# A WATER QUALITY MANAGEMENT SIMULATION GAME

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## PREFACE

This paper is a description of a simulation game applied to Transferable Discharge Permits (TDP's). It uses a participant program to input data, a proctor program to simulate seasonal conditions, a cost program to evaluate the economic effectiveness of the TDP's, and the QL2SMG package to measure the impact on water quality.

I would like to express sincere gratitude to my major advisor Dr. Richard N. Devries, for his guidance and motivation. I am also thankful to Dr. Keith D. Willett and Dr. Ramesh Sharda for their insightful suggestions and invaluable help during the course of this work. An extra thank you must go to Dr. Vernon A. Mast and Dr. Enos L. Stover for agreeing to serve on my committee.

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# CHAPTER I

## INTRODUCTION

In recent years, environmental policy has become an increasingly important part of government regulatory activities. This, in turn, has motivated questions addressing the effectiveness of these activities. In particular, these questions are concerned with the cost effectiveness of regulatory activities as well as the ability to bring waste dischargers into compliance with environmental quality standards. An important concern is to evaluate the use of Transferable Discharge Permits (TDP's) in the attainment of water quality objectives.

A number of methods are available that could be used to evaluate the effectiveness of TDP's. David et al. [1] and Eheart et al. [2], for example, have used mathematical programming methods to evaluate the effectiveness of TDP's. In assessing the use of mathematical programming models, perhaps it could be argued that behavior cannot be predicted in a deterministic way. That is, optimization models presuppose some form of rational behavior on the part of managers such as profit maximization or cost minimization.

A viable alternative to mathematical programming models for addressing the effectiveness of TDP's is simulation gaming. The simulation game can be helpful for examining theories involving simplified situations and for abstracting phenomena from the real world. Simulation gaming has been employed as a tool for researching and for training in various fields. However, it is a new issue to Water Quality Management (WQM) decisions. Simulation gaming is valuable not only for teaching aspects of water quality decisions, but it can also be used as a research tool in understanding economic issues of water quality management.

The objective of this dissertation is to develop a water quality management simulation game to be used in exploring the effectiveness of achieving water quality standards with a system of transferable discharge permits. The potential for substantial cost savings from trading TDP's is demonstrated using data on a hypothetical river. The game will be tested initially without offering a TDP as an alternative. After four periods the game will include TDP's as an option for water quality decisions. A simulation model of water quality (QL2SMG) is used to study the impact of waste loads (magnitude, quality and location) on in-stream water quality. QL2SMG permits simulation of oxygen dynamics in a one-dimensional system with steady state hydraulics. Details of QL2SMG are given in Chapter III.

# CHAPTER II

# BACKGROUND AND LITERATURE REVIEW

## An Overview of TDP's

Transferable Discharge Permits (TDP's) have been examined over the past 20 years as a policy to achieve any desired level of air or water pollution abatement [3, 4, 5, 6]. Under this policy, the agency considers the assimilative capacity of the environment and issues the permit. Once distributed, the permits are tradable among polluters, their price being set by market forces and the cost of alternatives to pollution. Of course, no polluter may discharge the pollutant in excess of permit holdings, and enforcement is effected by the provision of fines which exceed the market value of the effluent permits.

The TDP system is called an "incentive type" system. The trading of permits allows more efficient waste processors to operate at a high removal efficiency and hold relatively few shares of effluent permits, while allowing less efficient waste processors to hold a relatively large number of permits, and perform little or no waste removal.

TDP's offer dischargers the alternative of purchasing a substitute for abatement. Entering the market is not coercive and will only be done when it appears profitable. In the short run, permits can be purchased to cover the excess discharges associated with plant failure or production overruns. On a seasonal basis, TDP's can be purchased to cover deficient capacity during a period of exceptionally limited assimilative capacity in the river. On a long-term basis, TDP's may be used to provide for a substantial part of abatement during periods where one firm is deficient in abatement capacity while another has excess capacity [7, 8, 9, 10].

## Economic Rationale for TDP's

The rationale for using TDP's as a policy approach for achieving water quality objectives can be examined by using a command and control approach to allocate the responsibility for meeting a specified water quality level standard [11].

An example for two wastewater discharges is shown in Figure 1. The amount of wastewater discharged for A and B is shown on the horizontal axis and is read from left to right. The amount of pollution abatement undertaken is essentially the same as reducing the total level of discharge and is represented by reading from right to left. The cost of undertaking pollution abatement is represented by marginal control cost curves $MC_A$ and $MC_B$. Marginal control costs are assumed to increase with an increase in the amount of pollution abatement. Prior to any regulatory action by the environmental authority, A will discharge $O\bar{E}_A$ and B will discharge $O\bar{E}_B$.

Now suppose that the environmental authority sets a discharge standard of $E_{T1}$ so that the total discharge from both dischargers cannot exceed $E_{T1}$(i.e., $OE_A + OE_B \leq OE_{T1}$). It is also decided that each discharger will be required to reduce discharge by an equal amount when allocating the responsibility for complying with the standard. Thus discharger A will be required to reduce its discharge by $E_{A1}\bar{E}_A$ and discharger B will be required to reduce its discharge by $E_{B1}\bar{E}_B$. The

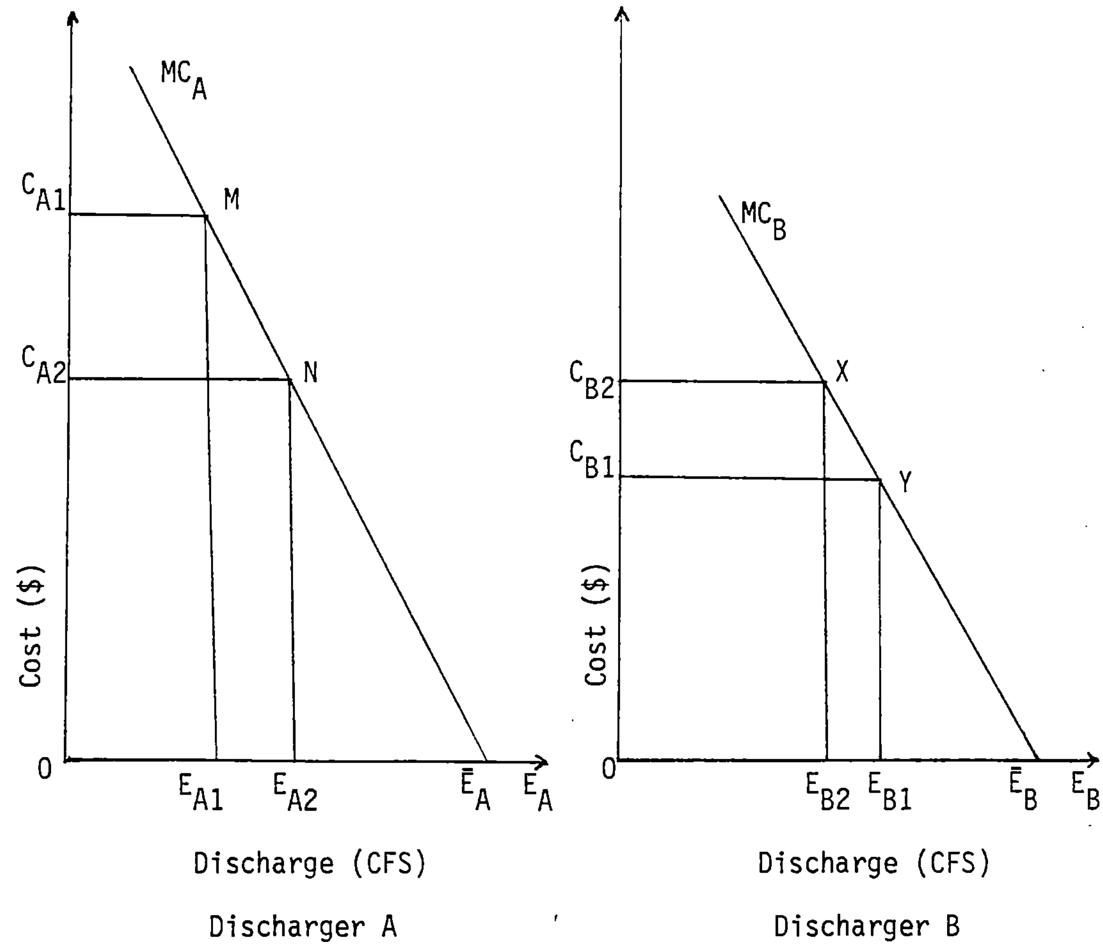
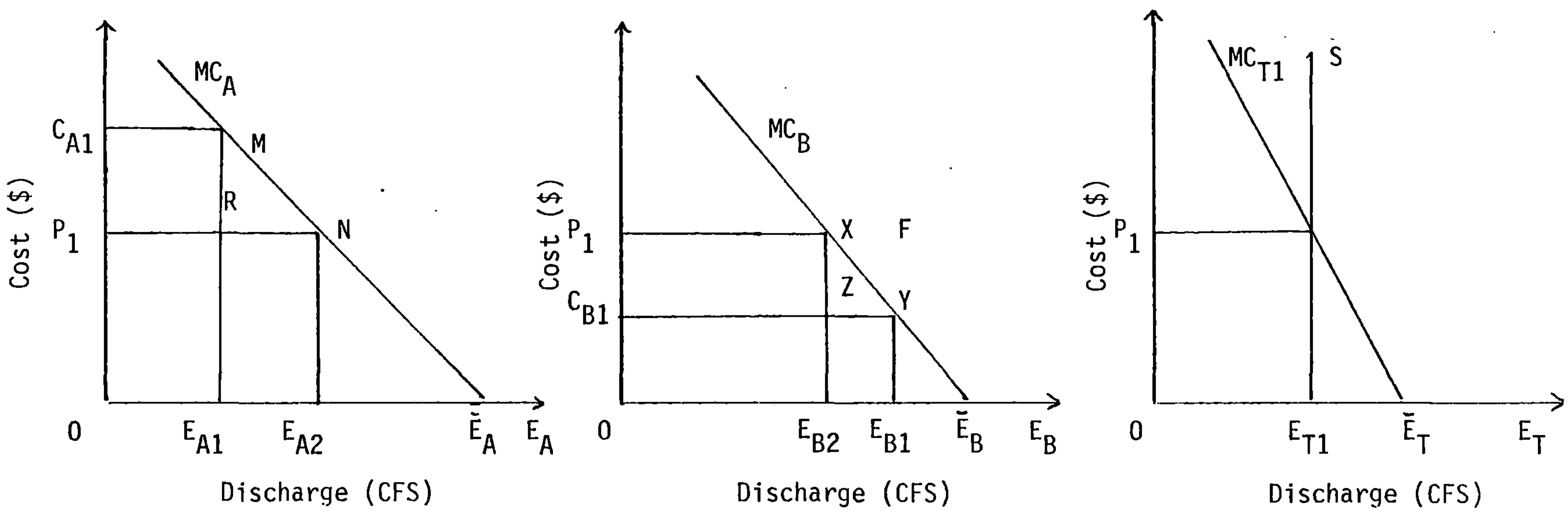



Figure 1. Command and Control Regulatory Approach

total control cost for discharger A is equal to the geometric area $E_{A1}M\bar{E}_A$ and the total control cost for discharger B is equal to the geometric area $E_{B1}Y\bar{E}_B$ on Figure 1. Total costs for complying with the standard are the control costs for the two dischargers.

It can be noted from Figure 1 that the marginal cost of reducing discharge by $E_{A1}\bar{E}_A$ for discharger A is $C_{A1}$ while the marginal cost of reducing discharge by $E_{B1}\bar{E}_B$ for discharger B is $C_{B1}$. This implies that total control costs can be reduced if discharger A is able to reduce the amount of its pollution abatement (i.e., increase its level of discharge) while discharger B is to increase its amount of pollution abatement (i.e., decrease its level of discharge). This is true because the reduction in total control cost for A to increase its emissions discharge, represented by the various points on its marginal cost curve as $MC_A$, is greater than the marginal cost or increased total control cost incurred by B for a higher level of pollution abatement. It is no longer possible for total costs to be reduced once marginal control costs for all dischargers are equal. In terms of Figure 1, this occurs when discharger A undertakes abatement equal to $E_{A2}\bar{E}_A$ units of discharge and discharger B undertakes abatement equal to $E_{B2}\bar{E}_B$ units of discharge. Of course, marginal control costs are equal at this point (i.e., $C_{A2} = C_{B2}$). Thus, the cost of achieving a given water quality standard will be minimized if and only if the marginal costs of control are equalized for all dischargers.

The rationale underlying the preference for TDP's as a regulatory mechanism for achieving a cost-minimizing solution for complying with a given water quality standard can be demonstrated with the aid of Figure 2. Assume that the environmental authority sets a standard for discharge of $OE_{T1}$ and creates the same number of TDP's. The supply of TDP's is predetermined since the total amount is controlled by the environmental authority. Thus, the supply of TDP's is given by $\bar{S}$. Assume also that the individual marginal control cost curves $MC_A$ and $MC_B$ can be horizontally aggregated into a total marginal cost curve $MC_{T1}$ as shown in Figure 2.




Discharger A — Discharger B — Total Discharges Market

Figure 2. Transferable Discharge Permit Market

Assume that the environmental authority makes an initial distribution of TDP's to the two dischargers as follows: discharger A receives $OE_{A1}$ permits and discharger B receives $OE_{B1}$ permits (Note that $OE_{A1} + OE_{B1} = OE_{T1}$). Dischargers are then allowed to buy and sell permits in a single clearing price TDP market. The decision to buy or sell permits will depend on the price of permits relative to the marginal cost of pollution abatement. Thus $MC_A$ and $MC_B$ are the individual dischargers demand curves for TDP's and $MC_{T1}$ is the total market demand curve for TDP's.

The market-clearing price in Figure 2 is given by $P_1$. Discharger A will then demand $OE_{A2}$ permits and discharger B $OE_{B2}$ permits (where $OE_{A2} + OE_{B2} = OE_{T1}$). In terms of their initial allocations, discharger B will sell discharger A a number of permits equal to $E_{A1}E_{A2} = E_{B1}E_{B2}$ at a price of $P_1$ per permit. Discharger A will now incur an abatement cost of $E_{A2}N\bar{E}_A$ for abating emissions equal to $E_{A2}\bar{E}_A$, and will spend an amount equal to $E_{A1}RNE_{A2}$ for a number of TDP's equal to $E_{A1}E_{A2}$. Discharger B, on the other hand, will increase its level of emissions abatement by $E_{B2}E_{B1}$. B will also realize an increase in its abatement cost equal to $E_{B2}XYE_{B1}$, but receives TDP revenue equal to $E_{B2}XFE_{B1}$. Discharger A is then subsidizing part of B's treatment cost plus providing B with a net profit equal to XFY.

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

Benefits of TDP's

The TDP system has four desirable attributes. These are simplified regulation, saving in treatment costs, incentive and flexibility, and the ability to deal with the gorwth and entry of dischargers.

Regulation. Regulation is reduced. For example, effluent charge control for a river basin can be made simple and inexpensive with the TDP system. In addition, when permits expire, the regulatory authority can reduce the total amount of permits by issuing fewer. More important, 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 can be accomplished without devising different rules and procedures for different polluters.

Treatment Cost Saving. The reduction in treatment costs under TDP's occurs because under a TDP system the most technically efficient treatment plants will remove more of the pollution load. Braasch and Joeres [12] estimated that TDP's would result in a cost saving for the Lake Michigan basin of Wisconsin of three quarters of a million dollars annually. This cost reduction will occur without violating the wastewater level standard.

Incentive and Flexibility. For the dischargers, the important incentive is that TDP's allow flexibility in operation. Industries can then more readily vary production and operate closer to the margin without always having to consider long-range capital investment planning. While it is hard to value flexibility in dollars, flexibility can be stressed as an advantage.

Municipalities can gain from improved timing of construction of wastewater treatment plants. Delays in construction can be handled with the purchase of permits, rather than requests for variances. And any delays in construction may allow refinement of population service demand projections. This creates potential for improved plant designs.

Incentive for the regulator derives from the fact that TDP's support the environmental mission of the agency. TDP's enhance the likelihood of meeting environmental goals. Requiring dischargers to fully explore TDP's prior to requesting variances will reduce the number of such requests to the agency, thus reducing the need for difficult social welfare decisions.

Growth and Change. The growth and entry of polluters are handled naturally and efficiently in the TDP system. Increasing waste discharges, through either entry or growth, is allowed only upon the acquisition of effluent permits. Thus, new entrants will increase the price of TDP's. This is an advantage to holders of rights who elect to sell. The increased demand for a fixed supply is a disadvantage for dischargers wanting to increase their discharge. The TDP system is preferable for all dischargers. Because although the unit cost of treatment rises as increasing amounts of pollutants must be eliminated, the average unit cost in a TDP system will still be the least cost. In a regulatory system without TDP's, the sum of the individual treatment costs is higher since each expanding facility must bear its own costs of increased treatment, some of which will be higher than the lowest cost achievable with TDP's.

Water Quality Consideration

One of the most important decisions the authority must make in designing any water quality management program for a particular water body is the form and stringency of the water quality goal. This goal is assumed here to be expressed as follows: A set of receiving water body conditions is chosen which represents a low extreme of assimilative capacity. These conditions, as usually represented for a stream by a low streamflow and high temperature, are referred to as the critical conditions. For example, the "sag point" in the levels of dissolved oxygen concentration. All of the authority's decisions regarding numbers of permits to issue, are assumed here to be undertaken on the basis of these conditions. Once the critical conditions have been determined, a mathematical model is assumed to be available for use by the authority to relate the water quality at all points in the receiving body to the waste discharge rates of each discharger.

Another policy decision is the basis of definition of the permits. Two definition bases are considered here. The first, called a BOD permit, entitles the holder to discharge a certain weight of BOD per day. The second type of permit entitles a discharger to deplete the dissolved oxygen at a specific location in the watercourse by a certain amount, as predicted by the water quality model for the critical conditions chosen. It is termed a Dissolved Oxygen Deficit Contribution permit (DODC). A DODC permit corresponds to a BOD permit of a certain size when held by a given discharger. However, unlike the BOD permit, it is revalued when transferred to another location [13, 14].

Water quality problems depend in part on local physical features with the type of trading restrictions chosen by the authority varying from one water body to another. However, the efficiency achieved by the TDP system comes about by letting the most efficient plant perform most of the waste removal without regard to where it is located, except when its location affects its cost of treatment. Thus, to maintain a specified water quality profile, the authority must recognize that the effects of discharges on water quality are different for different discharge locations and must formulate the effluent permits accordingly.

This research assumed seven participants located within a given zone to allow one-to-one trades of permits. The definition base for the permits is pounds of BOD per day (Lbs-BOD/day). A simulation model of water quality (QL2SMG) is used to estimate the relations between dischargers and DO levels at various locations along the stream.

## An Overview of Simulation Gaming

Simulation gaming is described by Wood [15] as follows: "As a form of simulation model, gaming is similar to other simulations where the major purpose is to understand dynamic process. While the approach emphasizes process, it attempts to comprehend human activities as the products of indeterministic forces which can lead to any one of a possible range of outcomes, and is in essence a probabilistic approach. Where gaming simulation differs from other methods is that it attempts to provide experience of a 'real world' decision making situation, where goals have to be formulated, problems evaluated and judgment exercised".

Because of the complexity of human nature, it is difficult to describe the social and political system in terms of ordinary equations. Simulation gaming is designed to overcome this difficulty. As its name implies simulation gaming comprises two basic components: gaming, involving interaction between human "players", and simulation, involving interactive computer facilities [16].

Simulation gaming can be traced back to the mid-1950s when Rand Corporation developed "crisis game". This game provided foreign policy makers with a set of useable alternatives in the event that similar crises actually occurred [17]. Since that time, the number of simulation games has increased at a rapid rate. Currently, simulation gaming is widely used for amusement, education, and research.

Although still somewhat of a novel concept, simulation gaming is becoming accepted as a tool in the analysis of water resource systems, especially when decisions are likely to involve conflict and compromise. Wright and Howell [18] described a simulation gaming analysis of a water resource development issue in New South Wales. Johnson and Whitehead [19] elaborate on the value of simulation gaming in increasing the awareness of planners involved in water resource issues. Diamond et al. [20] discuss the design of simulation games for teaching and researching drought management.

One of the most recent and successful applications of water resource gaming occurred in 1982, when a one-day exercise was conducted in Washington D.C. The focus of the exercise was on reservoir operating policy in the Potomac River Basin. The water supply situation in and around the Washington D.C. area has been the source of considerable controversy for many years. Three agencies are responsible for supplying water, primarily from the Potomac River, to the 2.5 million residents of the region. Complicated relationships have evolved between these agencies as to how water should be allocated during periods of low flow in the Potomac River. Traditionally, there have been many disputes and little cooperation between the agencies. As a result, what should have been an adequate supply of water to the region during dry periods has been allocated inefficiently, and the reliability of the regional water distribution scheme has been questioned.

A group of researchers at Johns Hopkins University developed an interactive simulation model of the Potomac River Basin water system. This model, the Potomac River Interactive Simulation Model (PRISM), was to be used as a research and learning tool for those groups involved in the water supply planning in the region. Though PRISM was valuable as an aid in identifying alternative management strategies, it was even more effective when incorporated into a simulation gaming exercise. The exercise brought together many of the key decision makers from each agency and from other groups involved with water supply management. Interacting with PRISM and among each other, these groups gained insight into many of the conflicts involved in the water supply issue. As a result of the research at Johns Hopkins, many of the obstacles which previously prevented efficient regional water management were removed. The investigation approach was so successful that the project was considered for the 1983 Outstanding Engineering Achievement Award [21].

A literature search has unveiled no game designed for water quality management. Timely and efficient disposal of the waste generated by the manufacturing plant requires engineering as well as economic analysis. This is because most companies have to operate under a permit issued by some state regulatory body. Typically these permits allow companies to release a specified maximum amount of waste with certain biochemical characteristics. The companies may also have the choice of releasing the waste into the city sewer system and paying the municipality a user charge. Obviously the decision on proper disposition of the waste can involve evaluation of several alternatives based on economic analysis. A decision to expand waste treatment also has to consider production forecasts. Thus, this game would be valuable not only for teaching aspects of water quality decisions, but it could also be used as a research tool for understanding economic issues of water quality management.

## The Benefits of Simulation Gaming

Research Tool. Simulation gaming may provide one or more advantages as research tools including: 1) Ease of observation and data collection; 2) Reproducibility; 3) Lower cost; and, 4) Ability to study phenomenon where direct research is not politically acceptable [22]. As a result of these advantages, simulation gaming has been used for research in psychology [23], sociology, the military, economics [24] and various other fields.

Teaching Tool. Simulation gaming may also provide one or more advantages as a teaching tool including: 1) Students exhibiting a high degree of interest and participation; 2) Students experiencing making managerial decisions; 3) The opportunity to integrate concepts from diverse areas of courses; 4) The experience of living with past decisions; and, 5) The decision-making experience is condensed into a relatively short period of time [25].

