. As stated, these calculations must be made for each level of treatment in order to obtain the marginal values, i.e., the worth of buying an additional permit. Suppose, for example, that the present discharge rate of the polluter is x_o, and the question is whether to purchase a permit allowing an increase in discharges of one unit per day. The cost of maintaining the x_o discharge rate is $A_t(x_o)$ per year, while the (lower) cost of maintaining the discharge rate at $x_o + 1$ is $A_t(x_o + 1)$. The value of the permit is thus the discounted sum of the annual savings of $A_t(x_o) - A_t(x_o + 1)$ over the term of the permit.

An example is useful here. Consider the cost data for Rome in Table 6-2 on page 87. For reduction of 6,872 lbs/day of BP, the capital and operating costs of scheme 1 are respectively \$2,343,000 and \$184,371/year. Let the discount rate be 10 percent per year with a 25 year equipment life. Then annualized capital costs are:

$$A_c = \frac{0.1 \times \$2,343,000}{[1 - (1 + 0.1)^{-25}]} = \$258,124$$

Thus total annualized costs are

$$A_t = A_c + A_m + \$258,124 + \$184,371 = \$442,495.$$

Similarly, for scheme 2 and a BP reduction of 12,900 lbs/day, total annualized costs are \$748,591. The additional cost of the waste reduction achieved with scheme 2 is thus:

$$\$748,591 - \$442,495 = \$306,096$$

and the average marginal costs is:

$$\frac{\$306,906}{(12,920 - 6,872)\text{lb/day}} = \$50.61/\text{lb/day}$$

Then, if the price of the permit is greater than \$50.61 per lb/day, the discharger will use scheme 2 rather than scheme 1. Of course, if costs are subsidized the calculation of A_t must be adjusted accordingly.

The above procedure yields estimates of the average marginal costs for seven waste reduction levels. Since cost data are used for a finite number of points on the treatment cost curve, an additional assumption is necessary in order to generate continuous permit demand curves. The assumption used in the Mohawk simulation model is that the demand curves for permits (and the associated marginal treatment cost curves) are piecewise linear. This allows us to compute the demand for the permits even at those levels of x_o for which we have no cost data, i.e., between the orignial data points.

The above procedure results in a set of individual demand schedules for permits giving the number of permits demanded at each price. These demand schedules are then aggregated over the entire river basin by finding, at each price, the sum of the individual demand levels. The aggregate demand curve and the individual demand schedules are used to predict the response of the basin to the issuance of a given number of permits. First, the market-clearing price for the amount issued is obtained from the aggregate demand schedule; at this price, the (given) supply of permits equals the total river basin demand. The resulting market price and the individual demand schedules are then used to determine individual discharger responses, the associated costs, and the other parameters of interest in the permit system.

The Simulation Results

Tables 6-3, 6-4 and 6-5 summarize the inputs to the simulation model for each run of the model. In all 27 different combinations of input data were used in the model in order to provide comparisons of different MEP systems under differing assumptions. Table 6-3 gives the relevant input data for each of the one-term permit situations; Table 6-4 does the same for the staggered-term model runs. Four additional one-term runs are described in Table 6-5.

For each of the runs, the number of the run, the discount rate, the subsidy rates, and the type of pollutant are specified in lines 1 through 5. Line 6 gives the length of term of the permit. For the one-term permit system the same length of term applies to all of the permits; however, for the staggered-term permits varying lengths of term obtain. It is assumed that the staggered-term permits are divided equally into five different terms, the length of those terms varying by equal increments. Line 6 of Table 6-4 gives the longest term; dividing the longest term by 5 gives the shortest term. Thus, for example, the permits of run 18 are equally divided into term lengths of 1, 2, 3, 4, and 5 years, while the permits of run 19 are divided into 2, 4, 6, 8, and 10 year term lengths.