Disadvantages of Simulation Gaming

Aronson and Carlsmith [26] delineated two types of realism: mundane and experimental. Mundane realism relates to how likely it is that the events occurring in a laboratory are likely to occur in the real world. Experimental realism relates to how seriously the subject takes the experiment. Some users have the tendency to treat simulation as a "game" rather than to treat problems with experimental realism. This results in lack of incentive to perform the game well. Nees [27] noted that the participants in her simulation "did not bear the consequences of their decision. Neither were they penalized for failure, nor did they have to live with their undertakings after the simulation was over".

The "lack of incentive" issue is intertwined with another issue, regarding the nature of the subject group, whether they are college students or managers. On one hand, the grade environment which exists in the classroom places an incentive on student subjects to do well. Slusher, Sims and Thiel [28] found that semester-long involvement in a competitive learning environment provides a high and consistent incentive. On the other hand, when Bass [29] discussed the high motivation level usually found among manager-subjects, he observed that "real managers try to do their best when confronted with simulated management problems". Incentive for play was attributed to competitive desires and to a sense of loyalty to one's team.

The best answer to the question of whether the game has experimental realism involves a comparison of the subjects' game behavior with their actual behavior. Obviously, this can present serious problems in the case of student subjects as they cannot be expected to be making actual decisions for most topics under investigation. However, there have been studies which compared the performance of manager-subjects in simulation games to their performance in the workplace. Babb and Bohl [30] found 70% of farmers', initial pricing decisions in a farm management game to be consistent with their real life decisions. Jones and Babb [31] found that retail managers' pricing decisions agreed with their real world behavior only about half the time. However, they did find that their non-price behavior was nearly identical to that used in the simulation games.

Babb, Leslie, and Van Slyke [32] noted that there are striking differences in game behavior and in results between students and experienced managers. Students are affected much more by information provided them, whereas managers apparently rely on experience. Managers follow more conservative policies then students, while students are more erratic in their decisions. Apparently students feel the need to learn something about the industry by experimenting with the game. Student performance was usually much lower than experienced managers in early decisions but quickly came to an equal level. The general conclusion is that experimentation on the subjects' part does take place and that this experimentation is not likely to be done in a real world environment. However, even when student subjects are used, game behavior moves toward real life after a few decisions.

The field of simulation games is still growing at a prodigious rate, as measured by their commercial availability. Yet many reports indicate that simulation games are not entering the classroom as fast as they are proliferating on publisher's lists. The major reason is that simulation games are often viewed as highly complex, strange, slightly upsetting phenomena by teachers who have never used them. Some professors who initially undertake the usage of simulation exercise because they think it represents an escape from their teaching duties soon find that it requires a great deal more of their time than they had expected. In most cases, more time than they normally would have spent using their traditional methods. The net result being that certain professors drop the use of simulation games and return to the traditional methods with which they feel more comfortable [33].

# CHAPTER III

# METHODOLOGY

## Description of the Game

### Basic Game Structure

The flow chart (Figure 3) illustrates the basic structure of the game. The game begins with a detailed description (illustrated in Appendix A) of the firm or of the municipality that the participants are to represent. This includes data on production plans, costs of production, and the relationships between the output and effluent of various pollutants. The municipal managers are given data related to city waste treatment and to the requirements from the firms in the area for waste treatment. The water quality standards that the firm or the municipal plant must meet are also given to the participants. They also receive information on legal consequences of releasing effluent without treatment. This includes the estimated penalties and probability of getting fined.

Besides the production data, the manager is also given a complete list of alternatives (described later in detail). Each alternative comes with its cost effectiveness figures. Costs are given for various stages of treatment for each plant capacity [34].

After considering all the information, the participant evaluates the alternatives and makes a decision in terms of production volumes,

INITIAL CONSIDERATIONS

Planned Production
Price
Cost of Production
Relationship Between Production and Pollution
Methods of Production
Water Quality Standards
Objectives
Violation Penalties
Probability of Getting Fined

↓

Determine the following based on the previous data

↓

1. Treat all wastewater in the company plant and release it to the river.

2. Pretreat all wastewater in the company plant and send it to the municipal plant.

3. Send all wastewater to the municipal treatment plant without treatment.

4. Treat part of the wastewater in the company plant and release; send other part of the wastewater, without treatment, to the municipal plant.

5. Pretreat part of the wastewater in the company plant and send to the municipal plant; send the other part of the wastewater, without treatment, to the municipal treatment plant.

6. Discharge all wastewater without permit and without treatment.

7. Treat part of the wastewater in the company plant and release; send the other part, without treatment, to the river.

8. Discharge wastewater after buying permit.

↓

Decision is Made

↓

The simulation game produces results based on the choices from above

Figure 3. Water Quality Management Game Flowchart

pollutant disposal alternatives, and size-cost data. Also included in the decision is the choice of expanding current treatment capacity which could be available two periods later.

The decision-making is followed by the entry of the data into the computer. Then the simulation game is started, and the gaming program prepares two reports. From all the decisions, the production-pollution relationships determine the generated pollutants. The individual cost and quality of effluents are derived from the abatement options of the teams. The game also uses the QL2SMG model to calculate the water quality for the whole region. The QL2SMG model considers pollution from several sources at several points and calculates water quality in terms of BOD and dissolved oxygen concentration.

Each participant obtains a summary of results of his or her decisions, including the actual cost incurred, fines for violating water quality standards, pollution clean-up alternatives, etc. The information also includes the overall water quality at different locations in the area. The game is then repeated for the next period, i.e., the next quarter, details of which will be given later.

## Participant Characteristics

Five industrial firms and two municipalities constitute the region simulated by the game in its current version. A team represents either a firm or a municipality. Using teams of two or more for each industry or municipality, the game can include more participants in each region. Figure 4 gives a schematic of the region. It also indicates that industries and cites are situated along a river and its tributaries. The numbered elements in the figure represent "mile-marks". Thus, for

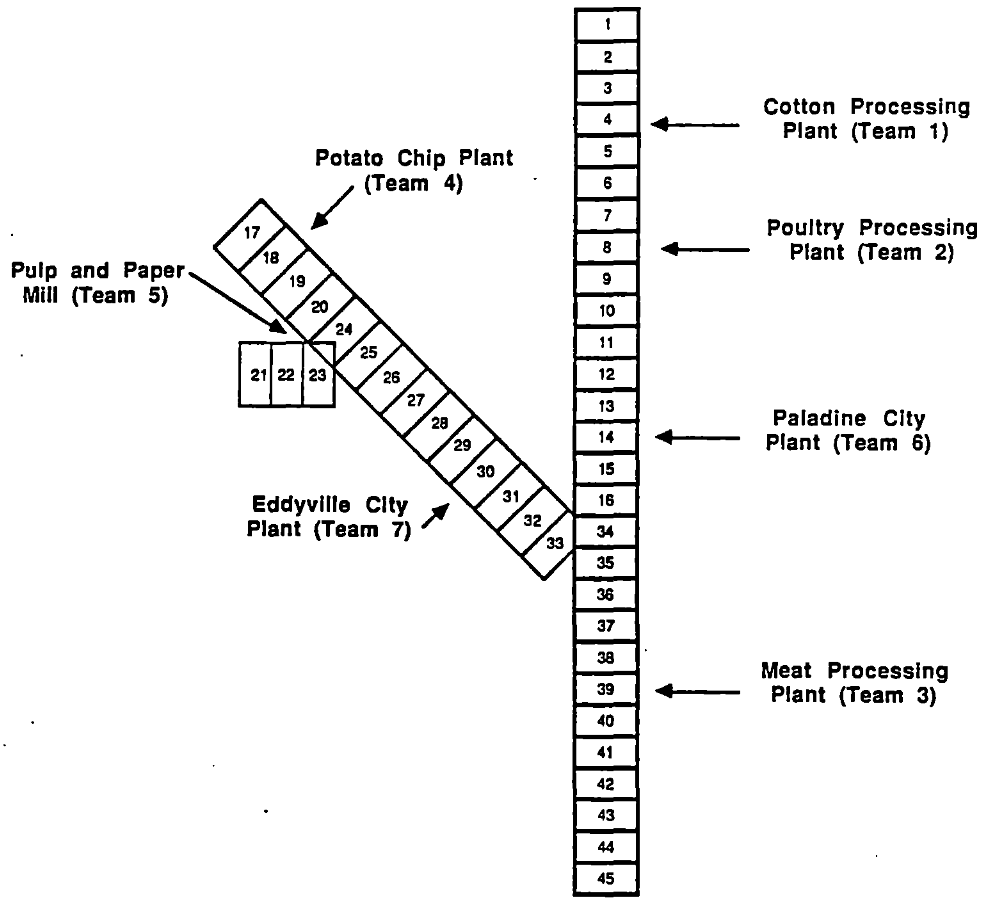



Figure 4. Typical River Region Consisting of Industries and Cities

example, team one is four miles upstream from team two. The first three industrial firms are assumed to be in Paladine City and the others are in Eddyville. The five industries selected in this game are industries which generate significant amount of industrial wastes.

The plants represented by the industrial firms are processors of cotton, poultry, and meat, and factories making things such as potato chips and pulp-and-paper. These plants could be either small- or medium-sized. Each participant gets a description of the production function of the firm. The data involve the production forecast for four quarters, associated expected wastewater flow rates in million gallons per day (MGD), and influent BOD in milligrams per liter (mg/1). The data also include the permitted discharge to the river in terms of maximum flow rate (MGD) with limits on BOD concentration in the effluent and with the capacity of the available wastewater treatment plant. The estimated fixed as well as variable costs of operating wastewater treatments at various levels are also provided. In case a firm decides to use the municipal plant for disposal of wastewater, the participant is given the estimated user charge at different flow rates and pretreatment levels. Finally, a table containing costs of larger plant sizes accompanies the information package to help in making decisions on upgrading the plant.

The five industrial firms and the two municipal plants have a wide range of plant sizes, permits, and production forecasts. Table I contains a summary of starting values of permitted discharges, and plant sizes. The information is realistically based on interviews with representatives of many of the regulatory agencies in the State of Oklahoma.

TABLE I

INITIAL WATER PARAMETERS FOR THE PARTICIPANTS

| | Max. Permitted Discharge | | Plant Capacity | |
|---|---|---|---|---|
| Team | Flow (MGD) | BOD (mg/l) | Flow (MGD) | BOD (mg/l) |
| 1 | 1.7 | 30 | 1.5 | 20 |
| 2 | 0.38 | 24 | 0.45 | 24 |
| 3 | 0.03 | 40 | 0.05 | 70 |
| 4 | 0.04 | 20 | 0.05 | 20 |
| 5 | 2.00 | 20 | 2.00 | 40 |
| 6 | 15.00 | 45 | 16.00 | 40 |
| 7 | 3.00 | 10 | 5.5 | 10 |

## Decisions and Alternatives

By learning the key concepts and performing skills used in a decision-making process, the participants gain the ability to frame a problem, identify useful data, predict and bargain permit prices, and render judgments about the appropriate actions.

The simulation game plays eight periods, each period representing one season. The first four periods don't involve the TDP case, while the later four periods cover the TDP case, in order to make a fair comparison, the production volume of the first four periods should equal that of the following four counterpart periods: i.e., the first period production volume is the same as that of the fifth period production volume. Three types of decisions are made during the first four periods. The participants determine the production volumes and choose any of the first six alternatives in disposing of the expected waste in the current period. The next step is to decide whether to upgrade the treatment plant. During the final four periods, participants have to make four kinds of decisions. First they negotiate the transfer of discharge permits with the other participants at a mutually agreeable price. Those who want to buy permits can only choose alternative 1, 4, 7 or 8, but if they want to sell permits, they can choose any of alternatives 1 to 7 to treat their wastewaters and finally, decide wheather to upgrade their existing plants or not. If they want to upgrade their plants, the upgrades take two periods of time.

The basic production-pollution relationships and production costs are a built-in feature of the program. The eight alternatives are:

1. Treat everything in the company plant and release to the river.
2. Pretreat everything in the company plant and send to the municipal plant.
3. Send all waste to the municipal plant without treatment.
4. Treat part in the company plant and release; send the other part of the wastewater, without treatment, to the municipal plant.
5. Pretreat part in the company plant and send to the municipal plant; send the other part, without treatment, to the municipal plant.
6. Discharge without permit and without treatment.
7. Treat part in the company plant and release; send the other part, without treatment, to the river.
8. Discharge wastewater after buying permit.

The first alternative requires treating the waste entirely in the company plant. The company then incurs capital and operating costs of a treatment plant. The next four alternatives use the municipal plant to some extent, involving the expense of a user charge. The sixth alternative is unacceptable. The last two alternatives are used for the TDP case only. If a company is caught discharging without permit and treatment, a heavy fine is imposed which simulates a penalty and bad publicity.

It is not easy to decide among these alternatives. The participants must calculate the total cost of each alternative. The alternatives involving partial treatment require consideration of the extent of treatment and of its effect on total cost. Some of the alternatives may not be practical due to the capacity of the treatment plant and/or the permitted discharge. For instance, if a firm has a wastewater treatment plant with a design capacity of 0.08 MGD flow and expects 0.09 MGD flow during a certain quarter, it cannot choose alternative 1, treating everything in the company plant and releasing to the river. Thus, the participant has to select the practical set of alternatives first, analyze their implications, and make a decision. The continuity from quarter to quarter is also an important issue to consider. The long term effect of a strategy cannot be ignored.

The decision to upgrade the plant may affect future decisions as well. The benefits of a larger plant, such as "pretreat the waste and release to the city sewer", or "treat part of the waste and release to the city sewer", have to be considered against the costs of these benefits as well as costs of alternatives. These two decisions require a thorough analysis of marginal costs of each alternative.

## The Conceptual Model of Game Program

There are five programs involved in this simulation game: (a) the participant input program, which lets the participants input their decision; (b) the proctor input program, which generates the QL2SMG input format for executing the QL2SMG program; (c) the cost program, which generates a financial report for each team; (d) the QL2SMG package, which calculates the water quality report for the whole region; and (e) the SAS package, which assesses the impacts of water quality and cost between the TDP system and the non-TDP system.

### Participant Input Program

After participants use computer command language to enter the program, the program will read plant design capacity, TDP price and permit numbers from different data files automatically. Afterwards, participants should input their team numbers (teams 1 to 5 represent industrial firms; teams 6 and 7 indicate municipal plants), period number and production volumes. The program will generate wastewater flow rates and BOD concentrations by built in production-pollution relationships. The flowchart of this program is found in Figure 5. The participant input program is given in Appendix F.

If the participants want to buy permits, they can choose alternative 1, 4, 7 or 8, but if they decide to sell permits, they can choose any alternative from 1 to 7 to treat their wastewater. Finally they are asked wheather to expand the existing plant or not. The optimal size of the plant should be the size that minimizes construction costs and penalty costs associated with inadequate capacity.

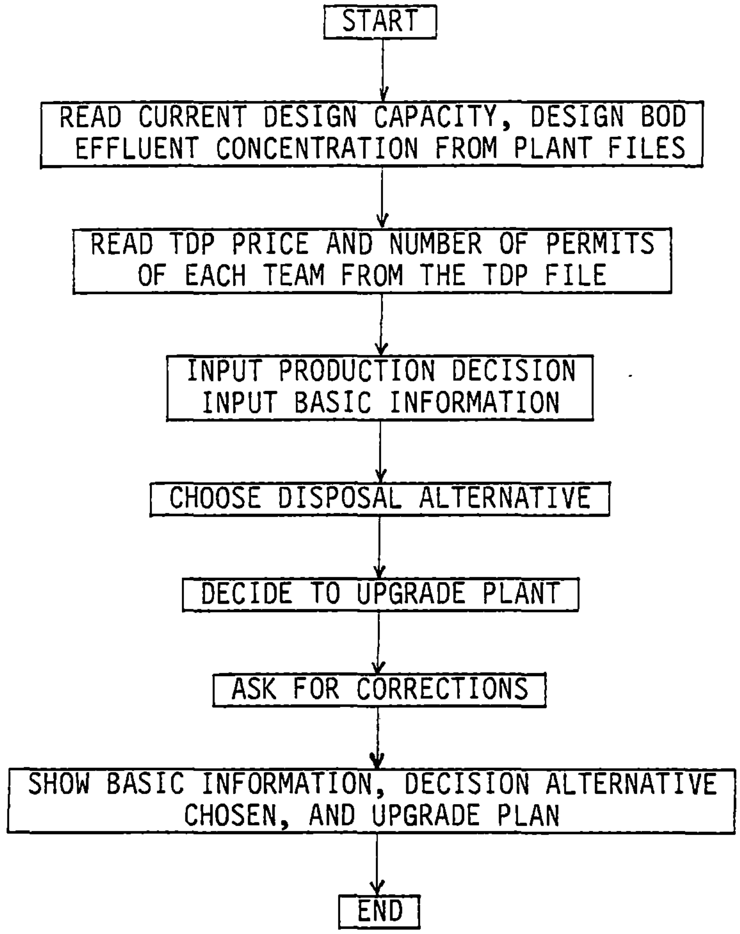



Figure 5. Participant Input Program Flowchart

## Alternatives

There are eight alternatives involved in the treatment options.

Alternative 1: Alternative 1 states "Treat all wastewater in the company plant and release to the river". This alternative will be restricted by five factors: (a) Treated wastewater flow rate should not exceed the plant's design capacity, (b) Treated wastewater flow rate should not exceed the maximum limitation of wastewater flow rate to the river, (c) Treated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, (d) Treated wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the river, and (e) The design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river. For the TDP case, this restriction will be released. In periods 5, 6, 7 and 8, the BOD effluent concentration is calculated by the formula:

$$BODE = (SBOD \times SQ)/Q1 + TDP \qquad \text{(Eq. 1)}$$

Where BODE is the treated BOD effluent concentration (mg/l)

SBOD is the allowed BOD effluent concentration to the river (mg/l)

SQ is the maximum limitation of wastewater flow rate to the river (MGD)

Q1 is treated wastewater flow rate (MGD)

TDP is the number of trading permits

Example: The allowed BOD effluent concentration to the river from plant 1 is 30 mg/l and the expected wastewater flow rate is 1.36 MGD in period 3 and period 7. Under the non-TDP case, team 1's discharged BOD effluent concentration should not exceed 30 mg/l. But during period 7, if this team does not trade permits, the BOD effluent concentration is 37.6 mg/l.

Alternative 2: The second alternative states "Pretreat all wastewater in the company plant and send to the municipal treatment plant". This alternative will be restricted by three factors: (a) Pretreated wastewater flow rate should not exceed the design capacity, (b) Pretreated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, and (c) Pretreated wastewater

BOD effluent concentration should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 3: The third alternative states "Send all wastewater to the municipal treatment plant without treatment". This alternative will be restricted by BOD effluent concentration of discharged wastewater, which should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 4: The fourth alternative states "Treat part of the wastewater in the company plant and release; send the other part of the wastewater, without treatment, to the municipal plant". This alternative will be restricted by seven factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, (c) Treated wastewater flow rate should not exceed the maximum limitation of wastewater flow rate to the river, (d) Treated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, (e) Treated wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the river, (f) Discharged wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the municipal treatment plant, and (g) The design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river (for the TDP case, this restriction is cancelled).

Alternative 5: The fifth alternative states "Pretreat part of the wastewater in the company plant and send to the municipal plant; send the other part of the wastewater, without treatment, to the municipal plant". This alternative will be restricted by four factors: (a)

Pretreated wastewater flow rate should not exceed the production wastewater flow rate, (b) Pretreated wastewater quantity should not exceed the design capacity, (c) Pretreated wastewater BOD effluent concentration should not exceed the design capacity for BOD effluent concentration, and (d) Pretreated and discharged wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the municipal treatment plant.

Alternative 6: The sixth alternative says "Discharge all wastewater without permit and without treatment". This alternative does not have any restrictions.

Alternative 7: The seventh alternative states "Treat part of the wastewater in the company plant and release; send the other part, without treatment, to the river". This alternative will be restricted by three factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, and (c) The discharge permitted is equal to the initial permit holdings plus traded permits. The teams must be careful because this situation can only exist in the TDP case.

Alternative 8: The eighth alternative says "Discharge wastewater after buying permit". This alternative will be restricted by the fact that the discharge permit needed is equal to the initial permit holding plus purchased permit numbers (for the TDP case only).

The upgrade plan is restricted by: (a) Future design capacity is not less than the current design capacity, and (b) Future design BOD effluent concentration is not larger than the current design BOD effluent concentration.

In the TDP system, each permit authorizes a specific rate of discharges, say one Lb-BOD/day. After initial distribution of permits among participants, if the participants still want to purchase permits, they can slacken wastewater discharge, i.e., the current maximum of limitation of BOD effluent concentration will be increased. For example, the current design BOD effluent concentration for team 3 is 70 mg/l, the maximum limitation of BOD effluent concentration is 40 mg/l and expected wastewater flow rate is 0.030 MGD. Owing to the restriction alternative 1 (e), "The design BOD effluent concentration should not exceed the allowed BOD effluent concentration to the river", under the non-TDP system, they can never choose alternative 1 for disposal of their wastewater, but under the TDP system if they purchase permits for 7.51 Lb-BOD/day, their discharged BOD effluent concentration can be 70 mg/l. In other words, the maximum limitation BOD effluent concentration is increased to 70 mg/l. Therefore, team 3 can choose alternative 1.

In certain cases, participants decide to expand the existing treatment facilities. This decision will invoke additional capital costs. These costs will vary with the wastewater design flow and BOD design effluent concentration. Once the wastewater treatment facilities are defined in terms of wastewater design flow and BOD design effluent concentration, the capital costs become fixed costs until further decisions are made to augment the treatment plant again. The additional capacity for the plant will not become available until two periods after the decision to upgrade the plant has been made.

Proctor Input Program

The stream flow rate and water temperature are the most important physical parameters that affect the capacity of a stream to assimilate BOD effect. In this program, it is assumed that flow and water temperature vary in a predictable sequence over the course of an annual cycle. For control purposes, the year is divided into four periods, each exhibiting constant stream conditions. After the proctor chooses a season index (1 for spring, 2 for summer, 3 for fall and 4 for winter), the program will set the suitable flow rates and temperatures for each computational element automatically. The discharge loading at various points is read from participant decision datasets and used to define the point source conditions. Finally, this program will generate an input format for the QL2SMG program (See Figure 6). The proctor input program is given in Appendix G.

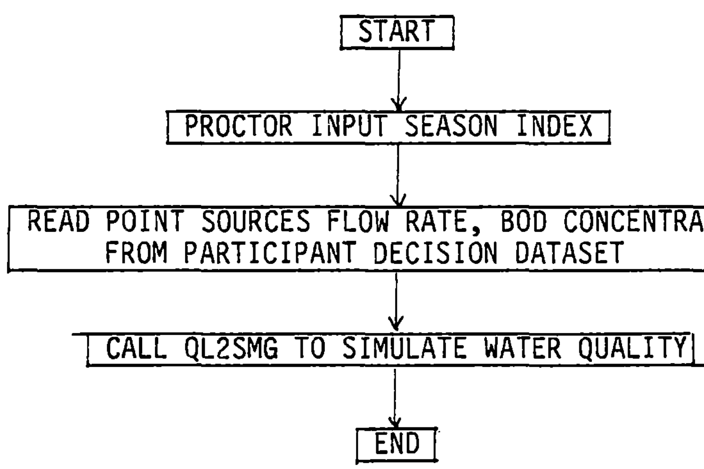



Figure 6. Proctor Input Program Flowchart

Cost Program

The purpose of the cost program is to calculate the capital costs (See Figure 7), operation costs, and total net income for each participant. Considerable effort was made to ensure the accuracy of the relationship included in the cost program. The Fortran program for cost calculations is given in Appendix E.

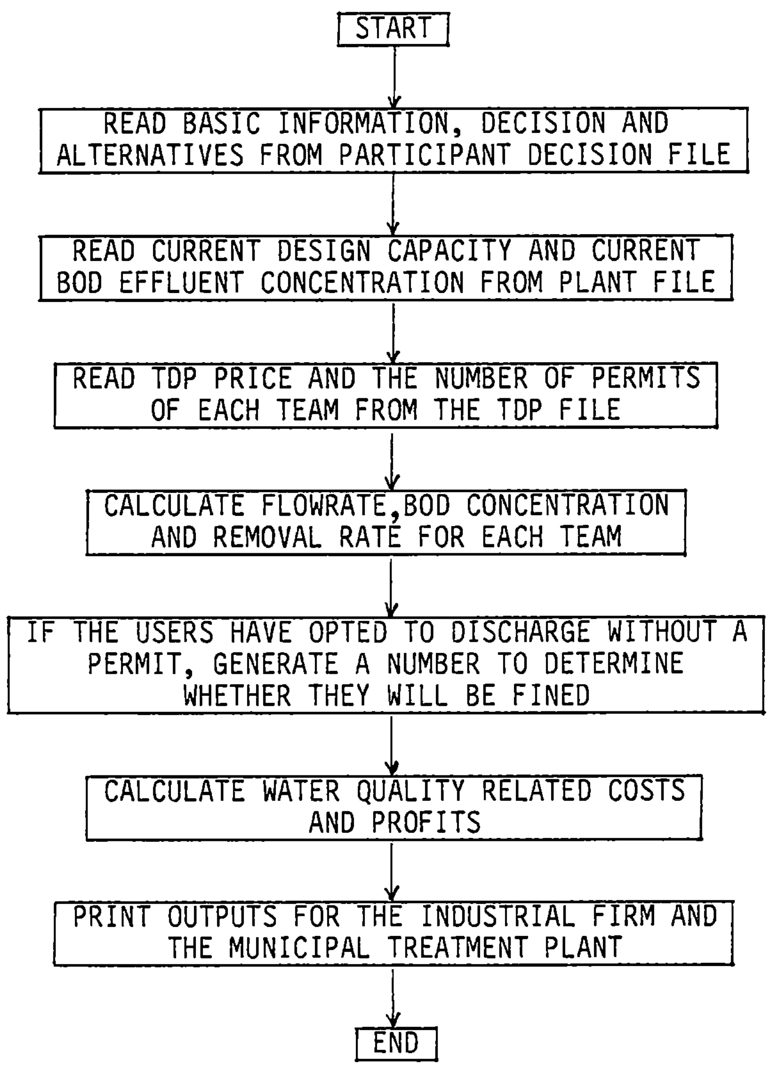



Figure 7. Cost Program Flowchart

Fixed Cost and Variable Cost. Wastewater treatment costs consist of both the capital cost incurred to construct the facility and operation and maintenance costs (O&M) associated with treating the waste stream. Capital cost would be expected to be related to design flow and performance, while O&M cost would be related to actual flow and performance. Design flow is used in the equation for capital cost and actual flow is used in the equation for O&M cost. Frass and Munley [35], based on statistical analysis, proposed the equations (2) and (3). C1 and C2 are used here to represent the cost adjustment factors for small-sized plants.

Fixed cost

$$= 78239 \times DQ^{0.89} \times BBOD^{0.24} \times DBOD^{-0.16} \times 0.25 + C1 \qquad \text{(Eq. 2)}$$

Variable cost

$$= 39244 \times AQ^{0.79} \times BBOD^{0.24} \times ABOD^{-0.07} \times 0.25 + C2 \qquad \text{(Eq. 3)}$$

Where AQ is actual flow (MGD)

DQ is design flow (MGD)

ABOD is actual effluent concentration (mg/l)

BBOD is actual influent concentration (mg/l)

DBOD is design BOD effluent concentration (mg/l)

C1 = $16,714 (for plant 3), $17,552 (for plant 4)

C2 = $6,416 (for plant 3), $1,445 (for plant 4).

User Charge. User charges are defined as those charges assessed against contributors to the treatment works for their proportional share of operation and maintenance costs. Considering constrained capacity and willingness to buy permits, dischargers decide whether to discharge pollutants to the municipal plant or not. If the discharged

BOD concentration exceeds 250 mg/l, the discharger must pay an additional charge for high-strength wastewater. Based on a statistical analysis Dyer et al. [36], proposed a formula to calculate user fees. For the purpose of this dissertation, this formula was modified because the formula establishes user charges on the basis of BOD, suspended solids, and phosphorous contents of the wastewater. BOD is assumed here to be the only criterion for measurement of water quality.

User Charge = (Q1 x 0.106) + (Q2 x 0.443 x (BOD - 250)) (Eq. 4)

Where Q1 is the average annual discharge rate expressed in thousand liters/year

Q2 is the average annual discharge rate expressed in million liters/year.

Permit Price. The total permit cost is equal to the unit permit price multiplied by total permit numbers. Dischargers with an excess of TDP's would offer them for sale. If the team decides to sell permits, the total permit price will be deducted from the water quality related cost. Those with a deficiency would seek to purchase them. If the team decides to buy permits, the total permit price will be added to the water quality related cost.

Enforcement. The idea of computing uncertainty of penalty is based on probability. The cost program uses the pseudo-random number uniform distribution (RANF) to generate a random number between 0 and 1. If a team decides to release untreated wastewater without appropriate permits, the game program attempts to simulate reality by randomly deciding whether the team is caught by the inspector, assuming that there is a 60% probability of getting caught. Therefore, if the outcome is less than 0.6, the team will be forced to pay a large amount in fines.

The fine for exceeding the allowable discharge or pollutant concentration 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 prices of permits rise, the incentive to discharge illegally grows; consequently, the penalty for non-compliance should increase.

Water Quality Related Cost. The water quality related cost is broken into five areas: (1) fixed cost, (2) variable cost, (3) user charge, (4) permit expense, and (5) penalty fine. Fixed cost reflects all construction cost for the treatment plant. The variable cost is all labor, material and supply costs necessary to operate the process after construction. All these costs must be estimated separately and added together to reflect total system costs.

## QL2SMG Water Quality Model Description

### Introduction

The model selected for this simulation game is an updated version of the stream quality model QUAL-II which was originally developed in 1973 by Water Resources Engineers, Inc. for the systems development branch of the U.S. Environmental Protection Agency. QUAL-II has been widely used and accepted across the country for the purposes of wasteload allocation and water quality management planning.

The updated version of QUAL-II that is used for this study is appropriately named QL2SMG, developed by the Southeast Michigan Council of Governments (SEMCOG). Although several modifications and capabilities were added to the original program, the model package still retains the basic QUAL-II structure. The QL2SMG model will predict both the temporal and spatial quantities of the following water quality variables; temperature, conservative mineral, carbonaceous BOD, algae, phosphorus, nitrogen, dissolved oxygen, and coliform [37, 38].

QL2SMG can simulate either the steady-state or the psuedo dynamic response of a river system to a set of specified input conditions. Steady state is applied in this dissertation. QL2SMG is a finite difference solution of the one-dimensional advection-dispersion equation. In addition, the program has the capability of determining the stream flow required to maintain a preselected target dissolved oxygen level [39, 40].

## Theoretical Consideration

BOD, DO, and hydraulic conditions are major concern parameters in this dissertation. Each of these variables are discussed in the following section. Table II lists the usual range of numerical values for these variables. The rest of the parameters can be found in reference [41].

TABLE II

INPUT PARAMETERS FOR QL2SMG

| Name | Range of Values |
|---|---|
| D | 3.0 - 100.0 |
| K1 | 0.1 - 2.0 |
| K2 | -0.36 - 0.36 |
| K3 | 0.0 - 10.0 |
| K4 | 0.0 - 5.0 |
| w1 | 1.4 - 1.8 |
| w2 | 1.6 - 2.3 |
| w3 | 3.0 - 4.0 |
| w4 | 1.0 - 1.14 |
| u | 1.0 - 3.0 |
| p | 0.05 - 0.5 |
| u1 | 0.1 - 0.5 |
| u2 | 0.5 - 2.0 |
| a | 0.22 - 0.30 |
| b | 0.30 - 0.37 |
| c | 0.43 - 0.51 |
| d | 0.38 - 0.61 |

Advection-Dispersion Equation. The QL2SMG model numerically solves the advection-dispersion mass transport equation for each water quality constituent being modeled. This equation represents a differential mass balance on the volume of each computational element in the system.

$$\partial C/\partial t = \partial(D\partial C/\partial X)/\partial X - \partial(UC)/\partial X + Z \qquad \text{(Eq. 5)}$$

(1) (2) (3) (4)

where: C = concentration (mg/l)

X = distance (L)

t = time (T)

U = average stream velocity (L/T)

Z = source or sink (mg/l/T)

D = dispersion coefficient (L x L/T)

The first term (1) represents the time rate of change of concentration, the second term (2) represents transport of mass by longitudinal dispersion, the third term (3) represents the advective component of mass transport, and the last term (4) is the sum of all sources and sinks of material. In a steady state simulation, the first term is omitted from the mass balance.

Hydraulics. QL2SMG assumes steady, gradually varied hydraulics. Steady hydraulics implies that the flow, velocity, width and depth at a given point in the stream are constant with time. Gradually varied flow allows these four factors to vary in the longitudinal direction, from element to element and from reach to reach. The flow in each computational element is calculated from a mass balance on the forcing functions applied to the element and inputs from upstream elements. Velocity can be found by $V = aQ^b$, and depth is calculated as $D = cQ^d$.

where: a = velocity coefficient

b = velocity exponent

c = depth coefficient

d = depth exponent.

Carbonaceous BOD. Carbonaceous BOD may be expressed as a three term equation. The general equation for BOD is:

$$L(T) = F - K1\ L - K2\ L \qquad \text{(Eq. 6)}$$

where: L(T) = ultimate BOD concentration at time t (mg/l)

F = input forcing function for carbonaceous BOD (mg/l)

K1 = bio-oxidation coefficient for CBOD (1/day)

K2 = coefficient for settling and scour effects

L = ultimate CBOD concentration in the computational element (mg/l).

Dissolved Oxygen. The reactive component of the source-sink term for dissolved oxygen is written for bio-oxidation of CBOD, reaeration, sediment oxygen demand, net oxygen production by algae, and oxidation of ammonia and nitrite. All of these factors are modeled as first order kinetics, except the SOD effect which is zero order.

$$dO/dt = F + K3\ (c^* - c) + (w1\ u - w2\ p)\ A - K1\ L - K4/Ax - w3\ u1\ N1 - w4\ u2\ N2 \qquad \text{(Eq. 7)}$$

where: F = input forcing function for dissolved oxygen (mg/l)

c* = saturation dissolved oxygen concentration (mg/l) (temperature dependent)

c = dissolved oxygen concentration (mg/l)

w1 = ratio of oxygen production per unit of algae growth

w2 = ratio of oxygen uptake per unit of algae respired

w3 = ratio of oxygen uptake per unit of ammonia nitrogen oxidation

w4 = ratio of oxygen uptake per unit of nitrite nitrogen oxidation

k3 = reaeration rate (1/day) (temperature dependent)

k4 = rate coefficient for sediment oxygen demand

u = local specific growth rate of algae

p = local settling rate for algae

A = algae biomass concentration in the computational element

Ax = average cross sectional area of the computational element

u1 = rate of conversion of NH3-N to NO2-N (1/day) (temperature dependent)

u2 = rate of conversion of nitrite to nitrate (1/day) (temperature dependent)

N1 = ammonia nitrogen as N (mg/l)

N2 = nitrite nitrogen as N (mg/l).

The Program

The computer program for the water quality model QL2SMG consists of a MAIN program and 23 subroutines. The MAIN program calls subroutine INDATA which reads and echo prints the input data. The main program then controls the sequence of subroutine calls for routing the desired water variables. It calls subroutines HYDRAU and TRIMAT to set up the hydrodynamic components of the mass balance. It then completes the balance by calling the constituent subroutine for the water quality variable being modeled. The resulting set of simultaneous equations is then solved in subroutine SOVMAT. If more than one water quality variable is being simulated, the mass balance is re-established in the appropriate subroutine and solved. When all the water quality variables have been solved for each computational element, the program time counters are advanced to the next time step. In the steady state mode, the final solution is obtained on the first time step although a number of interations may be required to balance the algae, nitrite, phosphorus, and temperature computations [42].

Input Option. In order to save time and effort, the input program can formulate QL2SMG package input data from an external file. One can specify the expected ambient temperature, flow conditions in the region and so on. All such environmental conditions can automatically be generated through this program if one specifies a season index for the quarter under consideration. The four sets of environmental conditions are built in, one for each season.

Input Requirements. Input information is provided to QL2SMG in groups called "data types". As a general rule, the different data types are input by reach, starting with the headwaters and proceeding downstream. All input data are read in by subroutine INDATA, with the exception of local climatology.

The descriptive titles of the data types are listed here, the detailed summary can be found in reference [43].

1. Program Titles.
2. Data Type 1; Program Control Data.
3. Data Type 1A; Algae Production and Nitrogen Oxidation Constants.
4. Data Type 2; Reach Identification and River Mile Data.

5. Data Type 3; Flow Augmentation Data.

6. Data Type 4; Computational Element Flag Field.

7. Data Type 5; Hydraulic Data for Determining Velocity and Depth.

8. Data Type 6; Reaction Coefficients for Deoxygenation and Reaeration.

9. Data Type 6A; Algae, Nitrogen, and Phosphorus Coefficients.

10. Data Type 6B; Other Coefficients (SOD, etc).

11. Data Type 7; Initial conditions.

12. Data Type 7A; Initial conditions (Algae and Coliform, etc.).

13. Data Type 8; Incremental Inflow.

14. Data Type 8A; Incremental Inflow (Algae and Coliform, etc).

15. Data Type 9; Stream Junction Data.

16. Data Type 10; Headwater Characteristics.

17. Data Type 10A; Headwater Characteristics (Algae and Coliform, etc.).

18. Data Type 11; Waste Inputs and Withdrawals.

19. Data Type 11A; Waste Inputs and Withdrawals (Algae and Coliform, etc.).

20. Local Climatological Data.

Output Information. The output from QL2SMG consists of three parts: an echo-printing of the input data (optional), intermediate summary (optional), and a final summary.

1. INPUT DATA - All input data (except local climatology) are echo printed by QL2SMG.

2. INTERMEDIATE SUMMARY - The intermediate summary is a brief

listing of computed values of the simulated water quality variables for each computational element in the basin. In the steady state mode it is printed after the steady state solution has converged.

3. FINAL SUMMARY - The final summary is a detailed listing of the results of the simulation and is printed in two parts. The first part contains location, flow and forcing function data as well as the final values of the simulated water quality variables for each computational element in the system. The second part contains river mile location, velocity, and depth data as well as the values of the reaction coefficients for each computational element in the system.

## Result Analysis

The reason for testing the TDP system is to see if it reduces water quality related cost without any adverse effects on the water quality. The measure of the true gain is when: X(po) > X(pe). (Where X = mean value of a performance variable, X(po) are data taken at the post-test [TDP system] period, and X(pe) are data taken at the pre-test [non-TDP system] period.) If X(po) is greater than X(pe), then statistical significance must be tested.

The successful statistical test requires rejecting a null hypothesis which states that the true mean of both populations are equal and accepting an alternative hypothesis which says that the true mean of these two populations is significantly different. To test the null hypothesis, some degree of desired significance is established and this factor determines the critical region between acceptance and rejection of the sampling distribution. For the paired comparison, there is a test presented by Wilcoxon to test wheather a particular sample came from a particular population. If the probability of significance is greater than 0.05, the null hypothesis is accepted but if it is less, then the null hypothesis is rejected. Rejecting the null hypothesis means accepting the alternative hypothesis.

The usual parametric counterpart to the Wilcoxon nonparametric test is the "paired t-test". If the sample size is less than 15, it is appropriate to use a Wilcoxon signed ranks test instead of the Student's t-test. The analyses in Chapter V are based on the Wilcoxon Ranks Test [44].

# CHAPTER IV

# APPLICATION

## Game Operation

### Computer Support of the Game

The players interface with the simulation when they input their data, after making their decisions based on engineering considerations and economic principles. The computer program is used to record these decisions and to analyze their effects. The overall game program consists of a number of computer programs, command procedures and datasets. Figure 8 presents a schematic of these programs and datasets.

Interactive Environment. The first of these two command procedures for interaction in the game is used by participants to enter their decisions. This command procedure (illustrated in Appendix D) arranges appropriate datasets, calls the participants input program, prompts the participants for decisions, allows corrections to be made, and records the decisions in two datasets. One dataset records the details of the decision for the current period's wastewater disposal, and the other dataset records the plant size available for two periods later, based on the upgrade decisions. Two periods are required to upgrade a plant.

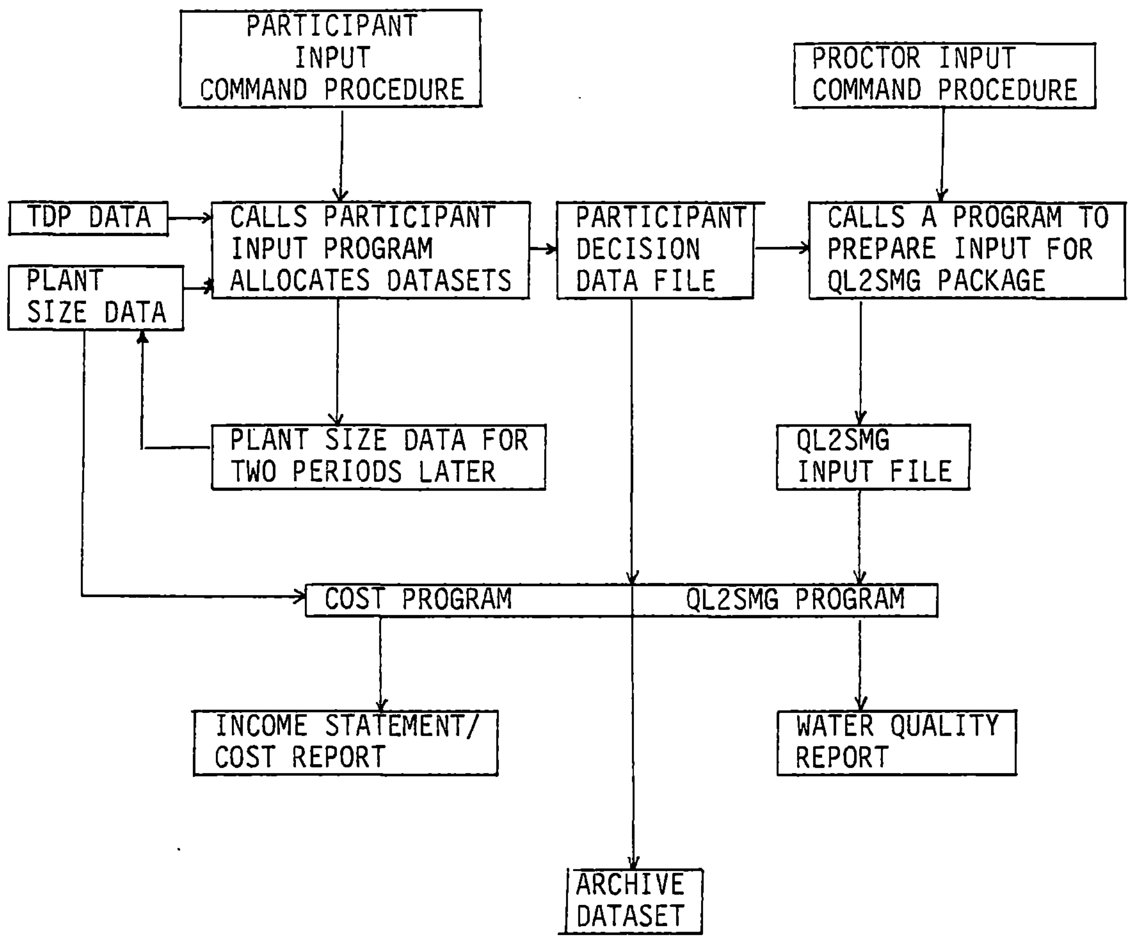



Figure 8. Computer Support and Datasets for the Game Program

The second command procedure (Appendix C) is used by the proctor to enter his or her decision. This command procedure arranges participant decision datasets, calls the proctor input program, prompts the proctor for the season index, and records the output in a dataset. This dataset is prepared as input for the QL2SMG program. The command procedure then submits two batch jobs, one for the execution of the cost program and the other for the QL2SMG program. The program also writes all relevant information onto the current history file and appends it to the archival dataset for further Statistical Analysis

System (SAS) analysis. The whole process is, therefore, automated. The proctor just needs to log on the computer once a week and input the seasonal index.

The game is programmed in FORTRAN for the interactive mode and delivered to the user in load module form. Participants need not have any prior knowledge of computer programming. The QL2SMG program, developed by the EPA, is also written in standard FORTRAN.

Input by Participants. Participants access the program through a password protected identification using remote terminals. They submit their decisions for the period of play in response to the questions from the interactive program. This program is "user friendly", which means that during the input mode, the participants can correct input errors easily. Through job control language manipulation, the decision dataset is created under a specified name and stored in a paritioned dataset form. During each decision period, the dataset reads decision data from the appropriate participant. If participants want to substitute new datasets, each decision dataset can be updated easily without interrupting the sequencing for input to the main program.

Input by Game Proctor. After all the decisions have been made and the data entered into a computer dataset, the proctor can specify the expected ambient temperatures and flow conditions of the region. Such environmental conditions can automatically be generated through a computer program if the proctor indicates a season for the specified quarter. Thus, four sets of environmental conditions are built into the program, one for each season.

Game Program Calculation. When the game participants and the proctor have entered their information, a cost program simulates economic effects of the decisions. Each team gets a financial report that includes the result of their decisions, upgraded plant capacity and cost analysis of their decisions. In addition, reports for industrial firms include simplified income statements based on their production decisions and on fixed relationships between production, price, and cost variables. Table III illustrates a sample financial report.