Line 7 gives the minimum required treatment technology for the polluters. The treatment scheme number given in

Table 6-3

Inputs for the One-term Permit Simulations

Run Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Discount rate (% per year)	10	7	10	10	10	10	10	20	10	10	10	10	7	10	10	10	10
Capital cost subsidy (%)	90	0	90	90	90	90	75	90	90	90	90	90	0	90	90	90	90
Operating and maintenance cost subsidy (%)	30	0	30	30	30	30	75	30	30	30	30	30	0	30	30	30	30
Pollutant type (BOD or BP)	BOD	BOD	BOD	BOD	BOD	BOD	BOD	BOD	BOD	BOD	BOD	BP	BP	BP	BP	BP	BP
Permit term (years)	5	25	5	1	10	15	5	5	5	5	5	5	25	5	10	15	5
Lower bound on treatment (scheme)	2	0	0	2	2	2	2	2	2	2	0	2	0	0	2	2	0

Runs 11 and 17 were made with only two cities in the system: Ft. Plain and Ilion. Runs 9 and 10 have all eight Mohawk cities plus an additional market participant representing the demand by environmentalists. All other runs were made with the market comprised of the eight Mohawk cities.

Table 6-4

Inputs for the Staggered-term Permit Simulations

Run Number	18	19	20	21	22	23
Discount rate (% per year)	10	10	10	10	10	10
Capital cost subsidy (%)	90	90	90	90	90	90
Operating and maintenance cost subsidy (%)	30	30	30	30	30	30
Pollutant type (BOD or BP)	BOD	BOD	BOD	BP	BP	BP
Permit term (years)	5	10	15	5	10	15
Lower bound on treatment (scheme number)	2	2	2	2	2	2

For all runs the market consists of the eight Mohawk cities.

Table 6-5

Inputs for Additional One-term Permit Simulations

Run Number	24	25	26	27
Discount rate (% per year)	10	10	10	10
Capital cost subsity (%)	75	90	75	90
Operating and maintenance cost subsidy (%)	0	0	0	0
Pollutant type (BOD or BP)	BOD	BOD	BP	BP
Permit term (years)	5	5	5	5
Lower bound on treatment (scheme number)	2	2	2	2

line 7 corresponds to the treatment technologies given in Table 6-2. Scheme 0 represents no required minimum treatment, while Scheme 2 implies the use of a secondary treatment process. In all cases the treatment level provided by the cities is constrained to be at least the level specified in the last column of Table 6-1.

For each of these runs the supply of permits was set at two different levels. For the BP runs, the supply of permits was set at 35,000 and at 70,000 pounds per day. The supply for the BOD runs was 2,000 and 4,000 pounds per day. For each of these supply levels, the market clearing price and the relevant market variables were computed.

The first 11 one-term runs outlined in Table 6-3 are simulations of BOD permit systems; the remaining 6 are BP permit simulations. The first 3 staggered-term runs of Table 6-4 are BOD permit simulations and the remaining 3 are BP permit simulations. They are grouped in this way because most of the important comparisons are among computer runs with the same kind of pollutant. For the four runs of Table 6-5 the capital subsidy rate varies while the operating subsidy is held at zero.

The input combinations for the simulation model given in Tables 6-3, 6-4 and 6-5 are typically chosen so as to show the results of changes in individual variables (such as the discount rate). Run 1 of the model for BOD and run 12 of the model for BP most closely represent the actual conditions in the Mohawk River Valley. Other runs can be compared with these in order to test the sensitivity of different variables. For example, changes in the length of permit term are made for BOD in runs 4, 5, and 6.

The primary outputs of the model are the demand curves for the market participants, the aggregate demand curve for the river basin, and the market-clearing responses of polluters (along with associated variables such as the price of the permit). Figures 6-1 and 6-2 are examples of the individual polluter demand curves from computer run 1. For each price of the permit, the curves give the corresponding demand for permits for Rome (Figure 6-1) and Utica (Figure 6-2). The aggregate demand curve for run 1 is presented in Figure 6-3. Under the assumptions of the model, this graph gives the total number of permits that are demanded by the eight cities at each of the prices. Given a total supply of permits, it is possible to obtain the market-clearing price using Figure 6-3. This price can in turn be used to determine the responses of each of the individual dischargers.