TABLE III

SAMPLE FINANCIAL REPORT

```
     WATER QUALITY SIMULATION GAME

 REGION                               : A
 GAME PERIOD                          : 6
 REPORT FOR TEAM                      : 3

     DECISIONS FOR WATER QUALITY MANAGEMENT
CURRENT DESIGN CAPACITY                  :  0.050 MGD
CURRENT DESIGN BOD EFFLUENT CONCENTRATION: 70.0   MG/L
CURRENT MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO THE RIVER:  40.0 MG/L
THIS IS INDUSTRIAL FIRM
PRODUCTION FORCAST                       :  1.250 MILLION POUNDS OF PRODUCT
 EXPECTED WASTEWATER FLOW RATE           :  0.047 MGD
 EXPECTED BOD INFLUENT CONCENTRATION     :400.0   MG/L

     THIS IS YOUR ALTERNATIVE
 DISCHARGE WITH PERMIT
DISCHARGED WASTEWATER FLOW RATE          :  0.047 MGD
DISCHARGED BOD EFFLUENT CONCENTRATION    :400.0   MG/L

     WATER QUALITY-RELATED COSTS
QUARTERLY  INVESTMENT AND FIXED OPERATING COSTS OF PLANT :     7081. DOLLARS
OPERATION COSTS                          :      1604. DOLLARS
INDUSTRIAL USER CHARGES                  :         0. DOLLARS
NUMBER OF PERMITS BOUGHT :    147.00 FROM TEAM  6 TO TEAM  3
UNIT PERMIT BUYING PRICE                 :        18. DOLLARS
COST OF PERMITS                          :      2617. DOLLARS
TOTAL CURRENT COSTS                      :     11301. DOLLARS

     PROFIT & LOSS STATEMENT
TOTAL SALES REVENUE                      : 2250000. DOLLARS
LABOR AND MATERIAL COSTS                 : 1350000. DOLLARS
OTHER EXPENSES                           :  225000. DOLLARS
TOTAL EXPENSES                           : 1586301. DOLLARS
TOTAL TAXABLE INCOME                     :  663699. DOLLARS
TAX ON CURRENT INCOME                    :  305302. DOLLARS
NET EARNING                              :  358397. DOLLARS
```

A second component of the game program simulates the water quality of the whole region based on discharges at various points and on environmental conditions. The QL2SMG package serves this purpose [45].

## Game Administration

A region represented by seven teams is simulated by the game. Two of these teams represent municipalities; the others are industrial firms. In this game, two participants represent one team and the entire section simulates one region.

The game was designed to be played in a Natural Resource Economics class, an elective taken by Economics, Business and Civil Engineering majors. The class normally meets on Mondays, Wednesdays, and Fridays for fifty minutes. After the proctor covers the topics relevant to water quality management, the game is introduced and the participants are handed descriptions of the firms they represent. By Friday of each week, their decisions must be entered into the computer. After all the decisions are entered, the proctor calls the appropriate command procedure to submit the jobs. The output containing cost reports and river water quality is then distributed back to participants, normally on Monday. After the participants receive the feedback regarding the accuracy of their predictions about the game consequences of their decisions, they keep these reports so that they can analyze their future strategies. Game participants understand that their decisions lead to predictable results, and they will try to follow a systematic process that will enable them to achieve optimal outcomes. When those outcomes are used in discussions between the participants and the proctor, to analyze the adequacy of past performance and to gain clues for improving future performance, Fletcher [46] found that this improved participants' decision-making effectiveness in the game context.

The game session extended over a six-week period in the fall of 1985. the Natural Resource Economics class students only played the first four-period game which involved non-TDP cases. The remaining four periods were played by two professors and three graduate students. Each professor represented one industrial firm and one municipal plant, and each graduate student represented one industrial firm. The final result is based on these two different stages of decision-making.

## Implementation of the TDP Market

A transferable Discharge Permit is not an effluent charge. Unlike the effluent charge, it does not purport to solve the problems of how much waste should be assimilated in water resources [47]. Rather, it assumes that some maximum loading has been selected and that the problem at hand is to find an efficient means for allocating that load among dischargers. Two major considerations in the allocating system are equity and efficiency. Some aspects of fairness are that each discharger should be allocated some share of the assimilative capacity of the stream, but that no discharger should have to bear an undue financial burden, and that dischargers do not make a sufficient effort to abate their pollution should not be entitled to a relatively larger share of TDP's than dischargers who do the cleanup. For the system to encourage efficiency, dischargers who can abate pollution relatively cheaply should do most of the required cleanup. TDP's provide a mechanism for the exchange of pollution discharge units such that each discharger pays an equitable share of the costs of abatement, but only those dischargers who can abate pollution relatively cheaply are required to do the physical treatment.

The first step in establishing a TDP market is to allocate shares to the dischargers. The second step is to allow these permits to be transferred among dischargers. The quantity which can be bought and sold is fixed partly by the total loading and partly by the wastewater treatment requirements [48].

The foregoing suggest the following administrative framework for TDP's:

1. All point sources of wastewater would be required to hold TDP's equal to their permitted discharge. Table IV shows the initial holdings of permitted discharges for each discharger.

TABLE IV

INITIAL DISTRIBUTION OF TDP'S

| | Maximum Permitted Discharge | | |
|---|---|---|---|
| Team | Flow (MGD) | BOD (mg/l) | Permit (Lbs-BOD/day) |
| 1 | 1.70 | 30 | 424.0 |
| 2 | 0.38 | 24 | 76.0 |
| 3 | 0.03 | 40 | 10.0 |
| 4 | 0.04 | 20 | 6.66 |
| 5 | 2.00 | 20 | 333.6 |
| 6 | 15.0 | 45 | 5629.5 |
| 7 | 3.0 | 10 | 250.2 |

2. Dischargers with an excess of TDP's would offer them for sale. Those with a deficiency would seek to purchase them. Exchange of TDP's would reallocate waste load so as to minimize the cost of attaining the desired water quality.

3. The penalty for exceeding the permitted discharge would be a fine sufficiently large to make the payment for TDP's preferable to the payment of fines.

## Permit Durations

Permits can be issued with finite durations or in perpetuity. If permits are of short duration, the authority will presumably have more flexibility in altering the supply to adjust waster quality. Long-term permits, on the other hand, would allow dischargers to plan capital investment with less uncertainty and would allow improved cost efficiency in waste management.

## The Market Mechanism

TDP market solutions are simulated by using engineering estimates of waste treatment costs. Other costs, such as transaction costs or administrative costs, are not taken into account. It is assumed that waste production levels and waste reduction costs will remain constant and that dischargers will trade permits as long as cost savings are possible. Their bids will reflect their marginal abatement costs since the dischargers will minimize the sum of the cost of the permits and of their treatment costs.

The combined usage of the "zero revenue auction" and the "incentive-compatible auction" were utilized to build a TDP market. At the beginning of each period, each participant would receive an initial allocation of free permits; an incentive-compatible auction would then be held. Incentive compatibility is defined as the property whereby the mechanism encourages truthful revelation of information by each participant. As long as bidder collusion may be ruled out, an individual discharger's dominant strategy in such an auction is to reveal (bid) the true value of his TDP's. This would result in an efficient allocation of aggregate discharge. (In contrast, procedures that are not incentive-compatible may not always be efficient because bids may reflect discharger's strategies rather than the true value of TDP's.) The incentive-compatible auction is a part of the general class of preference revelation mechanisms investigated by Vickrey [49] and Clarke [50]. When homogenous (i.e., identical) TDP's are being allocated, the mechanism operates as follows: Bidders submit binding bid schedules to the authority, which then allocates permits to the highest bidders, as in the single-price auction. Instead of paying a uniform price for permits, however, a discharger winning k permits would pay the k highest rejected bids of all dischargers except himself. So, for example, if a discharger wins two permits, he would pay the two highest rejected bids for permits submitted by other dischargers. This procedure encourages bidders to always pay different prices for rights, instead of the uniform price as in the single-price auction [51, 52].

The incentive-compatible approach has the advantage, however, that it does not encourage strategic behavior by individual participants even where there are small numbers of them. Thus, the procedure is always efficient, even when the bidders have dissimilar beliefs. Such dissimilarities may be important in real-world applications. Different dischargers, for example, may be expected to have different demands for TDP's based on their observable size or output characteristics. This is the reason why the incentive-compatible auction was used rather than the single-price auction because the TDP demand curve is non-continuous.

The zero revenue auction has several attractive features. It is designed so that net revenue collection by the authority is zero. All the revenues from the auction are completely redistributed to the participants. Firms who reduce emissions relative to their initial allocations receive payments from firms who increase their emissions relative to their initial allocations. Thus, there is a net monetary transfer from polluters to abaters.

# CHAPTER V

# RESULTS AND DISCUSSIONS

## Water Quality Analysis

One of the most important decisions the authority must make in designing any water quality management problem for a particular water body is to maintain the water quality standards. A water quality standard is assumed here to be expressed as the DO concentration and the BOD concentration. This research compares the water quality in a system with and without TDP's. A general hypothesis - water quality will deteriorate in the TDP system - was tested by using the Wilcoxon Ranks Test to consider performances of each team. For this evaluation the null hypothesis is defined as: there is no difference in water quality between the non-TDP system and TDP systems. Rank values can be calculated using the following relationship:

$$D = WQ(pe) - WQ(po)$$

Where D is difference

pe is pre-test (non-TDP case)

po is post-test (TDP case)

WQ is the water quality parameter

The results are analyzed at the location of all discharge points and at the sag point. Figure 4 indicates Teams 1 through 7 correspond to region elements 4, 8, 39, 18, 22, 14, and 30 respectively. The sag point is downstream element 45.

Table V presents general wastewater quality and quantity information for each team for the eight periods of play. Table VI and

TABLE V

GENERAL WASTEWATER QUANTITY AND QUALITY PARAMETERS PRODUCTION WASTEWATER

| Team | PERIOD 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 FLOW* | 1.2 | 1.2 | 1.36 | 1.45 | 1.2 | 1.26 | 1.36 | 1.45 |
| BOD** | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 2 FLOW | 0.5 | 0.56 | 0.61 | 0.68 | 0.5 | 0.56 | 0.61 | 0.68 |
| BOD | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 |
| 3 FLOW | 0.04 | 0.05 | 0.06 | 0.06 | 0.04 | 0.05 | 0.06 | 0.06 |
| BOD | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| 4 FLOW | 0.04 | 0.05 | 0.05 | 0.06 | 0.04 | 0.05 | 0.05 | 0.06 |
| BOD | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 5 FLOW | 2.00 | 2.04 | 2.08 | 2.12 | 2.00 | 2.04 | 2.08 | 2.12 |
| BOD | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| 6 FLOW | 15.54 | 15.61 | 15.66 | 15.09 | 15.11 | 15.16 | 15.23 | 15.04 |
| BOD | 202.6 | 204.2 | 202.9 | 202.8 | 200.9 | 200.7 | 201.0 | 201.5 |
| 7 FLOW | 5.04 | 5.08 | 5.13 | 5.18 | 3.0 | 3.04 | 3.08 | 3.12 |
| BOD | 171.3 | 220.2 | 139.7 | 141.7 | 200.0 | 202.4 | 205.1 | 207.6 |

*Flow is measured in MGD
**BOD is measured in mg/l

VII list the probabilities of significance and mean differences of DO concentrations and BOD concentrations for the eight system elements. Table VIII and IX list the stream quality parameters for periods 2 and 6 respectively.

TABLE VI

WILCOXON RANKS TEST RESULT IN
DO CONCENTRATIONS (mg/l) AND
PROBABILITY OF SIGNIFICANCE

| System# Element | *Mean of Non-TDP System | **Mean of TDP System | Difference | Probability of Significance |
|---|---|---|---|---|
| 4 (Team 1) | 8.00 | 7.98 | 0.02 | 0.77 |
| 8 (Team 2) | 7.97 | 7.78 | 0.19 | 0.56 |
| 14 (Team 6) | 6.61 | 6.60 | 0.01 | 1.00 |
| 18 (Team 4) | 8.75 | 8.72 | 0.03 | 0.56 |
| 22 (Team 5) | 8.67 | 7.64 | 1.03 | 0.24 |
| 30 (Team 7) | 7.93 | 7.81 | 0.12 | 0.66 |
| 39 (Team 3) | 6.76 | 6.77 | -0.01 | 0.88 |
| 45 (Sag Point) | 6.68 | 6.67 | 0.01 | 0.77 |

*Non-TDP system, periods 1, 2, 3, and 4.

**TDP system, periods 5, 6, 7, and 8.

#See Figure 4

TABLE VII

WILCOXON RANKS TEST RESULT IN BOD CONCENTRATIONS (mg/l) AND PROBABILITY OF SIGNIFICANCE

| System# Element | *Mean of Non-TDP System | **Mean of TDP System | Difference | Probability of Significance |
|---|---|---|---|---|
| 4 (Team 1) | 18.82 | 19.69 | -0.87 | 0.04 |
| 8 (Team 2) | 16.96 | 17.84 | -0.88 | 0.14 |
| 14 (Team 6) | 26.69 | 24.81 | 1.88 | 0.08 |
| 18 (Team 4) | 18.25 | 18.60 | -0.35 | 0.24 |
| 22 (Team 5) | 18.64 | 21.60 | -2.96 | 0.02 |
| 30 (Team 7) | 13.94 | 15.71 | -1.77 | 0.04 |
| 39 (Team 3) | 17.46 | 17.48 | -0.02 | 1.00 |
| 45 (Sag Point) | 15.20 | 15.22 | -0.02 | 1.00 |

*Non-TDP system, periods 1, 2, 3, and 4.

**TDP system, periods 5, 6, 7, and 8.

#See Figure 4

TABLE VIII

STREAM QUALITY PARAMETERS FOR PERIOD 2

| System# Element | Point Source | | Stream Condition | | |
|---|---|---|---|---|---|
| | Flow (MGD) | BOD (mg/l) | Flow (MGD) | DO (mg/l) | BOD (mg/l) |
| 4 (Team 1) | 1.26 | 30 | 17.86 | 6.64 | 18.13 |
| 8 (Team 2) | 0. | 0. | 18.32 | 6.22 | 15.52 |
| 12 | 0. | 0. | 19.20 | 6.07 | 13.24 |
| 13 | 0. | 0. | 19.20 | 6.06 | 12.72 |
| 14 (Team 6) | 15.61 | 45 | 34.81 | 5.32 | 26.51 |
| 18 (Team 4) | 0. | 0. | 8.70 | 7.77 | 17.97 |
| 22 (Team 5) | 0. | 0. | 10.31 | 7.63 | 18.20 |
| 30 (Team 7) | 5.09 | 10 | 26.80 | 6.41 | 12.77 |
| 39 (Team 3) | 0. | 0. | 64.12 | 4.77 | 15.72 |
| 45 (Sag Point) | 0. | 0. | 65.49 | 4.70 | 12.83 |

#See Figure 4

TABLE IX

STREAM QUALITY PARAMETERS FOR PERIOD 6

| System# Element | Point Source Flow (MGD) | Point Source BOD (mg/l) | Stream Condition Flow (MGD) | Stream Condition DO (mg/l) | Stream Condition BOD (mg/l) |
|---|---|---|---|---|---|
| 4 (Team 1) | 1.26 | *46 | 17.86 | 6.61 | 19.24 |
| 8 (Team 2) | 0.45 | 24 | 18.78 | 6.01 | 16.62 |
| 12 | 0. | 0. | 19.70 | 5.91 | 14.17 |
| 13 | 0. | 0. | 19.70 | 5.91 | 13.61 |
| 14 (Team 6) | 15.11 | 40 | 34.81 | 5.30 | 24.43 |
| 18 (Team 4) | 0.05 | 100 | 8.93 | 7.73 | 18.38 |
| 22 (Team 5) | 2.0 | 40 | 12.37 | 6.61 | 21.61 |
| 30 (Team 7) | 3.04 | 10 | 26.80 | 6.19 | 14.62 |
| 39 (Team 3) | 0.05 | 400 | 64.12 | 4.77 | 15.70 |
| 45 (Sag Point) | 0. | 0. | 65.49 | 4.70 | 12.81 |

*Treated wastewater flow rate is 1.08 MGD, BOD concentration is 20 mg/l.

Discharged waste flow rate is 0.18 MGD, BOD concentration is 200 mg/l.

Total wastewater flow is 1.26 MGD, Average BOD concentration is 46 mg/l.

#See Figure 4

## Water Cost Analysis

The relationship between effluent treatment cost and level of treatment achieved represents an essential element in evaluation of water quality pollution control policies. The objective of the wastewater treatment plant manager is to determine the minimum cost combination of treatment levels that meets a certain stream quality standard. Therefore, a purpose of this game is to see if it is possible to lower the financial burden on industrial firms and municipal plants without an adverse impact on the water quality standards.

This game uses the SAS package NPAR1WAY procedure to analyze TDP's impact on water quality related costs. The differences of the water quality related costs form a symmetric distribution. Therefore, Wilcoxon Ranks Test for significance can be utilized to measure and evaluate the differences between the water quality related costs under the TDP and non-TDP systems. The analysis is then performed on the average difference as a single sample observation. The samples are divided into groupings that represent each team and all teams (the whole region).

Table X indicates the water quality related cost for each team, Table XI presents the difference in water quality related costs for the paired comparisons, Table XII presents the Wilcoxon Ranks Test results, Table XIII presents the variable costs, Table XIV lists user charges for each team, and Table XV lists the transaction record for permits.

Based on the results shown in the tables, the following discussions are made:

TABLE X

WATER QUALITY RELATED COSTS ($)

| Team | PERIOD 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 93818 | 95070 | 97067 | 99067 | 92307 | 93149 | 96517 | 98306 |
| 2 | 53606 | 47417 | 57493 | 62574 | 41632 | 44185 | 46310 | 49541 |
| 3 | 11067 | 11484 | 12080 | 12437 | 10887 | 11301 | 11889 | 12248 |
| 4 | 8756 | 9013 | 9086 | 9342 | 8333 | 8579 | 8626 | 8879 |
| 5 | 209876 | 208586 | 217673 | 220115 | 154419 | 156689 | 159131 | 161573 |
| 6 | 669018 | 664570 | 664473 | 662579 | 661786 | 662302 | 660634 | 658498 |
| 7 | 243885 | 253037 | 239783 | 238163 | 290995 | 289690 | 288955 | 287498 |

TABLE XI

DIFFERENCE IN WATER QUALITY RELATED COSTS FOR PAIRED COMPARISONS ($)

| Team | Pairs WC (1)- WC (5) | WC (2)- WC (6) | WC (3)- WC (7) | WC (4)- WC (8) | AVERAGE |
|---|---|---|---|---|---|
| 1 | 1511 | 1921 | 550 | 739 | 1178 |
| 2 | 11974 | 3232 | 11183 | 13033 | 9855 |
| 3 | 180 | 183 | 191 | 189 | 186 |
| 4 | 423 | 434 | 460 | 463 | 445 |
| 5 | 55457 | 51897 | 58542 | 58542 | 56109 |
| 6 | 7232 | 2268 | 3839 | 4081 | 4355 |
| 7 | -47110 | -36653 | -49172 | -49335 | -45567 |

TABLE XII

WILCOXON RANKS TEST RESULT IN WATER QUALITY COSTS ($) AND PROBABILITY OF SIGNIFICANCE

| System Team | *Mean of Non-TDP System | **Mean of TDP System | Difference | Probability of Significance |
|---|---|---|---|---|
| 1 | 96247 | 95069 | 1178 | 0.38 |
| 2 | 55272 | 45417 | 9855 | 0.04 |
| 3 | 11767 | 11581 | 186 | 0.56 |
| 4 | 9049 | 8604 | 445 | 0.04 |
| 5 | 214062 | 157953 | 56109 | 0.02 |
| 6 | 665160 | 660805 | 4355 | 0.02 |
| 7 | 243717 | 289284 | -45567 | 0.02 |

*Non-TDP System for periods 1, 2, 3, and 4.

**TDP System for periods 5, 6, 7, and 8.

TABLE XIII

VARIABLE COSTS ($)

| Team | Period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 31850 | 33102 | 35099 | 37067 | 25647 | 30040 | 34549 | 37033 |
| 2 | 11434 | 0 | 10247 | 12862 | 16430 | 16430 | 16430 | 16430 |
| 3 | 1604 | 1604 | 1604 | 1604 | 1604 | 1604 | 1604 | 1604 |
| 4 | 361 | 361 | 361 | 361 | 361 | 361 | 361 | 361 |
| 5 | 47629 | 48547 | 55192 | 55192 | 55127 | 55192 | 55192 | 55192 |
| 6 | 234872 | 236085 | 236414 | 237342 | 230902 | 231079 | 231746 | 232759 |
| 7 | 102926 | 110126 | 99387 | 100466 | 70939 | 71838 | 72828 | 73813 |

TABLE XIV

USER CHARGES ($)

| Team | Period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 19453 | 24697 | 24527 | 26993 | 2213 | 4780 | 6905 | 10136 |
| 3 | 2382 | 2799 | 3395 | 3752 | 2382 | 0 | 0 | 0 |
| 4 | 1464 | 1721 | 1794 | 2050 | 0 | 0 | 0 | 0 |
| 5 | 77632 | 75425 | 77867 | 80309 | 0 | 2204 | 4646 | 7088 |
| 6 | (21835) | (27497) | (27992) | (30745) | (4595) | (4780) | (6705) | (10136) |
| 7 | (79097) | (77145) | (79660) | (82359) | 0 | (2204) | (4646) | (7088) |

*The numbers in parentheses indicate the revenue from user charges

TABLE XV

PERMIT TRANSACTION RECORD

| | Number of Permits | | | | Permit Costs ($) | | | |
|---|---|---|---|---|---|---|---|---|
| Period<br>Team | 5 | 6 | 7 | 8 | 5 | 6 | 7 | 8 |
| 1 | 260.7 | 64.2 | 0 | *(39.1) | 4693 | 1141 | 0 | **(695) |
| 2 | 14.2 | 14.2 | 14.2 | 14.2 | 270 | 256 | 256 | 256 |
| 3 | *(10.0) | 147.0 | 180.0 | 200.2 | **(180) | 2617 | 3204 | 3564 |
| 4 | 26.7 | 33 | 34.2 | 40.7 | 1041 | 1287 | 1334 | 1587 |
| 5 | 333.6 | 333.6 | 333.6 | 333.6 | 14678 | 14678 | 14678 | 14678 |
| 6 | (625.5) | (592.0) | (570.34) | (558) | (20502) | (19979) | (20189) | (20107) |
| 7 | 0 | 0 | 8.34 | 8.34 | 0 | 0 | 717 | 717 |

*Parentheses indicate selling of permits.
**Parentheses indicate revenue from selling permits.

Team 1

The bidding permit price is lower for Team 1 than for other teams (details are given in Appendix I). Therefore, during periods 5 and 6, Team 1 can only buy the remaining available permits from the TDP market and can only discharge a portion of their wastewater to the river. Team 1's design BOD capacity is 20 mg/l and permitted BOD discharge concentration is 30 mg/l (Table I). Even though this team improves its treatment level of BOD to 20 mg/l in periods 5 and 6, the discharged waste flow to the river is increased with a BOD concentration of 200 mg/l (Table XVI). Therefore, the BOD loading to the river for periods

TABLE XVI

TREATED WASTEWATER QUANTITY AND QUALITY FOR TEAM 1

| Period | Alt. | Treated Waste Flow (MGD) | Treated Waste BOD (mg/l) | Discharged Waste Flow (MGD) | Discharged Waste BOD (mg/l) |
|---|---|---|---|---|---|
| 1 | 1 | 1.2 | 30 | 0 | 0 |
| 2 | 1 | 1.26 | 30 | 0 | 0 |
| 3 | 1 | 1.36 | 30 | 0 | 0 |
| 4 | 1 | 1.45 | 30 | 0 | 0 |
| 5 | 7 | 0.88 | 20 | 0.32 | 200 |
| 6 | 7 | 1.08 | 20 | 0.18 | 200 |
| 7 | 1 | 1.36 | 37.6 | 0 | 0 |
| 8 | 1 | 1.45 | 30.4 | 0 | 0 |

5 and 6 is larger than that of the counterpart periods 1 and 2. In periods 7 and 8, as illustrated by the characteristics of the TDP system, the discharged BOD concentration can be slightly reduced. Therefore, the average BOD concentration under the TDP system is larger than that under the non-TDP system by 0.87 mg/l (Table VII), and the increased BOD loading results in decreasing DO concentration by 0.02 mg/l (Table VI).

The variable cost is a reflection of the treatment level, during periods 5 and 6, even though Team 1 uses its extra treatment capacity of 10 mg/l to lower its BOD effluent concentration to 20 mg/l, but since the treated wastewater flow is reduced (Table XVI), the variable cost for periods 5 and 6 is still less than that of the corresponding periods 1 and 2 (Table XIII), and the permit expense can not offset the variable cost saving. Therefore, the water quality related cost is reduced at periods 5 and 6 (Table XI). In period 7, since there are only a few remaining permits available in the TDP market, this team does not want to trade any permits. In period 7, the BOD effluent concentration is required to be 37.6 mg/l (calculation is given on page 29) to meet the discharge regulation. However, in period 3, in order to meet the water quality standard, the BOD effluent concentration has to be treated to 30 mg/l (Table XVI). The water quality related cost savings for paired period 7 is $550, which means the free initial permit value is worth $550 (Table XI). In period 8, since the unit treatment cost is lower than the permit market-clearing price for this team, it is a profitable option to sell permits. The policy for deciding the best strategy under the TDP system is given in Appendix B.

Team 2

Discharge point 2 is not far from discharge point 1, and the ratio of discharge flow is approximately 2% of the river flow near this point. Therefore, the stream water quality is slightly affected by this point source.

During periods 1, 2, 3, and 4, Team 2 allocates its pollution loading to municipal plant 6 by paying the user charge. During periods 5, 6, 7, and 8, the permit bid price for this team is higher than most teams in the TDP market (Appendix I), which means that this team can buy permits from the market and adjust to full capacity to obtain lower unit treatment costs. For this team, the trade-off is between difference of the variable cost, the user charge, and the permit expense. For instance, in period 7, the generated wastewater flowrate is 0.61 MGD (Table XVII). The initial permit holding is 76 (Table IV). If this team wants to send all its wastewater to the municipal plant, it needs to pay a $26,822 user charge. But, if this team wants to choose alternative 4, it needs to buy 14.2 permits to adjust its permit discharge capacity from 0.38 MGD to its full plant capacity 0.45 MGD (Table I) and pay $6,905 (Table XIV) in user charges and $16,430 (Table XIII) in variable costs. From these data, the permit price is $38.67 and can be calculated using the following relationship:

Permit price = (difference in user charge + difference in variable cost) / number of permits

During periods 2, Team 2 chooses alternative 3 without paying the variable cost (Table XIII). During periods 1, 3, and 4, this team chooses alternative 5 by paying both the variable costs and user

TABLE XVII

TREATED WASTEWATER QUANTITY AND QUALITY FOR TEAM 2

| Period | Alt. | Treated Waste Flow (MGD) | Treated Waste BOD (mg/l) | Send Waste to Municipal Plant Flow (MGD) | Send Waste to Municipal Plant BOD (mg/l) |
|---|---|---|---|---|---|
| 1 | 5 | 0 | 0 | 0.35 | 250 |
| | | | | 0.15 | 300 |
| 2 | 3 | 0 | 0 | 0.56 | 300 |
| 3 | 5 | 0 | 0 | 0.3 | 210 |
| | | | | 0.31 | 300 |
| 4 | 5 | 0 | 0 | 0.40 | 210 |
| | | | | 0.28 | 300 |
| 5 | 4 | 0.45 | 24 | 0.05 | 300 |
| 6 | 4 | 0.45 | 24 | 0.11 | 300 |
| 7 | 4 | 0.45 | 24 | 0.16 | 300 |
| 8 | 4 | 0.45 | 24 | 0.23 | 300 |

charges (Table XIII, Table XIV). However, the difference in variable cost is much larger than that of the user charges. Therefore, this team does not choose the less expensive treatment alternatives during periods 1, 3, and 4. This can be illustrated by the significant reduction in the water quality related costs (Table XI) for the paired periods 2 and 6, compared to the remainder of paired periods. The average difference of water quality related cost savings for this team is $9,855, and the probability of significance is less than 0.05 (Table XII). Obviously, this team is benefiting from the TDP system.

## Team 3

The discharge at this point is less than 1% of the local river flow. Therefore, the stream water quality is slightly affected by this point source. Treated wastewater quantity and quality for Team 3 is shown in Table XVIII.

TABLE XVIII

TREATED WASTEWATER QUANTITY AND QUALITY FOR TEAM 3

| | | Send Waste to Municipal Plant | | Discharge Waste to the River | |
|---|---|---|---|---|---|
| Period | Alt. | Flow (MGD) | BOD (mg/l) | Flow (MGD) | BOD (mg/l) |
| 1 | 3 | 0.04 | 400 | 0 | 0 |
| 2 | 3 | 0.05 | 400 | 0 | 0 |
| 3 | 3 | 0.06 | 400 | 0 | 0 |
| 4 | 3 | 0.06 | 400 | 0 | 0 |
| 5 | 3 | 0.04 | 400 | 0 | 0 |
| 6 | 8 | 0 | 0 | 0.05 | 400 |
| 7 | 8 | 0 | 0 | 0.06 | 400 |
| 8 | 8 | 0 | 0 | 0.06 | 400 |

Team 3 represents a small plant, and generally a small plant is less efficient in treating wastewater. Therefore, under the non-TDP system, Team 3 always chooses alternative 3, "send all wastewater to the municipal palnt" under the non-TDP system. In period 5, the bidding permit price for this team is the second lowest in the TDP market (Appendix I). So this team sells 10 free initial permits (Table XV) to Team 1 and chooses alternative 3. The revenue for selling the permits is $180 (Table XI). Again, this means that the free initial permits are worth $180. The trade-off for this team is between the permit expense and the user charge. For periods 6, 7, and 8, the permit expense (Table XV) is less than the user charge of corresponding periods 2, 3 and 4 (Table XIV). Therefore, this team always chooses alternative 8, "discharge wastewater after buying permits".

Team 4

Team 4 is a small plant, and the unit treatment cost is higher than the user charge and the permit expense. Therefore, under the non-TDP system, this team always chooses alternative 3, "send all wastewater to the municipal plant 7" (Table XIX). Under the TDP system, this team always buys permits and chooses alternative 8, "discharge wastewater after buying permits".

The result of these alternatives is that under the TDP system, the BOD loading to the river increases at this point, however, the discharge from this point is very small, and the amount of impact on the water quality is not significant. The water quality related cost savings for this team comes from the difference between the user charge and the permit expense. The average cost savings is $445, and the

TABLE XIX

TREATED WASTEWATER QUANTITY AND QUALITY FOR TEAM 4

| Period | Alt. | Send Waste to Municipal Plant Flow (MGD) | Send Waste to Municipal Plant BOD (mg/l) | Discharge Waste to the River Flow (MGD) | Discharge Waste to the River BOD (mg/l) |
|---|---|---|---|---|---|
| 1 | 3 | 0.04 | 100 | 0 | 0 |
| 2 | 3 | 0.05 | 100 | 0 | 0 |
| 3 | 3 | 0.05 | 100 | 0 | 0 |
| 4 | 3 | 0.06 | 100 | 0 | 0 |
| 5 | 8 | 0 | 0 | 0.04 | 100 |
| 6 | 8 | 0 | 0 | 0.05 | 100 |
| 7 | 8 | 0 | 0 | 0.05 | 100 |
| 8 | 8 | 0 | 0 | 0.06 | 100 |

probability of significance is 0.04 (Table XII), which means that the null hypothesis of two systems being equal is rejected.

## Team 5

Team 5 is a large plant, and the unit treatment cost is lower compared to that of other plants. The design BOD effluent concentration is 40 mg/l and the maximum permitted discharge BOD concentration is 20 mg/l, which means that this team can not choose alternative 1 "treat wastewater in the company plant and release to the river", unless they upgrade the plant. Therefore, under the non-TDP system, this team allocates its wasteload to municipal plant 7. Under the TDP system, Team 5 buys 333.6 additional permits (Table XV), adjusts the permitted BOD effluent concentration to 20 mg/l, and chooses inexpensive treatment option 1 or 4 to treat its wastewater in its own plant (Table XX). Therefore, the BOD loading from this point discharge to the river is increased. According to the Wilcoxon Ranks Test, the probability of significance is approximately 0.02 (Table VII), which means the increased BOD loading is significant. The lower DO profile

TABLE XX

TREATED WASTEWATER QUANTITY AND
QUALITY FOR TEAM 5

| Period | Alt. | Treated Waste Flow (MGD) | Treated Waste BOD (mg/l) | Send Waste to Municipal Plant Flow (MGD) | Send Waste to Municipal Plant BOD (mg/l) |
|---|---|---|---|---|---|
| 1 | 5 | 0 | 0 | 1.8<br>0.2 | 100<br>400 |
| 2 | 5 | 0 | 0 | 2.0<br>0.04 | 250<br>400 |
| 3 | 5 | 0 | 0 | 2.0<br>0.08 | 40<br>400 |
| 4 | 5 | 0 | 0 | 2.0<br>0.12 | 40<br>400 |
| 5 | 1 | 2.0 | 40 | 0 | 0 |
| 6 | 4 | 2.0 | 40 | 0.04 | 400 |
| 7 | 4 | 2.0 | 40 | 0.08 | 400 |
| 8 | 4 | 2.0 | 40 | 0.12 | 400 |

downstream of this point is a consequence of a higher BOD loading under the TDP system. The mean differences for the DO concentration is 1.03 mg/l (Table VI) and for the BOD concentration is -2.96 mg/l (Table VII). Table XI indicates the average water quality related cost saving is $56,109 for this team. Certainly this team benefits from using the TDP system.

Team 6

The structure of this game is to let the industrial firms discharge the wastewater to the municipal plant by paying the user charge. The major concern of the municipal plant managers is to bring the influent wastewater to the quality standard of the river authority. Under the non-TDP system, for the municipal plant, even though this plant has extra treatment capacity (the BOD permitted discharge concentration is 45 mg/l, and the design BOD effluent concentration is 40 mg/l), there is no strong incentive for reducing the BOD effluent concentration to 40 mg/l (Table XXI). Industrial firms under the non-TDP system are not allowed to buy permits and the only remaining feasible option is to send excess wastewater to the municipal plant, as illustrated in Table XXII, Team 2 and Team 3 allocate their wasteloads to this plant under the non-TDP system, this creates uncertainty about influent wastewater and the possibility of degrading water quality.

The purpose of TDP's is to facilitate exchange among treatment plants by compensating those who undertake a higher level of treatment in favor of those who don't. Under the TDP system, plant 6, by engaging in such treatment, receives revenue from selling permits and reduces the BOD effluent concentration to 40 mg/l (Table XXI).

TABLE XXI

TREATED WASTEWATER QUANTITY AND
QUALITY FOR TEAM 6

| Period | Treated Waste Flow (MGD) | BOD (mg/l) |
|---|---|---|
| 1 | 15.54 | 45 |
| 2 | 15.61 | 45 |
| 3 | 15.67 | 45 |
| 4 | 15.74 | 45 |
| 5 | 15.09 | 40 |
| 6 | 15.11 | 40 |
| 7 | 15.16 | 40 |
| 8 | 15.23 | 40 |

TABLE XXII

INFLUENT FLOWRATE (MGD) FOR
MUNICIPAL PLANTS

| | Period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Team | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2 | 0.50 | 0.56 | 0.61 | 0.68 | 0.05 | 0.11 | 0.16 | 0.23 |
| 3 | 0.04 | 0.05 | 0.06 | 0.06 | 0.04 | 0.04 | 0. | 0. |
| 6 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| Total for 6 | 15.54 | 15.61 | 15.67 | 15.74 | 15.09 | 15.11 | 15.16 | 15.23 |
| 4 | 0.04 | 0.05 | 0.05 | 0.06 | 0. | 0. | 0. | 0. |
| 5 | 2.00 | 2.04 | 2.08 | 2.12 | 0. | 0.04 | 0.08 | 0.12 |
| 7 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Total for 7 | 5.04 | 5.09 | 5.13 | 5.18 | 3 | 3.04 | 3.08 | 3.12 |

These phenomena reflect in the cost analysis: Under the non-TDP system, the major income is user fees (Table XIV). Under the TDP system, the major revenue is from selling permits (Table XV). For Team 6, the average water quality related cost savings is $4,355 which is approximately 0.7% of the total water quality related cost (Table XXIV).

## Team 7

Under the TDP system, plant 7 receives a relatively small amount of wastewater from plants 4 and 5 (Table XXIII). Under the non-TDP system, plant 7 receives a relatively large amount of wastewater from plants 4 and 5, causing the increased discharge from this point to the river (Table XXIII). However, the BOD effluent concentration from this point source is 10 mg/l, which is lower than that of the point source

TABLE XXIII

TREATED WASTEWATER QUANTITY AND QUALITY FOR TEAM 7

| Period | Treated Waste Flow (MGD) | Treated Waste BOD (mg/l) |
|---|---|---|
| 1 | 5.04 | 10 |
| 2 | 5.09 | 10 |
| 3 | 5.13 | 10 |
| 4 | 5.18 | 10 |
| 5 | 3.00 | 10 |
| 6 | 3.04 | 10 |
| 7 | 3.08 | 10 |
| 8 | 3.12 | 10 |

of Team 4 (Table XIX) and Team 5 (Table XX). Plant 7 is located downstream from the discharge points of plant 4 and plant 5. The aggregated discharge from plant 4, plant 5, and plant 7 are equal at this point. Therefore, the increased discharge from this point results in a decreased BOD concentration in the river under the non-TDP system. The general rule is that the lower the BOD concentration, the higher the DO concentration. Considering these two systems, under the non-TDP system, the larger discharge from this point results in a lower BOD concentration and a higher DO concentration. These phenomena reflect in the water quality analysis: In period 2 (non-TDP system) the stream DO concentration is 6.41 mg/l and BOD concentration is 12.77 mg/l (Table VIII). In period 6 (TDP system), the stream DO concentration is 6.19 mg/l and BOD concentration is 14.62 mg/l (Table IX). The mean differences for the DO concentration and BOD concentration of these two systems are 0.12 mg/l (Table VI) and -1.77 mg/l (Table VII) respectively.

During periods 1, 2, 3, and 4, the influent wastewater from plants 4 and 5 is approximately 40% of the influent residential wastewater to plant 7. During periods 5, 6, 7, and 8, the influent wastewater from plants 4 and 5 is approximately 2% of the influent residential wastewater to this plant (Table XXII). These effects reflect in the cost analysis report: Under the non-TDP system, the average user charge is $79,000, but in the TDP system the average user charge drops to $4,000 (Table XIV), which means the uncertainty of influent wastewater quality and quantity can be minimized.

Team 7 does not have extra treatment capacity for incoming industrial wastewater. (The permitted discharge BOD concentration is 10 mg/l, and design BOD effluent concentration is 10 mg/l). In order to meet the water quality, this team needs to buy additional permits for an external wasteload (Table XV). Under the non-TDP system, the water quality related cost is subsidized by the user fees. But under the TDP system, this team only receives a small amount from the user fees and the drop in the user fees is greater than the drop in the variable costs (Table XIII). Even though this team has extra flow capacity (the permitted discharge capacity is 3.0 MGD, and design flow capacity is 5.5 MGD), it can not use its extra flow capacity, since the TDP's are distributed on the basis of permitted standards. Therefore, Team 7 is the only team losing under the TDP system (Table XI).

## Sag Point

In this simulation game, the critical DO point occurs at element 45 (Figure 4). For the DO concentration, the average concentration is 6.68 mg/l before the TDP scheme. After implementing the TDP system, the average concentration is 6.67 mg/l. the probability of significance in this case is approxiamtely 0.77 (Table VI); the null hypothesis can be accepted, and there is no significant difference between these two systems.

## Water Quality Impact for the Whole Region

When the Wilcoxon Ranks Test is analyzed in terms of the BOD concentration, only seven elements (elements 22, 23, 24, 25, 26, 27, and 30) show less than 0.05 significant probabilities. In terms of DO concentration, there is no significant effect on these elements. The conclusion is that the null hypothesis is accepted and the environmental impact of discharge is identical before and after the TDP system.

## Cost Efficiency for the Whole Region

The cost efficiency of a particular program is measured by the aggregate economic cost of achieving the water quality standard. Only the costs of real resources are considered in calculating the aggregate cost. The payments for discharge should not be included because these payments are transferred between parties.

Table XXIV lists the water quality related cost savings for each team. The total cost savings for all the teams is $26,561 per quarter and approximately $106,000 per year. Table XII, the Wilcoxon Ranks Test results, shows the probability of significance for Teams 2, 4, 5, and 6 is less than 0.05, i.e., four out of seven teams benefit from the TDP system.

TABLE XXIV

WATER QUALITY RELATED COST SAVING ($)

| System Team | *Mean of Non-TDP System | **Mean of TDP System | Difference | Ratio |
|---|---|---|---|---|
| 1 | 96,247 | 95,069 | 1,178 | 1.2% |
| 2 | 55,272 | 45,417 | 9,855 | 17.8% |
| 3 | 11,767 | 11,581 | 186 | 1.5% |
| 4 | 9,049 | 8,604 | 445 | 4.9% |
| 5 | 214,062 | 157,953 | 56,109 | 26.2% |
| 6 | 665,160 | 660,805 | 4,355 | 0.7% |
| 7 | 243,717 | 289,284 | -45,567 | -18.7% |
| Total Cost Saving | | | 26,561 | |

*Non-TDP system, periods 1, 2, 3, and 4.
**TDP system, periods 5, 6, 7, and 8.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The analyzed results indicate that the TDP system is cost efficient. Using the TDP system would result in a total annual savings of approximately $106,000. The average DO concentration at the sag point however, is decreased slightly. Transferable permits are important because the total costs of attaining water quality standards are lower with transfers.

After implementing the TDP system, the whole region will have water quality related cost savings without an adverse effect on water quality. Also, four teams benefit from the TDP system, and the reasons can be attributed to: (1) Incentive-compatible auctions, (2) Plants have different alternatives for controlling effluent, and (3) Free initial distribution of permits.

Team 7 is the only team that bears an undue financial burden under the TDP system. For this team, the design capacity is 5.5 MGD, but the permitted discharge capacity is 3.0 MGD (Table I). Since the TDP's are distributed on the basis of permitted standards, this team can not use its extra capacity in terms of flow. A reasonable approach to the permit distribution should be considered in terms of both the permitted standards and design capacity.

Transferable discharge permits would result in higher actual (in contrasted to permitted) wasteloads. Dischargers who, for example, expand their production and find their waste treatment capacity inadequate can acquire permission to discharge from those with excess treatment capacity. With such offsets, water quality standards continue to be met, but the level of actual discharge to the watercourse is closer to the water quality limits.

BOD is an important representative of the category of water pollutants that degrade once discharged. In such cases the location of discharges affects water quality (dissolved oxygen in the BOD case) at a given location. Also, because physical parameters typically vary throughout a watercourse, a change in the location of a discharge usually not only shifts the location of impact, but it also affects the degree of impact. But in this dissertation, the transfer coefficient for each permit is the same for allowing one-to-one trades of permits, however the effect of discharges on water quality is different for different discharge locations. Therefore, it is better to formulate the effluent permits by impact coefficients. If the goal is to achieve a given level of dissolved oxygen concentration, the impact coefficients can be generated by simulating a series of DO levels associated with increased individual effluent loadings and calculating the changes in the DO at the sag points. Sensitivity analysis may confirm the accuracy of using linear approximations to define the effluent/water quality relationship at different combinations of stream flow and stream temperature. In this way, the number of permits issued by an authority would depend on the desired water quality. To account for the differential impact of different polluters on the water quality, permits will be worth different amounts to different polluters.

Time variability in the assimilative capabilities of the environment and in demands for the waste disposal services of the environment have long posed problems for pollution control systems. Streamflows vary and atmospheric conditions change over both long and short periods, requiring variations in TDP's if water quality standards are not to be violated. This research does not deal with this problem and assumes the river flow is constant for the entire period. To avoid violating real-world facts, a "priority rights" system for allocating available assimilative capacity should be established. In the case of surface water, the functioning of a priority system depends on the probability distribution of streamflows: More senior rights have a higher probability of getting their streamflow to assimilate waste than do more junior rights.

To help ensure the continued maintenance of water quality, market restrictions may be added to prevent or discourage transfers of permits that would cause violations. Since water quality problems depend in part on local physical features, the type of trading restrictions chosen by policymakers would be expected to vary from one water body to another. One way to restrict transfers is to define permits so that they can be exercised in only a certain zone in a waterway. This mechanism can allow equal opportunities for dischargers within a given zone to purchase BOD permits (This research assumes seven teams are located within one zone). Between-zone inequities could still be perceived, however, depending on the characteristics of the dischargers and of the physical river system under study.

## Recommendations

Future research work should be continued in the TDP system in several areas:

1. Transferable discharge permits should be formulated by impact coefficients. The nature of the impact is modified by - temperature and flow - which affect the assimilative capacity of the stream.

2. Transferable discharge permit distribution should be considered in terms of both the permitted standards and discharge capacity.

3. Priority rights can increase the adaptability of the TDP system to short-term fluctuations in the assimilative capacity of the environment. They should be combined with the TDP system.

4. The definition base of permits should not be restricted by only BOD and DO. Nitrogen, phosphate, and heavy metals seem to be candidates for the basis of definition of permits.

5. Unrestricted transfers of BOD permits could cause violations of the water quality standard. Restricting transfers of permits to geographical zones could be used to reduce or possibly prevent violations of a standard.

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APPENDICES

# APPENDIX A

# CASE STUDY INDUSTRIAL DISCHARGE NO. 1

COTTON PROCESSING PLANT

Synopsis

You are the water quality manager for the Sunbelt Cotton Company. This company is a major producer of cotton fiber products and is located along the Paladine River. The area has experienced a lot of growth in the last 50 years, with a resultant decrease in stream water quality. The State Water Resources Board, as mandated by the Environmental Protection Agency, has established standards or waste load allocations for each discharger along the river. You have a number of alternatives for complying with the waste load allocations. These alternatives are: (I) Treat all wastewater in the company plant and release to the river; (II) Pretreat all wastewater in the company plant and send to the municipal treatment plant; (III) Send all wastewater to the municipal treatment plant without treatment; (IV) Treat part of the wastewater in the company plant and release, send the other part of the wastewater, without treatment, to the municipal plant; (V) Pretreat part of the wastewater in the company plant and send to the municipal plant, send the other part of the wastewater, without treatment, to the municipal treatment plant: (VI) Discharge all wastewater without permit and without treatment; (VII) Treat part of the waste in the company and release it to the river, send the other part, without treatment, to the river; (VIII) Discharge wastewater after buying permit. If the cost of treatment outweigh the marginal profits, you might recommend reducing the production levels. You might also decide to upgrade the plant. Your task is to determine the best alternative for disposing of the current period's waste and decide if any upgrades of the plant should be made.