The graphical data facilitate the comparison of different types of MEP systems and are of interest in themselves. More important, however, are the numerical data that are associated with each computer run. A complete set of

Figure 6-1

DEMAND CURVE OF ROME FOR RUN 1
OF THE MOHAWK PERMIT SYSTEM SIMULATION

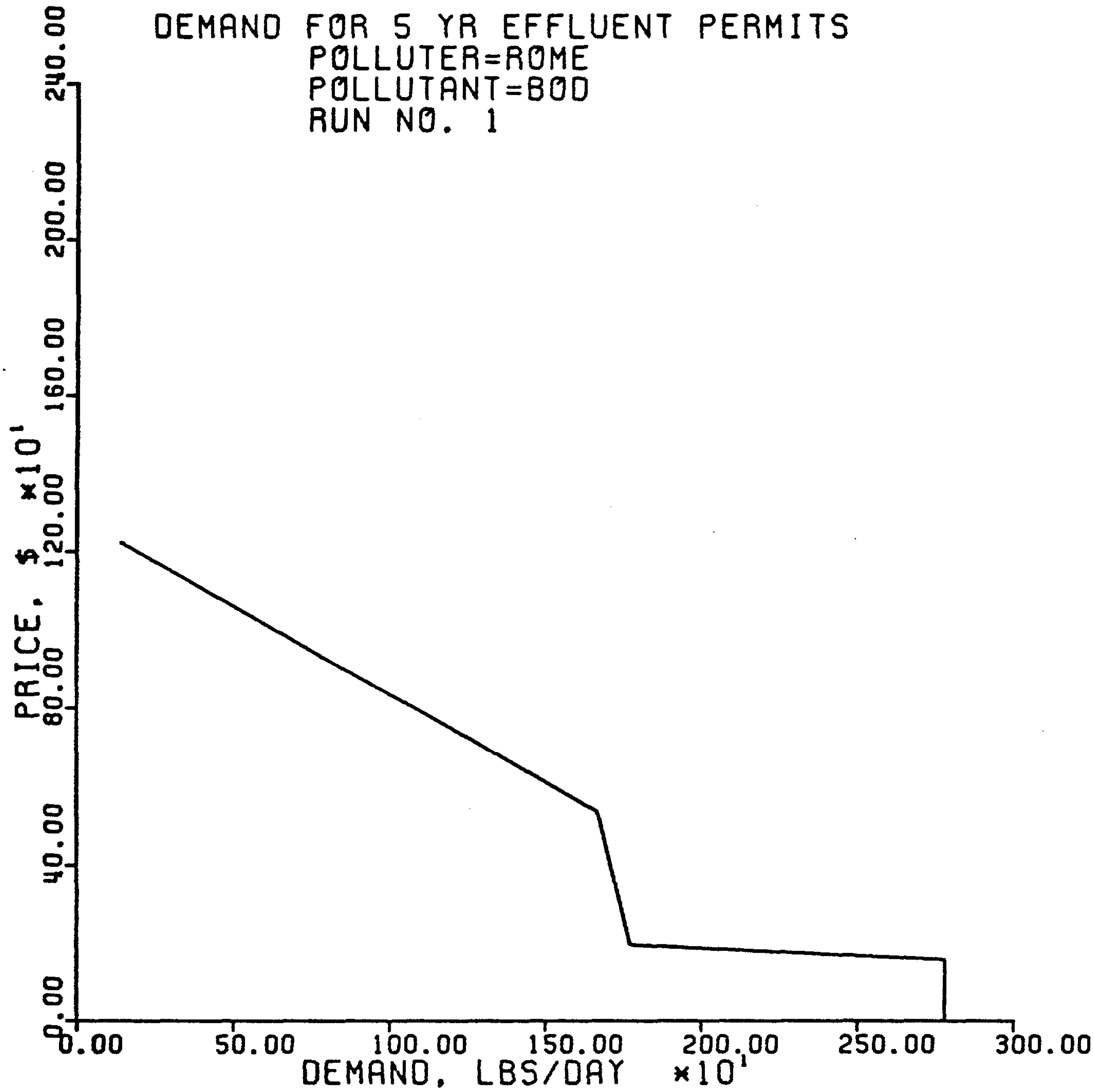


Figure 6-2

DEMAND CURVE OF UTICA FOR RUN 1
OF THE MOHAWK PERMIT SYSTEM SIMULATION

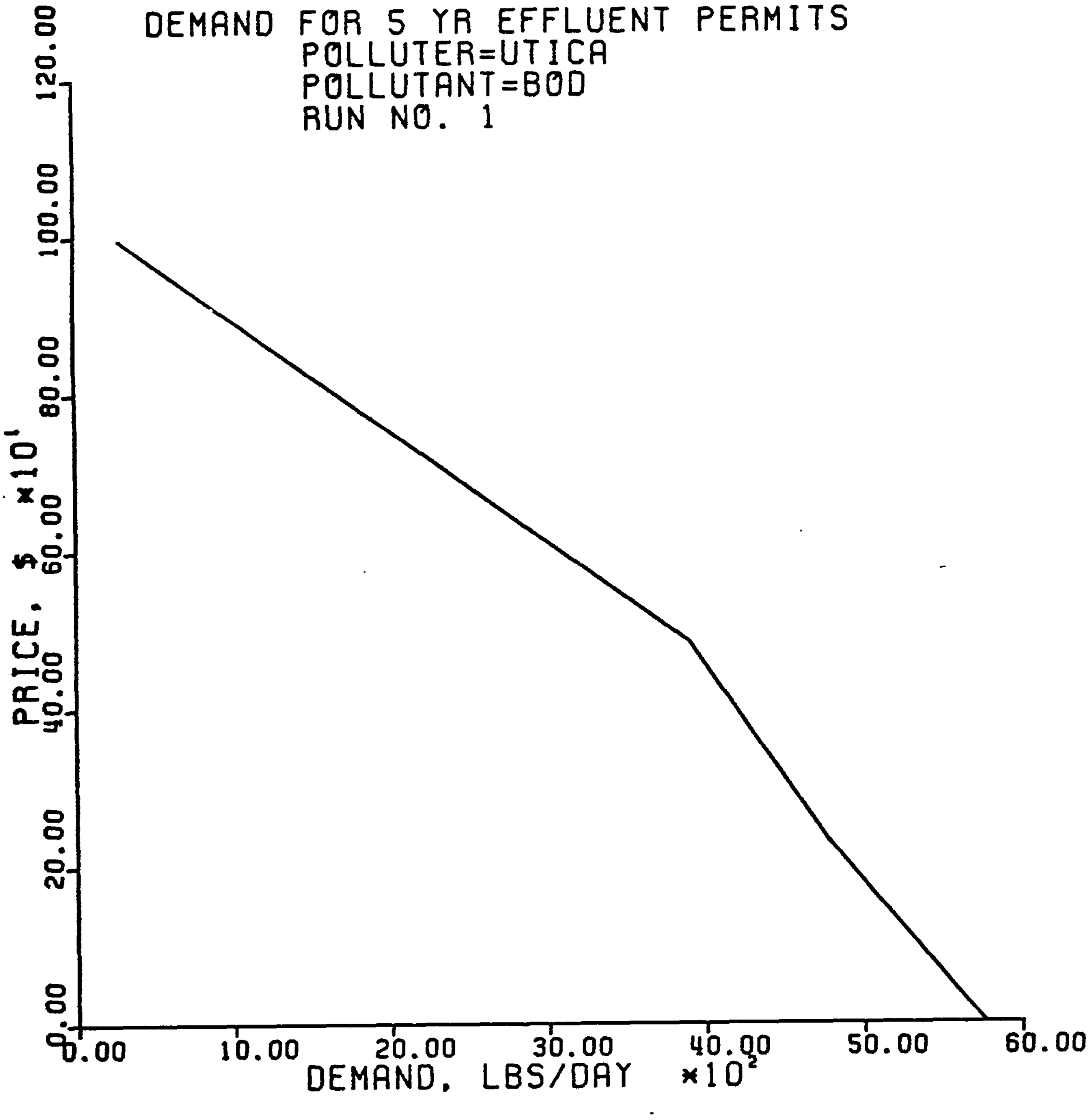
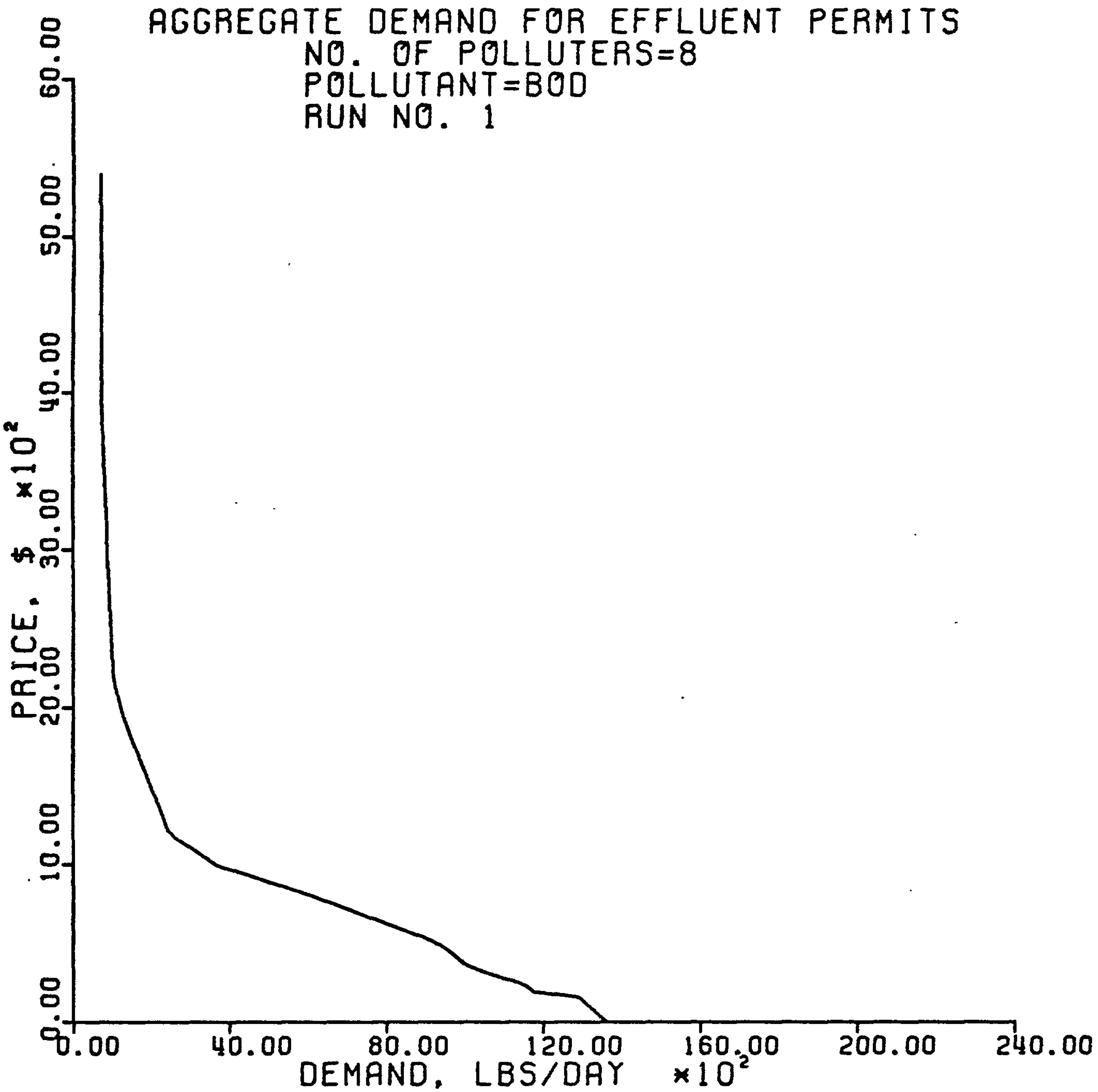


Figure 6-3

AGGREGATE DEMAND FOR EFFLUENT PERMITS



numerical data is available giving the aggregate demand curve and the market-clearing responses of polluters for each of the computer runs. Tables 6-6, 6-7, and 6-8 are used here to illustrate the form of these data. They are taken from computer run 1. Table 6-6 gives the nodes on the aggregate permit demand curve for the river basin. Demand is assumed to vary linearly between the nodes. Thus the number of permits demanded when the price is 0.0 is 13,624 while the demand at $100.00 per permit is 13,176.

Tables 6-7 and 6-8 give the market-clearing responses of the dischargers when the supply of permits is fixed at 4000 and 2000 pounds per day of BOD, respectively. Thus, Table 6-7 contains the price of a permit, the amount dischargers spend on permits and the number of permits they buy, the amount dischargers spend on waste treatment and the amount of wastes they discharge, and the associated totals under the assumption of a 4,000 pound per day supply of permits. Table 6-8 contains the same data under the assumption of a 2,000 pound per day supply. Both the total and the annualized (based on the discount rates in Table 6-3) cost figures are given. The annualized figures are given below the total cost figures.

An example can help to elucidate Table 6-7. The beginning lines of the table give the number of permits issued and the length of their term. The effluent permits