Description of the Company

The Sunbelt Cotton Company is a large producer of cotton fiber products. Sunbelt's products are sold in a national market with the company having a 9% share of the market. However, the market is very competitive. The company cannot increase prices without a reduction in demand. Also, price promotions are usually copied by competitors as well.

The company was founded by the Simpson family. This family was among the first families to settle in Paladine City and thus chose to locate the plant close to the local river, the Paladine River, so that most of the effluent of the plant could simply be released into the river. This was an effective and inexpensive way to dispose of the waste of the plant. The flow of the river was sufficient to carry all the waste that was generated. The city had a treatment plant which was able to treat the biological waste efficiently. The river water quality was acceptable for body contact recreation and for aquatic life.

As the years went by, other companies located in the area. The city also experienced a lot of growth. Since the founding family, the Simpsons, was very conscientious about the river water quality, they installed a treatment plant in the company to treat the waste. The plant was installed in 1976, the same year the Simpsons sold the company to a national concern. The plant has not been upgraded since then even though the company has continued to experience a rapid growth. The parent company viewed the treatment plant as an unnecessary overhead.

As the quality of discharge from Sunbelt deteriorated and the city and other companies grew in size, there was a noticeable decline in the water quality of the Paladine River. One other factor in this decline was a new major reservoir upstream which resulted in frequent low flow conditions.

A number of letters to the editor in the local papers was followed by protests to the Water Resources Board from the citizens of Jonesville, a city located 15 miles downstream. The first task of the board was to establish the effect of existing effluent loads on the water quality. An acceptable total waste load was then deduced from the desired water quality target. This total waste load was then allocated among the different dischargers along the river. This was accomplished by allocating to each discharger a claim on the receiving stream's capacity to assimilate waste, which is called a "waste load allocation". These waste load allocations are developed in terms of Biochemical Oxygen Demand (BOD) and its corresponding water quality parameter, Dissolved Oxygen (DO). The waste load allocation is used as the basis for permit limits for each discharger. (Water quality is measured only in terms of BOD levels. While this is a narrow view of the quality of water, this simplification permits us to concentrate on other economic issues.)

You have been hired by Sunbelt to manage its effluent treatment program and are thus responsible for making decisions for treating the company's wastewater. You report directly to the vice president of operations. While you are not directly involved in the production decisions, the V.P. has assured you that your inputs will be given high consideration in making final decisions on production levels.

Production Function

The conversion of cotton fiber into a finished product involves a number of different operations. The cotton is received in bales which are opened and cleaned by machines which blend the cotton while removing a great deal of loose dirt. The cotton is then rolled into sheets ready for the carding and spinning operations. The carding operation combs the cotton, aligning the fibers in parallel prior to spinning them into yarn. Before the yarn can be woven into fabric, it must be strengthened. This is done in an operation known as slashing. The purpose of slashing is to stiffen the fiber by loading it with starch and with other substances called sizing. The sized yarn is then woven into the fabric, brushed, singed and inspected. Finally, the fabric is put through dyeing and finishing operations.

The marketing, finance, and operations departments have developed the final forecasts of production over the next year. The total fabric processed (in millions of pounds) is expected to be as shown in Table A-1.

Even though production fluctuates from quarter to quarter the company tries to maintain the same payroll. The company has been reasonably profitable to date. A simplified earnings statement indicates that the company can sell its output at $1,200,000 per million pounds of fabric produced. Cost of goods sold is about 60% of sales revenue, exclusive of waste treatment costs. Other expenses are about 10% of sales revenue. The company has a healthy balance sheet. It has very little debt and a $15 million line of credit which is mostly used

TABLE A-1

PRODUCTION AND EFFLUENT FORECAST

| | First Quarter | Second Quarter | Third Quarter | Fourth Quarter |
|---|---|---|---|---|
| Millions Of Pounds Of Fabric | 2.475 | 2.600 | 2.800 | 3.000 |
| Discharge (MGD) | 1.200 | 1.260 | 1.360 | 1.460 |
| BOD (mg/l) | 200 | 200 | 200 | 200 |

to finance the purchase of cotton. Last year, the company earned about $1.8 million on sales of about $12 million.

## Effluents

The cotton processing plant in the company has state-of-the-art equipment. However, a large amount of biological waste is generated. The waste is a function of the production volume. The wastewater flow rate is 32,000 gallons of water per 1,000 pounds of output produced and the BOD concentration is 200 mg/l. Based on historical analysis, you have determined that the wastewater discharges and BOD levels in Table A-1 would result if planned production was realized. (Other BOD discharge for any other production levels can be determined by using the participant input program.)

Effluent Removal Strategies

At the present time, Sunbelt's water quality standard has been set at a BOD concentration of 30 mg/l and wastewater flow of 1.7 MGD. The company's wastewater treatment plant has a wastewater design flow rate of 1.5 MGD and a BOD concentration design level of 20 mg/l.

The options available for complying with the waste load allocations established by Water Resources are:

Alternative 1: Alternative 1 involves "Treat all wastewater in the company plant and release to the river". This alternative is subjected to a number of restrictions; (a) Treated wastewater flow rate should not exceed the plant's design capacity, (b) The treated wastewater flow rate should not exceed the maximum limitation of wastewater flow rate established by the Water Resources Board, (c) The treated wastewater BOD effluent concentration should not exceed the plant's design BOD effluent concentration, (d) The treated wastewater BOD effluent concentration should not exceed the allowed BOD effluent concentration to the river set by the Water Resources Board, (e) The plant's design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river. For the TDP case, this restriction will be released.

Alternative 2: The second alternative states "Pretreat all wastewater in the company plant and send to the municipal treatment plant." This alternative will be subjected to the following restrictions: (a) Pretreated wastewater flow rate should not exceed the design capacity, (b) Pretreated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, and (c) Pretreated wastewater BOD effluent concentration should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 3: The third alternative states "Send all wastewater to the municipal treatment plant without treatment". This alternative will be restricted by BOD effluent concentration of discharged wastewater, which should not exceed the allowed BOD effluent concentration to the municipal treatment plant.

Alternative 4: The fourth alternativew states "Treat part of the wastewater in the company plant and release; send the other part of the wastewater, without treatment, to the municipal plant". This alternative will be restricted by seven factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, (c) Treated wastewater should not exceed the maximum limitation of wastewater flow rate to the river, (d) Treated wastewater BOD effluent concentration should not exceed the design BOD effluent concentration, (e) Treated wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the river, (f) Discharged wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the municipal treatment plant, and (g) The design BOD effluent concentration should not be larger than the allowed BOD effluent concentration to the river (for TDP case, this restriction is cancelled).

Alternative 5: The fifth alternative states "Pretreat part of the wastewater in the company plant and send to the municipal treatment; send the other part of the wastewater, without treatment, to the municipal treatment plant". This alternative will be restricted by four factors: (a) Pretreated wastewater flow rate should not exceed the production wastewater flow rate, (b) Pretreated wastewater quantity should not exceed the design capacity, (c) Pretreated wastewater BOD effluent concentration should not exceed the design capacity for BOD effluent concentration, and (d) Pretreated and discharged wastewater BOD effluent concentration should not exceed allowed BOD effluent concentration to the municipal treatment plant.

Alternative 6: The sixth alternative says "Discharge all wastewater without permit and without treatment". This alternative does not have any restrictions.

Alternative 7: The seventh alternative states "Treat part of the wastewater in the company plant and release; send the other part, without treatment, to the river". This alternative will be restricted by three factors: (a) Treated wastewater flow rate should not exceed the production wastewater flow rate, (b) Treated wastewater flow rate should not exceed the plant's design capacity, (c) The discharge permitted is equal to the initial permit holdings plus traded permits.

Alternative 8: The eighth alternative says "Discharge wastewater after buying permit". This alternative will be restricted by the fact that the discharge permit needed is equal to the initial permit holding plus buying permit numbers (for TDP case only).

Upgrade Plan: Should your production forecasts indicate that you will not have enough capacity in your company's treatment plant and you decide to treat the waste in your plant, you might decide to upgrade your plant capacity. The upgrade plant is restricted by the following: (a) The future design capacity is not less than the current design capacity, and (b) The future design BOD effluent concentration is not more than the current design BOD effluent concentration (i.e., quality of treated waste should not be worse than the current quality of the effluent).

If the costs of treatment outweigh the marginal profits, you might recommend reducing the production levels. It is assumed in the statement of these alternatives that it is not feasible for Sunbelt to install new cotton processing technology.

The selection of any one of the options listed above will involve several types of costs. These include capital or fixed costs, variable costs, and municipal user charges. (Fixed costs will always be greater than zero regardless of your decision for handing the company's waste.) These costs vary with the wastewater design flow rate and the BOD design effluent concentration. As stated above, the wastewater design flow rate for Sunbelt's treatment plant is 1.5 MGD and the design BOD effluent concentration is 20 mg/l. For this plant, the annual fixed costs are $61,968.00.

The variable costs are shown in Table A-2. For a given BOD capacity design removal rate, variable costs vary with the actual BOD treatment level and the actual waste flow rate.

The transfer of any amount of waste to the municipal treatment plant involves the payment of a user charge to the municipal treatment plant. The size of this charge will vary with the volume of wastewater flow and the concentration of BOD if it is greater than 250 mg/l. A schedule of user charges for Sunbelt is shown in Table A-3.

TABLE A-2

VARIABLE COSTS ($)

| Wastewater (MGD) | BOD Effluent Concentration (mg/l) | | | |
|---|---|---|---|---|
| | 160 | 140 | 40 | 20 |
| 1.1 | $26,447 | $26,695 | $29,142 | $30,591 |
| 1.2 | 28,329 | 28,595 | 31,215 | 32,767 |
| 1.3 | 30,178 | 30,461 | 33,253 | 34,906 |
| 1.4 | 31,997 | 32,298 | 35,258 | 37,011 |
| 1.5 | 33,790 | 34,107 | 37,233 | 39,084 |
| 1.6 | 35,557 | 35,891 | 39,181 | 41,129 |
| 1.7 | 37,302 | 37,652 | 41,103 | 43,146 |
| 1.8 | 39,024 | 39,391 | 43,001 | 45,139 |
| 1.9 | 40,727 | 41,110 | 44,878 | 47,109 |
| 2.0 | 42,412 | 42,810 | 46,734 | 49,057 |

In certain cases you may decide to expand and/or upgrade the existing treatment facilities. This decision involves additional capital costs. The annual fixed capital costs for a number of upgraded plants are shown in Table A-4. These costs will vary with the wastewater design flow and with the BOD design removal rate. Once the waste treatment facility capcity is defined in terms of the wastewater design flow and the BOD capacity design removal rate, the capital costs become fixed costs until further decisions are made to again augment the treatment plant. The operation of the plant in this case will

TABLE A-3

MUNICIPAL USER CHARGES ($)

| Wastewater (MGD) | BOD Effluent Concentration (mg/l) 200 | 140 | 120 | 100 |
|---|---|---|---|---|
| 1.0 | $36,610 | $36,610 | $36,610 | $36,610 |
| 1.1 | 40,271 | 40,271 | 40,271 | 40,271 |
| 1.2 | 43,932 | 43,932 | 43,932 | 43,932 |
| 1.3 | 47,593 | 47,593 | 47,593 | 47,593 |
| 1.4 | 51,255 | 51,255 | 51,255 | 51,255 |
| 1.5 | 54,915 | 54,915 | 54,915 | 54,915 |
| 1.6 | 58,577 | 58,577 | 58,577 | 58,577 |
| 1.7 | 62,238 | 62,238 | 62,238 | 62,238 |
| 1.8 | 65,899 | 65,899 | 65,899 | 65,899 |
| 1.9 | 69,560 | 69,560 | 69,560 | 69,560 |
| 2.0 | 73,221 | 73,221 | 73,221 | 73,221 |

TABLE A-4

CAPITAL COSTS ($)

| Design Wastewater (MGD) | Design BOD Effluent Concentration (mg/l) 20 | 10 |
|---|---|---|
| 1.5 | $61,968 | $69,235 |
| 1.7 | 69,269 | 77,394 |
| 1.8 | 72,884 | 81,433 |
| 2.0 | 80,050 | 89,438 |
| 2.1 | 83,603 | 93,408 |
| 2.2 | 87,137 | 97,387 |
| 2.3 | 90,653 | 101,280 |

involve variable costs which will increase nonlinearly with changes in the actual BOD effluent concentration level and the actual wastewater flow rate. The additions to the plant will not become available for actual use until two periods after the decision to upgrade and/or add to the plant has been made.

# APPENDIX B

## EXAMPLE OF WASTE DISPOSAL DECISIONS

## FOR CASE STUDIES

## Decisions Without TDP

Team 1: Cotton Processing Plant

Production Forecast = 2.475 million pounds of product

Discharge = 1.200 MGD

BOD Concentration = 200 mg/l

## Water Quality Standard

Discharge = 1.70 MGD

BOD Concentration = 30 mg/l

## Treatment Plant Design Capacity

Discharge = 1.50 MGD

BOD Concentration = 20 mg/l

## Viable Alternatives for Disposing of Waste

Could use one of the following alternatives:

A) Alternative 1

B) Alternative 2

C) Alternative 3

D) Alternative 4

E) Alternative 5

## Costs of the Different Alternatives

**Note:** All of the different alternatives have the same capital or fixed cost which is $61,968 (illustrated in Table B-3).

A) Cost of alternative 1: Treat all wastewater in the company plant and release to the river. This alternative would require payment of variable cost for operation of the treatment plant. The amount of waste to be treated in the company plant and released cannot exceed the standard of a BOD concentration equal to 30 mg/l and wastewater flow equal to 1.70 MGD.

The variable cost for a treatment plant treating 1.2 MGD wastewater with a BOD effluent concentration of 30 mg/l can be calculated from Table B-1 by extrapolation.

Using Table B-1, look at the row of wastewater flow for 1.2 MGD and the columns of BOD effluent concentration of 40 mg/l and 20 mg/l.

If the BOD concentration is 40 mg/l and the treated wastewater flow is 1.2 MGD, the variable cost is $31,497.

If the BOD concentration is 20 mg/l and the treated wastewater flow is 1.2 MGD, the variable cost is $32,767. Find the approximate charge for a BOD effluent concentration by extrapolating as follows:

1) Let X1 = lower BOD effluent concentration.

   Let X2 = upper BOD effluent concentration.

   Let Xa = actual BOD effluent concentration.

   P = proportionality factor

   Calculate P as follows:

   $P = (xa - x1)/(x2 - x1)$

   For this example, X1 = 20, X2 = 40, Xa = 30.

   $P = (30 - 20)/(40 - 20) = 0.50.$

2) Let C1 = Variable cost associated with X1.

TABLE B-1

VARIABLE COSTS ($)

| Wastewater (MGD) | BOD Effluent Concentration (mg/l) 160 | 140 | 40 | 20 |
|---|---|---|---|---|
| 1.1 | $26,447 | $26,695 | $29,142 | $30,591 |
| 1.2 | 28,329 | 28,595 | 31,497 | 32,767 |
| 1.3 | 30,178 | 30,461 | 32,253 | 34,906 |
| 1.4 | 31,997 | 32,298 | 35,258 | 37,011 |
| 1.5 | 33,790 | 34,107 | 37,233 | 39,084 |
| 1.6 | 35,557 | 35,891 | 39,181 | 41,129 |
| 1.7 | 37,302 | 37,652 | 41,103 | 43,146 |

Let C2 = Variable cost associated with X2.

Let D = Difference in variable cost.

D = C2 - C1

For this example, C1 = $31,497 and C2 = $32,767.

From Table B-1:

D = 32,767 - 31,497 = $1,270

3) Let I = Proportionality cost.

For this example, I = (0.50) (1,270) = $635

4) Let Ce = estimated variable cost

Ce = C1 + I

Ce for this example:

Ce = 31,497 + 635 = 32,132

The total cost of alternative 3 is as follows:

Fixed Cost = $61,968

Variable Cost = $32,132

Total Cost = $94,100.

B) Cost of alternative 2: Pretreat all wastewater in the company plant and send to the municipal plant. This alternative would require payment of a municipal user charge as well as incurring variable cost for operating the treatment plant.

Since the generated BOD concentration is 200 mg/l, the municipal user charge will be the same as that of alternative 3.

Therefore, total cost of alternative 2 will always be more expensive than that of alternative 3.

C) Cost of alternative 3: Send all waste to the municipal plant without treatment.

This alternative would require payment of a municipal user charge.

Waste flow parameters are as follows:

BOD concentration = 200 mg/l

Discharge flow = 1.2 MGD.

The municipal user charge can be found from Table B-2. Using Table B-2, and the column for 100 mg/l and the row of wastewater flow for 1.2 MGD; the user charge is $43,932.

Fixed Cost = $61,968

Municipal User Charge = $43,932

Total Cost = $105,900.

TABLE B-2

MUNICIPAL USER CHARGES ($)

| Wastewater (MGD) | BOD Effluent Concentration (mg/l) 200 | 140 | 120 | 100 |
|---|---|---|---|---|
| 1.0 | $36,610 | $36,610 | $36,610 | $36,610 |
| 1.1 | 40,271 | 40,271 | 40,271 | 40,271 |
| 1.2 | 43,932 | 43,932 | 43,932 | 43,932 |
| 1.3 | 47,593 | 47,593 | 47,593 | 47,593 |
| 1.4 | 51,255 | 51,255 | 51,255 | 51,255 |
| 1.5 | 54,915 | 54,915 | 54,915 | 54,915 |

D) Cost of alternative 4: Treat part of the wastewater in the company plant and release; send the other part of the wastewater, without treatment, to the municipal plant.

E) Cost of alternative 5: Pretreat part of the wastewater in the company plant and send to the municipal plant; send the other part of the wastewater, without treatment, to the municipal plant.

These alternatives would require payment of a municipal user charge as well as incurring a variable cost for operating the treatment plant.

Since the municipal user charge is more expensive than the variable cost, no matter what proportion of wastewater is treated in the company plant, the total cost will always be greater than alternative 1.

Based on these calculations, the best alternative for Team 1 is alternative 1.

TABLE B-3

CAPITAL COSTS ($)

| Design Wastewater (MGD) | Design BOD Effluent Concentration (mg/l) 20 | 10 |
|---|---|---|
| 1.5 | $61,968 | $69,235 |
| 1.7 | 69,269 | 77,394 |
| 1.8 | 72,884 | 81,433 |
| 2.0 | 80,050 | 89,438 |
| 2.1 | 83,603 | 93,408 |

## Example of Waste Disposal Decisions with TDP's

## Determination of Bid/Ask Price for a TDP

Again, consider Team 1. One permit entitles the holder to discharge one Lb. of BOD per day for one quarter.

Lbs-BOD/day = (mg/l) x (MGD) x 8.34 lbs/[(mg/l) x (MG)]

Each discharger is given an initial number of permits to coincide with its stated wasteload allocation.

In this example, BOD Lbs/day is as follows:

Lbs-BOD/day = (30 mg/l) x (1.70 MGD) x (8.34 Lbs/[(mg/l) x (MG)])

For this example, the discharger is allowed to emit 424 Lbs of BOD per day for one quarter.

Discharger now has 424 permits.

## The Decision to Buy or Sell Permits

When break-even analysis is used to determine the bidding permit price, the logical boundaries for when to buy and sell permits must be considered.

The decision to buy or sell TDP's entails a comparison of the internal estimated cost of removal of waste at the local plant and the cost of TDP's. If TDP's are less costly than local treatment, TDP's will be purchased and local treatment will not be undertaken.

If alternative 8, "Discharge wastewater after buying permits" is chosen, 1577 permits are needed, and the cost of this option would be the permit buying cost.

The revenues from buying the permits could be used to offset the variable cost.

Additional permits needed are equal to

(1.2 x 200 x 8.34) - 424 = 1577.

If alternative 1, "Treat wastewater in the company plant and release it to the river" is selected, 1.2 MGD wastewater is treated to BOD effluent concentration 20 mg/l.

The number of permits to be sold in alternative 1 is based on the difference between the treatment plant capacity and the permitted discharge standard.

Fixed Cost = $61,968

Variable Cost = $32,767

Surplus Permit Sold = 424 - (1.2 x 20 x 8.34) = 224

Using break-even analysis:

32767 - 224 x unit permit price = 1577 x unit permit price.

Unit Permit Price = $18.19.

This means that if the TDP market price is less than 18.19, and if Team 1 decides to choose alternative 8, Team 1 will buy 1577 permits, at most. On the contrary, if the TDP market price is more expensive than 18.19, and if Team 1 decides to select alternative 1, Team 1 will sell 224 permits, at most.

## How to Decide Market Price for Permit

The market model is based on the multiple-price auction, negotiation between bidders, and rational bidder behavior. The following table is obtained from Appendix I.

| Team | # of permit bought | buying Price | # of permit sold | selling price |
|---|---|---|---|---|
| 1 | <-1577 | <-18.19 | <-224 | 18.19-> |
| 2 | <-14.2 | <-38.67 | <-76 | 38.67-> |
| 3 | <-123 | <-17.8 | <-10 | 17.8-> |
| 4 | <-26.66 | <-43.88 | <-6.66 | 43.88-> |
| 5 | <-333.6 | <-95.8 | <-333.6 | 95.8-> |
| 6 | --- | --- | <-625.5 | 5.0-> |
| 7 | --- | --- | --- | --- |

Based on the above information, the administration decides to make the following trading transactions:

Team 1 will buy 10.0 permits at \$18 from Team 3

Team 1 will buy 250.7 permits at \$18 from Team 6

Team 2 will buy 14.2 permits at \$19 from Team 6

Team 3 will sell 10.0 permits at \$18 to Team 1

Team 4 will buy 26.7 permits at \$39 from Team 6

Team 5 will buy 333.6 permits at \$44 from Team 6

Team 6 will sell 250.7 permits at \$18 to Team 1

Team 6 will sell 14.2 permits at \$19 to Team 2

Team 6 will sell 26.7 permits at \$39 to Team 4

Team 6 will sell 333.6 permits at \$44 to Team 5.

## Best Strategy With TDP Case

Current permit holding = 424 + 260.7 = 684.7

Design flow rate = 1.5 MGD

Actual flow rate = 1.2 MGD

Design BOD effluent concentration = 20 mg/l

Expected BOD influent concentration = 200 mg/l

Apparently, alternative 7, "Treat part of the wastewater in the company plant and release; send the other part, without treatment, to the river", will be a less expensive alternative.

Assumption: Y is the discharged flow rate

$(200 \times Y \times 8.34) + (1.2 - Y) \times 20 \times 8.34 = 684.7$

$Y = 0.32$ MGD

Therefore, the best alternative for Team 1 is to treat 0.88 MGD wastewater from BOD 200 mg/l influent concentration to 20 mg/l effluent concentration, and discharge 0.32 MGD to the river.

# APPENDIX C

# COMMAND PROCEDURE TO SPECIFY DATASETS AND SUBMIT THE COST PROGRAM AND THE QL2SMG PACKAGE

```
**** TSO FOREGROUND HARDCOPY ****
DSNAME=U11502C.TEACHERA.CLIST

00000100CONTROL MSG
00000200FREEALL
00000300WRITE THIS PROGRAM WILL TAKE YOUR INPUT FOR THE WATER QUALITY
00000400WRITE SIMULATION GAME AND GENERATE THE OUTPUT FILE
00000500WRITE
00000600WRITE ENTER  PERIOD NUMBER (E.G. 1)
00000700READ &PERIOD
00000800WRITE ENTER  PASSWORD
00000900READ &PASSWORD
00001000ATTRIB TEMP BLKSIZE(6160) LRECL(80) RECFM(F B)
00001100ALLOC F(FT15F001) DS(DECISION.DATA(A1&PERIOD)) SHR
00001200ALLOC F(FT16F001) DS(DECISION.DATA(A2&PERIOD)) SHR
00001300ALLOC F(FT17F001) DS(DECISION.DATA(A3&PERIOD)) SHR
00001400ALLOC F(FT18F001) DS(DECISION.DATA(A4&PERIOD)) SHR
00001500ALLOC F(FT19F001) DS(DECISION.DATA(A5&PERIOD)) SHR
00001600ALLOC F(FT20F001) DS(DECISION.DATA(A6&PERIOD)) SHR
00001700ALLOC F(FT21F001) DS(DECISION.DATA(A7&PERIOD)) SHR
00001800ALLOC F(FT11F001) DS(QUALITY.DATA(A&PERIOD)) OLD CATALOG +
00001810      UNIT(STORAGE) TRACKS SPACE(1,1) DIR(10) USING(TEMP)
00001900WRITE DATA SETS ARE ALLOCATED
00002000CALL 'U11502C.QUI.LOAD(INQUI)'
00002100EDIT COST.CNTL(A)
00002200C 700  /ZZ/&PERIOD./
00002300C 800 1500 /ZZ)/&PERIOD.)/ ALL
00002400C 1600 /ZZ./&PERIOD../
00002500C 2200 2300 /ZZ/&PERIOD./ ALL
00002600C 300 /????/&PASSWORD./
00002700SUBMIT
00002800C 700 /&PERIOD../ZZ./
00002900C 800 1500 /&PERIOD.)/ZZ)/ ALL
00003000C 1600 /&PERIOD../ZZ./
00003100C 2200 2300 /A&PERIOD./AZZ/ ALL
00003200C 300 /&PASSWORD./????/
00003300END S
00003400FREEALL
```

# APPENDIX D

# COMMAND PROCEDURES TO BE USED BY PARTICIPANTS FOR ENTERING DECISIONS

```
**** TSO FOREGROUND HARDCOPY ****
DSNAME=U11502C.INPUTA.CLIST

00000100CONTROL MSG
00000200FREEALL
00000400WRITE THIS PROGRAM WILL TAKE YOUR INPUT FOR THE WATER QUALITY
00000500WRITE SIMULATION GAME AND PREPARE THE DATA FILE
00000600WRITE
00000700WRITE ENTER YOUR TEAM NUMBER (E.G. 1)
00000800READ &TEAM
00000900WRITE ENTER YOUR PERIOD NUMBER (E.G. 1)
00001000READ &PERIOD
00001100SET &P=&PERIOD + 2
00001200ATTRIB TEMP BLKSIZE(6160) LRECL(80) RECFM(F B)
00001300ALLOC F(FT20F001) DS(PLANTA&P..CNTL) MOD USING(TEMP)
00001400ALLOC F(FT10F001) DS(PLANTA&PERIOD..CNTL) SHR
00001410ALLOC F(FT09F001) DS(TDPSA&PERIOD..CNTL) SHR
00001500ALLOC F(FT11F001) DS(DECISION.DATA(A&TEAM&PERIOD)) OLD
00001600WRITE DATA SETS ARE ALLOCATED
00001700CALL 'U11502C.SIMT.LOAD(TEMPNAME)'
00001800FREE F(FT11F001) ATTRLIST(TEMP)
00001900FREE F(FT20F001) ATTRLIST(TEMP)
```

# APPENDIX E

# FORTRAN PROGRAM FOR COST CALCULATIONS

```
*** TSO FOREGROUND HARDCOPY ****
SNAME=U11502C.MSIMU.CNTL

      THIS IS THE MAIN PROGRAM WHICH CONTAINS COST FUNCTION TO CALCULATE
      THE COST OF EACH TEAM. THE PROGRAM WILL READ STUDENT DECISION
      FILES, PLANT FILE, AND TDP FILE. THIS PROGRAM WILL GENERATE A
      FINANCILA REPORT FOR EACH TEAM.


      CH  -> CONVERSION FACTOR 1MGD IS EQUAL TO 157.7 CUBIC METERS/HOUR
      CML -> CONVERSION FACTOR 1MGD IS EQUAL TO 1381.525 MILLION LITERS/
             YEAR
      CTL -> CONVERSION FACTOR 1MGD IS EQUAL TO 1381525 THOUSAND LITERS/
             YEAR
      PLA(I) -> PRICE OF LABOR AND MATERIAL COSTS PER UNIT PRODUCT, FIRM
                I
      POE(I) -> PRICE OF OTHER EXPENSES PER UNIT PRODUCT, FIRM I
      PRI(I) -> PRICE PER UNIT PRODUCT, FIRM I


      DIMENSION PR(7),PQ(7),PBOD(7),DQ(7),DBOD(7),FQ(7),FBOD(7),Q1(7),
     *BOD1(7),Q2(7),BOD2(7),Q3(7),BOD3(7),Q4(7),BOD4(7),UQ(7),UBOD(7),
     *IT(7),IJ(7),IP(7),IS(7),BQ(7),BBOD(7),ABOD(7),RAT(7),C1(7),UC(7),
     *VC(7),PC(7),WC(7),TC(7),SR(7),ALM(7),OE(7),TTI(7),TCI(7),TNE(7),
     *PRI(5),PLA(5),POE(5),PP(7,7),TDPN(7,7),PTDP(7,7),SBOD(7),CBOD(7),
     *TPP(7)

      CHARACTER*1 AR
      DATA CH,CML,CTL/157.7,1381.525,1381525./
      DATA PRI/1200000.,1850000.,1800000.,1200000.,370000./
      DATA BQ,BBOD,C1,UC,TPP/7*0.,7*0.,7*0.,7*0.,7*0./

C     CALCULATE LABOR & MATERIAL COSTS AND OTHER EXPENSES
      DO 27 I=1,5
      PLA(I)=PRI(I)*0.6
      POE(I)=PRI(I)*0.1
   27 CONTINUE
C     READ DATA FROM STUDENT DECISION FILES
      DO 29 I=1,7
      READ(14+I,105) AR,IT(I),IJ(I),IS(I),IP(I),PR(I),PQ(I),PBOD(I),Q1(I
     *),BOD1(I),Q2(I),BOD2(I),Q3(I),BOD3(I),Q4(I),BOD4(I),UQ(I),UBOD(I),
     *FQ(I),FBOD(I),SBOD(I),CBOD(I)
C     SEED OF THE UNIFORMLY DISTRIBUTED PSEUDO-RADDOM NUMBERS
      NRG=NRG+PR(I)
  105 FORMAT(A1,4I1,F6.3,6(F6.3,F5.1)/F6.3,3F5.1)
   29 CONTINUE
C     INITIALIZE PERMIT PRICE, PERMIT NUMBER, AND TOTAL PERMIT PRICE
      DO 240 I=1,7
      DO 240 J=1,7
      PP(I,J)=0.
      TDPN(I,J)=0.
      PTDP(I,J)=0.
  240 CONTINUE
C     READ PLANT DESIGN CAPACITY AND DESIGN BOD EFFLUENT CONCENTRATION
   28 READ(11,106,END=30) I,DQ(I),DBOD(I)
  106 FORMAT(I2,1X,F6.3,F5.1)
      GO TO 28
C     READ TDP PRICE AND NUMBER OF PERMITS OF EACH TEAM
   30 READ(22,107) ((PTDP(I,J),J=1,7),I=1,7)
  107 FORMAT(7F10.0)
      READ(24,108) ((TDPN(I,J),J=1,7),I=1,7)
  108 FORMAT(7F10.2)

C     FIND FLOW RATES, BOD CONCENTRATIONS AND DESIGN BOD REMOVAL RATE
C     FOR EACH INDIVIDUAL WASTEWATER TREATMENT PLANT OF INDUSTRIAL FIRMS
      DO 32 I=1,5
      GO TO (121,122,123,121,122,123,121,123),IS(I)
  121 BQ(I)=Q1(I)
      BBOD(I)=PBOD(I)
      ABOD(I)=BOD1(I)
      RAT(I)=(BBOD(I)-DBOD(I))/BBOD(I)
      GO TO 32
  122 BQ(I)=Q2(I)
      BBOD(I)=PBOD(I)
      ABOD(I)=BOD2(I)
      RAT(I)=(BBOD(I)-DBOD(I))/BBOD(I)
      GO TO 32
  123 IF (IS(I).NE.6) GO TO 125
C     DISCHARGE WITHOUT PERMIT -> USE UNIFORMLY DISTRIBUTED PSEUDO -
C     RANDOM NUMBER U TO CATCH INFRACTIONS IF U IS LESS THAN 60 PERCENT
      U=RANF(2*IABS(NRG)+1)
      IF (U.LE.0.6) GO TO 124
      GO TO 125
  124 PC(I)=200000.
  125 BBOD(I)=PBOD(I)
      ABOD(I)=0.
      RAT(I)=0.
   32 CONTINUE

C     CALCULATE FLOW RATES, BOD CONCENTRATIONS AND DESIGN BOD REMOVAL
C     RATES FOR MUNICIPAL WASTEWATER TREATMENT PLANTS
      DO 33 I=1,3
      BQ(6)=BQ(6)+Q2(I)+Q3(I)
      BBOD(6)=BBOD(6)+Q2(I)*BOD2(I)+Q3(I)*BOD3(I)
   33 CONTINUE
      DO 34 I=4,5
      BQ(7)=BQ(7)+Q2(I)+Q3(I)
      BBOD(7)=BBOD(7)+Q2(I)*BOD2(I)+Q3(I)*BOD3(I)
   34 CONTINUE
      DO 35 I=6,7
      BQ(I)=BQ(I)+UQ(I)
      BBOD(I)=(BBOD(I)+UQ(I)*UBOD(I))/BQ(I)
      ABOD(I)=CBOD(I)
      RAT(I)=(BBOD(I)-DBOD(I))/BBOD(I)
   35 CONTINUE

C     CALCULATE INVESTMENT COSTS AND OPERATION COSTS
      DO 36 I=1,7
      C1(I)=78239*DQ(I)**0.89*BBOD(I)**0.24*DBOD(I)**(-0.16)*0.25
C     IF (RAT(I).NE.0.) GO TO 128
C     DURING MAINTENANCE PERIOD, QUARTERLY INVESTMENT AND FIXED
C     OPERATION COSTS OF THE DISCHARGER IS EQUAL TO HALF OF THE NORMAL
C     COST
C     C1(I)=0.5*C1(I)
      VC(I)=39244*BQ(I)**0.79*BBOD(I)**0.24*ABOD(I)**(-0.07)*0.25
C     CALCULATE TOTAL PERMIT PRICE, BUYING PERMIT IS PLUS, SELLING
C     PERMIT IS MINUS AND PRICE IS ALWAYS PLUS
      DO 36 J=1,7
      PP(I,J)=PTDP(I,J)*TDPN(I,J)
   36 CONTINUE
      C1(6)=78239*DQ(6)**0.89*200**0.24*DBOD(6)**(-0.16)*0.25
      C1(7)=78239*DQ(7)**0.89*200**0.24*DBOD(7)**(-0.16)*0.25
      DO 250 I=1,7
      DO 250 J=1,7
  250 TPP(I)=TPP(I)+PP(I,J)
      C1(3)=C1(3)+(16714*0.25)
      C1(4)=C1(4)+(17552*0.25)
      VC(3)=VC(3)+(6416*0.25)
```

```
      VC(4)=VC(4)+(1445*0.25)

      CALCULATE WATER QUALITY-RELATED COSTS AND PROFIT
      DO 37 I=1,5
      UC(I)=(Q2(I)*CTL*0.106+Q3(I)*CTL*0.106)/4
      IF BOD EFFLUENT CONCENTRATION EXCEEDS 250 MG/L THE FIRM HAS TO PAY
      SURCHARGE FEE
      IF (BOD2(I).LE.250) GO TO 51
      UC(I)=UC(I)+(Q2(I)*CML*0.443*(BOD2(I)-250))/4
   51 IF (BOD3(I).LE.250) GO TO 52
      UC(I)=UC(I)+(Q3(I)*CML*0.443*(BOD3(I)-250))/4
   52 WC(I)=C1(I)+VC(I)+UC(I)+PC(I)+TPP(I)
      SR(I)=PR(I)*PRI(I)
      ALM(I)=PR(I)*PLA(I)
      OE(I)=PR(I)*POE(I)
      TC(I)=WC(I)+ALM(I)+OE(I)
      TTI(I)=SR(I)-TC(I)
      TAX IS 46 PERCENT
      TCI(I)=0.46*TTI(I)
      TNE(I)=(1-0.46)*TTI(I)
   37 CONTINUE
      DO 38 I=1,3
      UC(6)=UC(6)+UC(I)
   38 CONTINUE
      DO 39 I=4,5
      UC(7)=UC(7)+UC(I)
   39 CONTINUE
      DO 40 I=6,7
      WC(I)=C1(I)+VC(I)-UC(I)+TPP(I)
   40 CONTINUE

      PRINT OUTPUT FOR INDUSTRIAL FIRMS
      DO 61 I=1,5
      CALL INFO(AR,I,IJ(I),IP(I),PR(I),DQ(I),DBOD(I),PQ(I),PBOD(I),UQ(I)
     *,UBOD(I),SBOD(I),CBOD(I))
      CALL SALT(IS(I),Q1(I),BOD1(I),Q2(I),BOD2(I),Q3(I),BOD3(I),Q4(I),BO
     *D4(I))
      IF (RAT(I).EQ.0.) GO TO 153
      WRITE(6,158) RAT(I)
  158 FORMAT(/1H0,'DESIGN BOD REMOVAL RATE                  :',F7.2)
  153 IF (FQ(I).LE.0.) GO TO 151
      CALL SHUPGR(FQ(I),FBOD(I))
  151 WRITE(6,159)
  159 FORMAT(/1H0,'     WATER QUALITY-RELATED COSTS')
      WRITE(6,160) C1(I)
  160 FORMAT(' QUARTERLY  INVESTMENT AND FIXED OPERATING COSTS OF PLANT
     *:',F9.0,' DOLLARS')
      WRITE(6,161) VC(I)
  161 FORMAT(' OPERATION COSTS                          :',F9.0,' DOLLAR
     *S')
      WRITE(6,162) UC(I)
  162 FORMAT(' INDUSTRIAL USER CHARGES                  :',F9.0,' DOLLAR
     *S')
      IF (PC(I).EQ.0.) GO TO 155
      WRITE(6,163) PC(I)
  163 FORMAT(' DISCHARGE WITHOUT PERMIT -> PENALTY COST :',F9.0,' DOLLAR
     *S')
  155 DO 300 J=1,7
      IF (TDPN(I,J)) 301,300,302
  301 WRITE(6,310) ABS(TDPN(I,J)),I,J
  310 FORMAT(' NUMBER OF PERMITS SOLD   :',F9.2,' FROM TEAM ',I2,' TO TE
     *AM ',I2)
      WRITE(6,311) PTDP(I,J)
  311 FORMAT(' UNIT PERMIT SELLING PRICE                :',F9.0,' DOLLAR
     *S')
      WRITE(6,312) ABS(PP(I,J))
  312 FORMAT(' REVENUE FROM PERMITS                     :',F9.0,' DOLLAR
     *S')
      IF (I.NE.7 .AND. J.NE.7) GO TO 300
      IF (I.EQ.7 .AND. J.EQ.7) GO TO 221
  302 WRITE(6,315) TDPN(I,J),J,I
  315 FORMAT(' NUMBER OF PERMITS BOUGHT :',F9.2,' FROM TEAM ',I2,' TO TE
     *AM ',I2)
      WRITE(6,316) PTDP(I,J)
  316 FORMAT(' UNIT PERMIT BUYING PRICE                 :',F9.0,' DOLLAR
     *S')
      WRITE(6,317) PP(I,J)
  317 FORMAT(' COST OF PERMITS                          :',F9.0,' DOLLAR
     *S')
  300 CONTINUE
  221 WRITE(6,169) WC(I)
  169 FORMAT(' TOTAL CURRENT COSTS                      :',F9.0,' DOLLAR
     *S')
      WRITE(6,170)
  170 FORMAT(/1H0,'     PROFIT & LOSS STATEMENT')
      WRITE(6,171) SR(I)
  171 FORMAT(' TOTAL SALES REVENUE                      :',F9.0,' DOLLAR
     *S')
      WRITE(6,172) ALM(I)
  172 FORMAT(' LABOR AND MATERIAL COSTS                 :',F9.0,' DOLLAR
     *S')
      WRITE(6,173) OE(I)
  173 FORMAT(' OTHER EXPENSES                           :',F9.0,' DOLLAR
     *S')
      WRITE(6,174) TC(I)
  174 FORMAT(' TOTAL EXPENSES                           :',F9.0,' DOLLAR
     *S')
      WRITE(6,175) TTI(I)
  175 FORMAT(' TOTAL TAXABLE INCOME                     :',F9.0,' DOLLAR
     *S')
      WRITE(6,176) TCI(I)
  176 FORMAT(' TAX ON CURRENT INCOME                    :',F9.0,' DOLLAR
     *S')
      WRITE(6,177) TNE(I)
  177 FORMAT(' NET EARNING                              :',F9.0,' DOLLAR
     *S')
      WRITE(23,230) AR,I,IJ(I),IS(I),IP(I),PR(I),PQ(I),PBOD(I),Q1(I),BOD
     *1(I),Q2(I),BOD2(I),Q3(I),BOD3(I),Q4(I),BOD4(I),UQ(I),UBOD(I),FQ(I)
     *,FBOD(I),SBOD(I),CBOD(I),RAT(I),C1(I),VC(I),UC(I),PC(I),WC(I),SR(I
     *),ALM(I),OE(I),TC(I),TTI(I),TCI(I),TNE(I),TPP(I)
  230 FORMAT(A1,4I1,F6.3,6(F6.3,F5.1)/F6.3,3F5.1,F5.3,6F9.0/6F9.0,F10.0)
   61 CONTINUE

C     PRINT OUTPUT FOR MUNICIPAL TREATMENT PLANTS
      DO 62 I=6,7
      CALL INFO(AR,I,IJ(I),IP(I),PR(I),DQ(I),DBOD(I),PQ(I),PBOD(I),UQ(I)
     *,UBOD(I),SBOD(I),CBOD(I))
      IF (I.EQ.6) GO TO 140
      IF (I.EQ.7) GO TO 141
  140 DO 142 J=1,3
      IF (Q2(J).LE.0.) GO TO 143
      WRITE(6,180) J,Q2(J)
  180 FORMAT(' ACTUAL PRETREATED WASTEWATER FLOW RATE FROM INDUSTRIAL FI
     *RM',I2,'                :',F7.3,' MGD')
      WRITE(6,181) J,BOD2(J)
  181 FORMAT(' ACTUAL PRETREATED WASTEWATER BOD INFLUENT CONCENTRATION F
     *ROM INDUSTRIAL FIRM',I2,' :',F5.1,'   MG/L')
  143 IF (Q3(J).LE.0.) GO TO 142
      WRITE(6,182) J,Q3(J)
  182 FORMAT(' ACTUAL RAW WASTEWATER FLOW RATE FROM INDUSTRIAL FIRM',I2,
     *'                :',F7.3,' MGD')
      WRITE(6,183) J,BOD3(J)
```

```
183  FORMAT(' ACTUAL RAW WASTEWATER BOD INFLUENT CONCENTRATION FROM IND
    *USTRIAL FIRM',I2,'          :',F5.1,'   MG/L')
142  CONTINUE
     GO TO 154
141  DO 144 J=4,5
     IF (Q2(J).LE.0.) GO TO 145
     WRITE(6,184) J,Q2(J)
184  FORMAT(' ACTUAL PRETREATED WASTEWATER FLOW RATE FROM INDUSTRIAL FI
    *RM',I2,'                  :',F7.3,' MGD')
     WRITE(6,185) J,BOD2(J)
185  FORMAT(' ACTUAL PRETREATED WASTEWATER BOD INFLUENT CONCENTRATION F
    *ROM INDUSTRIAL FIRM',I2,' :',F5.1,'   MG/L')
145  IF (Q3(J).LE.0.) GO TO 144
     WRITE(6,186) J,Q3(J)
186  FORMAT(' ACTUAL RAW WASTEWATER FLOW RATE FROM INDUSTRIAL FIRM',I2,
    *'                         :',F7.3,' MGD')
     WRITE(6,187) J,BOD3(J)
187  FORMAT(' ACTUAL RAW WASTEWATER BOD INFLUENT CONCENTRATION FROM IND
    *USTRIAL FIRM',I2,'          :',F5.1,'   MG/L')
144  CONTINUE
154  WRITE(6,188) BQ(I)
188  FORMAT(' ACTUAL TOTAL WASTEWATER FLOW RATE
    *                      :',F7.3,' MGD')
     WRITE(6,189) BBOD(I)
189  FORMAT(' ACTUAL AVERAGE BOD INFLUENT CONCENTRATION
    *                      :',F5.1,'   MG/L')
     WRITE(6,191) CBOD(I)
191  FORMAT(' ACTUAL MUNICIPAL PLANT WASTEWATER BOD EFFLUENT CONCENTRAT
    *ION                   :',F5.1,'   MG/L')
     WRITE(6,190) RAT(I)
190  FORMAT(/1H0,'DESIGN BOD REMOVAL RATE                        :',F7.2)
     IF (FQ(I).LE.0.) GO TO 152
     CALL SHUPGR(FQ(I),FBOD(I))
152  WRITE(6,201)
201  FORMAT(/1H0,'     WATER QUALITY-RELATED COSTS')
     WRITE(6,202) C1(I)
202  FORMAT(' ANNUAL INVESTMENT AND FIXED OPERATING COSTS OF PLANT :',F
    *9.0,' DOLLARS')
     WRITE(6,203) VC(I)
203  FORMAT(' OPERATION COSTS                                      :',F
    *9.0,' DOLLARS')
     IF (I.EQ.6) GO TO 146
     IF (I.EQ.7) GO TO 147
146  DO 148 J=1,3
     IF (UC(J).LE.0.) GO TO 148
     WRITE(6,204) J,UC(J)
204  FORMAT(' MUNICIPAL USER CHARGE FROM INDUSTRIAL FIRM',I2,'
    *:',F9.0,' DOLLARS')
148  CONTINUE
     GO TO 150
147  DO 149 J=4,5
     IF (UC(J).LE.0.) GO TO 149
     WRITE(6,205) J,UC(J)
205  FORMAT(' MUNICIPAL USER CHARGE FROM INDUSTRIAL FIRM',I2,'
    *:',F9.0,' DOLLARS')
149  CONTINUE
150  WRITE(6,206) UC(I)
206  FORMAT(' TOTAL MUNICIPAL USER CHARGES                         :',F
    *9.0,' DOLLARS')
     DO 400 J=1,7
     IF (TDPN(I,J)) 401,400,402
401  WRITE(6,410) ABS(TDPN(I,J)),I,J
410  FORMAT(' NUMBER OF PERMITS SOLD   :',F9.2,' FROM TEAM ',I2,' TO TE
    *AM ',I2)
     WRITE(6,411) PTDP(I,J)
411  FORMAT(' UNIT PERMIT SELLING PRICE                   :',F9.0,' DOLLAR
    *S')
     WRITE(6,412) ABS(PP(I,J))
412  FORMAT(' REVENUE FROM PERMITS                        :',F9.0,' DOLLAR
    *S')
     IF (I.NE.7 .AND. J.NE.7) GO TO 400
     IF (I.EQ.6 .AND. J.EQ.7) GO TO 400
     IF (I.EQ.7 .AND. J.EQ.7) GO TO 222
402  WRITE(6,415) TDPN(I,J),J,I
415  FORMAT(' NUMBER OF PERMITS BOUGHT :',F9.2,' FROM TEAM ',I2,' TO TE
    *AM ',I2)
     WRITE(6,416) PTDP(I,J)
416  FORMAT(' UNIT PERMIT BUYING PRICE                    :',F9.0,' DOLLAR
    *S')
     WRITE(6,417) PP(I,J)
417  FORMAT(' COST OF PERMITS                             :',F9.0,' DOLLAR
    *S')
400  CONTINUE
222  WRITE(6,210) WC(I)
210  FORMAT(' TOTAL CURRENT COSTS                                 :',F
    *9.0,' DOLLARS')
     WRITE(23,230) AR,I,IJ(I),IS(I),IP(I),PR(I),BQ(I),BBOD(I),Q1(I),BOD
    *1(I),Q2(I),BOD2(I),Q3(I),BOD3(I),Q4(I),BOD4(I),UQ(I),UBOD(I),FQ(I)
    *,FBOD(I),SBOD(I),CBOD(I),RAT(I),C1(I),VC(I),UC(I),PC(I),WC(I),SR(I
    *),ALM(I),OE(I),TC(I),TTI(I),TCI(I),TNE(I),TPP(I)
 62  CONTINUE
     STOP
     END

C    THIS SUBROUTINE IS USED FOR PRINTING BASIC INFORMATION
     SUBROUTINE INFO(AR,IA,IJ,IP,PRIT,DQIT,DBODIT,PQIT,PBODIT,UQ1IT,
    *UBODIT,SBODIT,CBODIT)
     CHARACTER*1 AR
     WRITE(6,112)
112  FORMAT(1H1,/1H0,'     WATER QUALITY SIMULATION GAME')
     WRITE(6,114) AR
114  FORMAT(1H0,' REGION                              :',1X,A1)
     WRITE(6,105) IP
105  FORMAT('  GAME PERIOD                         :',I2)
     WRITE(6,115) IA
115  FORMAT('  REPORT FOR TEAM                     :',I2)
     WRITE(6,125)
125  FORMAT(/1H0,'     DECISIONS FOR WATER QUALITY MANAGEMENT')
     WRITE(6,135) DQIT
135  FORMAT(' CURRENT DESIGN CAPACITY                     :',F7.3,' MGD')
     WRITE(6,145) DBODIT
145  FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION:',F5.1,'   MG/L
    *')
     WRITE(6,146) SBODIT
146  FORMAT(' CURRENT MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION
    *TO THE RIVER:',F6.1,' MG/L')
     IF (IJ.GT.1) GO TO 101
     WRITE(6,155)
155  FORMAT(' THIS IS INDUSTRIAL FIRM')
     GO TO 102
101  WRITE(6,165)
165  FORMAT(' THIS IS MUNICIPAL TREATMENT PLANT')
     WRITE(6,175) UQ1IT
175  FORMAT(' ACTUAL RESIDENTIAL WASTEWATER FLOW RATE
    *                         :',F7.3,' MGD')
     WRITE(6,185) UBODIT
185  FORMAT(' ACTUAL RESIDENTIAL WASTEWATER BOD INFLUENT CONCENTRATION
    *                         :',F5.1,'   MG/L')
     GO TO 103
102  IF (IA.EQ.2) GO TO 104
     WRITE(6,195) PRIT
195  FORMAT(' PRODUCTION FORCAST                          :',F7.3,' MILLIO
```

```
     *N POUNDS OF PRODUCT')
      GO TO 106
  104 WRITE(6,196) PRIT
  196 FORMAT(' PRODUCTION FORCAST                          :',F7.3,' MILLIO
     *NS OF BIRDS')
  106 WRITE(6,205) PQIT
  205 FORMAT('  EXPECTED WASTEWATER FLOW RATE              :',F7.3,' MGD')
      WRITE(6,215) PBODIT
  215 FORMAT('  EXPECTED BOD INFLUENT CONCENTRATION        :',F5.1,'   MG/L
     *')
  103 RETURN
      END

C     THIS SUBROUTINE IS USED FOR PRINTING ALTERNATIVE
      SUBROUTINE SALT(IS,Q1IT,BOD1IT,Q2IT,BOD2IT,Q3IT,BOD3IT,Q4IT,BOD4IT
     *)
      WRITE(6,201)
  201 FORMAT(/1H0,'     THIS IS YOUR ALTERNATIVE')
      GO TO (101,102,103,104,106,107,108,109),IS
  101 WRITE(6,105)
  105 FORMAT(' TREAT EVERYTHING IN THE COMPANY PLANT & RELEASE.')
      WRITE(6,115) Q1IT
  115 FORMAT(' TREATED WASTEWATER FLOW RATE                :',F7.3,' MGD')
      WRITE(6,125) BOD1IT
  125 FORMAT(' EXPECTED BOD EFFLUENT CONCENTRATION         :',F5.1,'   MG/L
     *')
      GO TO 325
  102 WRITE(6,135)
  135 FORMAT(' PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO THE MU
     *NICIPAL PLANT.')
      WRITE(6,145) Q2IT
  145 FORMAT(' PRETREATED WASTEWATER FLOW RATE             :',F7.3,' MGD')
      WRITE(6,155) BOD2IT
  155 FORMAT(' EXPECTED BOD EFFLUENT CONCENTRATION         :',F5.1,'   MG/L
     *')
      GO TO 325
  103 WRITE(6,165)
  165 FORMAT(' SEND ALL WASTEWATER TO THE MUNICIPAL PLANT WITHOUT TREATM
     *ENT.')
      WRITE(6,175) Q3IT
  175 FORMAT(' SEND WASTEWATER FLOW RATE                   :',F7.3,' MGD')
      WRITE(6,185) BOD3IT
  185 FORMAT(' SEND WASTEWATER BOD CONCENTRATION           :',F5.1,'   MG/L
     *')
      GO TO 325
  104 WRITE(6,195)
  195 FORMAT(' TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OTHER
     * PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT.')
      WRITE(6,205) Q1IT
  205 FORMAT(' TREATED WASTEWATER FLOW RATE                :',F7.3,' MGD')
      WRITE(6,215) BOD1IT
  215 FORMAT(' TREATED WASTEWATER BOD EFFLUENT CONCENTRATION            :
     *',F5.1,' MG/L')
      WRITE(6,225) Q3IT
  225 FORMAT(' WITHOUT TREATMENT WASTEWATER FLOW RATE   :',F7.3,' MGD')
      WRITE(6,235) BOD3IT
  235 FORMAT(' WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION :
     *',F5.1,'MG/L')
      GO TO 325
  106 WRITE(6,245)
  245 FORMAT('  PRETREAT PART IN THE COMPANY PLANT & SEND TO MUNICIPAL P
     *LANT, SEND THE OTHER PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT
     *')
      WRITE(6,255) Q2IT
  255 FORMAT(' PRETREATED WASTEWATER FLOW RATE             :',F7.3,' MGD')
      WRITE(6,265) BOD2IT
  265 FORMAT(' PRETREATED WASTEWATER BOD EFFLUENT CONCENTRATION         :
     *',F5.1,' MG/L')
      WRITE(6,275) Q3IT
  275 FORMAT(' WITHOUT TREATMENT WASTEWATER FLOW RATE   :',F7.3,' MGD')
      WRITE(6,285) BOD3IT
  285 FORMAT(' WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION :
     *',F5.1,' MG/L')
      GO TO 325
  107 WRITE(6,295)
  295 FORMAT('  DISCHARGE WITHOUT PERMIT')
      WRITE(6,305) Q4IT
  305 FORMAT(' DISCHARGED WASTEWATER FLOW RATE             :',F7.3,' MGD')
      WRITE(6,315) BOD4IT
  315 FORMAT(' DISCHARGED BOD EFFLUENT CONCENTRATION       :',F5.1,'   MG/L
     *')
      GO TO 325
  108 WRITE(6,335)
  335 FORMAT(' TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OTHER
     * PART WITHOUT TREATMENT TO THE RIVER.')
      WRITE(6,345) Q1IT
  345 FORMAT(' TREATED WASTEWATER FLOW RATE                :',F7.3,' MGD')
      WRITE(6,355) BOD1IT
  355 FORMAT(' TREATED WASTEWATER BOD EFFLUENT CONCENTRATION            :
     *',F5.1,' MG/L')
      WRITE(6,225) Q4IT
  365 FORMAT(' DISCHARGED WASTEWATER FLOW RATE             :',F7.3,' MGD')
      WRITE(6,375) BOD4IT
  375 FORMAT(' DISCHARGED WASTEWATER BOD EFFLUENT CONCENTRATION         :
     *',F5.1,'MG/L')
      GO TO 325
  109 WRITE(6,385)
  385 FORMAT('  DISCHARGE WITH PERMIT')
      WRITE(6,395) Q4IT
  395 FORMAT(' DISCHARGED WASTEWATER FLOW RATE             :',F7.3,' MGD')
      WRITE(6,405) BOD4IT
  405 FORMAT(' DISCHARGED BOD EFFLUENT CONCENTRATION       :',F5.1,'   MG/L
     *')
  325 RETURN
      END

C     THIS SUBROUTINE IS USED FOR PRINTING UPGRADE PLAN
      SUBROUTINE SHUPGR(FQIT,FBODIT)
      WRITE(6,105)
  105 FORMAT(/1H0,'     THIS IS YOUR UPGRADE PLAN')
      WRITE(6,115) FQIT
  115 FORMAT(' FUTURE DESIGN CAPACITY                      :',F7.3,' MGD')
      WRITE(6,125) FBODIT
  125 FORMAT(' FUTURE DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'   MG/L
     *')
      RETURN
      END
```

# APPENDIX F

## INTERACTIVE FORTRAN PROGRAM FOR PARTICIPANT INPUT

```
*** TSO FOREGROUND HARDCOPY ****
NAME=U11502C.SIMT.CNTL

      THIS IS AN INTERACTIVE INPUT PROGRAM FOR STUDENTS. THE STUDENT HAS
      TO PROVIDE TEAM NUMBER (TEAM 1 TO 5 ARE INDUSTRIAL FIRMS, TEAM 6
      AND 7 ARE MUNICIPAL TREATMENT PLANTS), PERIOD NUMBERS, BASIC
      INFORMATIOM OF PRODUCTION VOLUME PRODUCED, WASTEWATER FLOW RATE
      AND BOD CONCENTRATION. IF THE STUDENT WANTS TO BUY PERMITS, HE CAN
      ONLY CHOOSE ALTERNATIVE 1, 4, 7 OR ALTERNATIVE 8, IF HE WANTS TO
      SELL PERMITS, HE CAN CHOOSE ANY ONE OF THESE EIGHT ALTERNATIVE TO
      TREAT ITS WASTEWATER AND DECIDE WHETHER TO UPGRADE EXISTING PLANT
      OR NOT. IF THE STUDENT WANTS TO UPGRADE THE PLANT, THE UPGRADING
      TAKES 2 PERIODS OF TIME.
      THIS PROGRAN WILL READ PLANT FILE AND TDP FILE.THE PROGRAM WILL
      BE CREATED AS A LOAD MODULE AND EXECUTED BY TSO COMMAND LANGUAGE
      (INPUTA.CLIST).
      THE PROGRAM WILL GENERATE STUDENT DECISION FILE AND PLANT FILE.
      THE STUDENT DECISION FILE WILL BE FED INTO MAIN PROGRAM AND
      INSTRUCTOR INPUT PROGRAM. THE PLANT FILE WILL BE FED INTO MAIN
      PROGRAM AND STUDENT INPUT PROGRAM LATER.


      SQ(I)   -> THE MAXIMUM LIMITATION OF WASTEWATER FLOW RATE TO THE
                 RIVER (MGD), TEAM I
      SBOD(I) -> THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO
                 THE RIVER (MG/L), TEAM I
      PBOD(I) -> WASTEWATER BOD CONCENTRATION PRODUCED (MG/L), FIRM I
      PF(I)   -> PRODUCTION FUNCTION OF INDUSTRIAL PRODUCT, FIRM I
      RMBOD   -> THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRAION TO
                 THE MUNICIPAL TREATMENT PLANT (MG/L)


      DIMENSION PR(7),PQ(7),PBOD(7),DQ(7),DBOD(7),FQ(7),FBOD(7),Q1(7),
     *          BOD1(7),Q2(7),BOD2(7),Q3(7),BOD3(7),Q4(7),BOD4(7),UQ1(7)
     *          ,UBOD1(7),IF(7),SQ(7),SBOD(7),PF(7),TDP(7),CBOD(7)

      CHARACTER*1 AR
      DATA SQ/1.7,0.38,0.03,0.04,2.,26.7,5.6/
      DATA SBOD/30.,24.,40.,20.,20.,45.,10./
      DATA PBOD/200.,300.,400.,100.,400.,0.,0./
      DATA PF/0.4848,0.1212,0.0379,0.1569,0.0379,0.,0./
      DATA RMBOD/400./

      READ TRADING NUMBER PERMITS OF EACH TEAM
      READ(9,107) (IF(I),TDP(IF(I)),I=1,7)
107   FORMAT(I2,1X,F10.2)
      READ CURRENT DESIGN CAPACITY AND DESIGN BOD EFFLUENT CONCENTRAION
114   READ(10,115,END=101) I,DQ(I),DBOD(I)
115   FORMAT(I2,1X,F6.3,F5.1)
      GO TO 114
101   DO 116 I=1,7
      PQ(I)=0.
116   CONTINUE
      SBOD(1)=30.
      SBOD(2)=24.
      SBOD(3)=40.
      SBOD(4)=20.
      SBOD(5)=20.
      SBOD(6)=45.
      SBOD(7)=10.
      MFLG AND INFLG ARE FLAGS TO CONTROL SWITCH
      MFLG=-1
      INFLG=-1
      IS=0

C     INPUT BASIC INFORMATION FOR THE SIMULATION GAME
      PRINT 123
  123 FORMAT(1X,'PLEASE ENTER YOUR REGION (E.G. A, B OR C)')
      READ(5,124) AR
  124 FORMAT(A1)
      PRINT 125
  125 FORMAT(1X,'PLEASE ENTER YOUR TEAM NUMBER AGAIN (E.G. 1)')
      READ*,IT
      PRINT 135
  135 FORMAT(1X,'PLEASE ENTER YOUR PERIOD NUMBER AGAIN (E.G. 1)')
      READ*,IP
      CALL INTALT(IFLAG,Q1(IT),BOD1(IT),Q2(IT),BOD2(IT),Q3(IT),BOD3(IT),
     *Q4(IT),BOD4(IT),UQ1(IT),UBOD1(IT),FQ(IT),FBOD(IT))
      IF (IT.LE.5) GO TO 201
      IF (IT.GT.5) GO TO 202
  201 IJ=1
      PRINT 145
  145 FORMAT(1X,'INDUSTRIAL FIRM')
   91 PRINT 155
  155 FORMAT(1X,'ENTER YOUR PRODUCTION FORCAST')
      READ*,PR(IT)
      PQ(IT)=PR(IT)*PF(IT)
      PRINT 165,PQ(IT)
  165 FORMAT(1X,'EXPECTED WASTEWATER FLOW RATE       :',F7.3,'MGD')
      PRINT 175,PBOD(IT)
  175 FORMAT(1X,'EXPECTED BOD INFLUENT CONCENTRATION :',F5.1,'  MG/L')
      PRINT 185
  185 FORMAT(1X,'DO YOU WANT TO TRY ANOTHER PRODUCTION LEVEL')
      CALL YESNO(IA)
      IF (IA.EQ.1) GO TO 91
      IF (IA.EQ.2) GO TO 210
C     IA.EQ.1 --> YES, IA.EQ.2 --> NO
  202 IJ=2
      PRINT 140
  140 FORMAT(1X,'MUNICIPAL TREATMENT PLANT')
      PRINT 150
  150 FORMAT(1X,'ENTER YOUR RESIDENTIAL WASTEWATER FLOW RATE (MGD)')
      READ*,UQ1(IT)
      PRINT 160
  160 FORMAT(1X,'ENTER YOUR RESIDENTIAL WASTEWATER BOD INFLUENT CONCENTR
     *ATION (MG/L)')
      READ*,UBOD1(IT)
      CALL MPEBOD(DBOD(IT),CBOD(IT),SBOD(IT))
  210 CALL INFO(AR,IT,IJ,IP,PR(IT),DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),UQ1(I
     *T),UBOD1(IT),TDP(IT),SBOD(IT),CBOD(IT))
  102 PRINT 195
  195 FORMAT(1X,'DO YOU WANT TO SELECT AN ALTERNATIVE FOR DISPOSING OF C
     *URRENT PERIOD WASTEWATER OR UPGRADING EXISTING PLANT')
      PRINT 196
  196 FORMAT('OR CORRECT SOME INFORMATION')
      CALL YESNO(IA)
      IF ((IA.EQ.2).AND.(IJ.EQ.2)) GO TO 765
      IF (IA.EQ.2) GO TO 501
C     FLAG FOR MUNICIPAL TREATMENT PLANT EFFECTIVE FOR 190 FORMAT
      IF (MFLG.EQ.0) GO TO 180
C     FLAG FOR INDUSTRIAL FIRM EFFECTIVE FOR 265 FORMAT
      IF (INFLG.EQ.0) GO TO 255
      PRINT 215
C     ASK FOR ANY CORRECTION ?
  215 FORMAT(1X,'IS THE INFORMATION SHOWN ABOVE CORRECT?')
      CALL CORT(IC)
      IF (IJ.EQ.1) GO TO 103
      IF (IC.EQ.1) GO TO 735
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      IF (IC.EQ.2) GO TO 180

      MAKE CORRECTION FOR THE MUNICIPAL TREATMENT PLANT
180   PRINT 190
190   FORMAT(' TYPE VARIABLE NUMBER TO BE CHANGED OR -1 TO LIST THE INFO
     *RMATION YOU HAVE')
      PRINT 200
200   FORMAT(' FOR EXAMPLE: TYPE 2 FOR PERIOD NUMBER')
      READ*,MFLG
      IF (MFLG.GE.0) GO TO 205
      MFLG=0
      GO TO 210
205   IN=MFLG
      GO TO (285,295,225,235,245),IN
      PRINT 260,IN
260   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 180
225   PRINT 150
      READ*,UQ1(IT)
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF (IB.EQ.2) GO TO 180
235   PRINT 160
      READ*,UBOD1(IT)
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF (IB.EQ.2) GO TO 180
245   CALL MPEBOD(DBOD(IT),CBOD(IT),SBOD(IT))
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF (IB.EQ.2) GO TO 180
103   IF (IC.EQ.1) GO TO 495
      IF (IC.EQ.2) GO TO 255

      MAKE CORRECTION FOR THE INDUSTRIAL FIRM
255   PRINT 265
265   FORMAT(' TYPE VARIABLE NUMBER TO BE CHANGED OR -1 TO LIST THE INFO
     *RMATION YOU HAVE')
      PRINT 275
275   FORMAT(' FOR EXAMPLE: TYPE 3 FOR PRODUCTION FORCAST')
      READ*,INFLG
      IF (INFLG.GE.0) GO TO 266
      INFLG=0
      GO TO 210
266   IN=INFLG
      GO TO (285,295,305),IN
      PRINT 260,IN
      GO TO 255
285   PRINT 125
      READ*,IT
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF ((IB.EQ.2).AND.(IJ.EQ.1)) GO TO 255
      IF ((IB.EQ.2).AND.(IJ.EQ.2)) GC TO 180
295   PRINT 135
      READ*,IP
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF ((IB.EQ.2).AND.(IJ.EQ.1)) GO TO 255
      IF ((IB.EQ.2).AND.(IJ.EQ.2)) GO TO 180
305   PRINT 155
      READ*,PR(IT)
      PQ(IT)=PR(IT)*PF(IT)
      CALL CORT(IB)
      IF (IB.EQ.1) GO TO 210
      IF (IB.EQ.2) GO TO 255

C     SELECT ALTERNATIVE FOR DISPOSING WASTEWATER
 495  PRINT 505
 505  FORMAT(/1X,'SELECT ALTERNATIVE FOR DISPOSING OF CURRENT PERIOD WAS
     *TEWATER - ENTER NUMBER')
 162  CALL INTALT(IFLAG,Q1(IT),BOD1(IT),Q2(IT),BOD2(IT),Q3(IT),BOD3(IT),
     *Q4(IT),BOD4(IT),UQ1(IT),UBOD1(IT),FQ(IT),FBOD(IT))
C     PRINT LIST OF ALTERNATIVES
      PRINT 515
 515  FORMAT(1X,'1 TREAT EVERYTHING IN THE COMPANY PLANT & RELEASE.')
      PRINT 525
 525  FORMAT(1X,'2 PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO TH
     *E MUNICIPAL PLANT.')
      PRINT 535
 535  FORMAT(1X,'3 SEND ALL WASTE TO THE MUNICIPAL PLANT WITHOUT TREATME
     *NT.')
      PRINT 555
 555  FORMAT(1X,'4 TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE O
     *THER PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT.')
      PRINT 565
 565  FORMAT(1X,'5 PRETREAT PART IN THE COMPANY PLANT &SEND TO MUNICIPAL
     * PLANT, SEND THE OTHER PART WITHOUT TREATMENT TO THE MUNICIPAL PLA
     *NT.')
      PRINT 574
 574  FORMAT(1X,'6 DISCHARGE WITHOUT PERMIT.')
      PRINT 575
 575  FORMAT(1X,'7 TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE O
     *THER PART WITHOUT TREATMENT TO THE RIVER.')
      PRINT 576
 576  FORMAT(1X,'8 DISCHARGE WITH PERMIT.')
      PRINT 577
 577  FORMAT(1X,'IF YOU BUY PERMITS, YOU CAN ONLY CHOOSE ALTERNATIVE 1,4
     *, 7 OR ALTERNATIVE 8')
      PRINT 578
 578  FORMAT(1X,'IF YOU SELL PERMITS, YOU CAN CHOOSE ANY ONE OF THESE SI
     *X ALTERNATIVES')
      READ*,IS
      GO TO (585,595,605,615,625,635,665,666),IS
      PRINT 645,IS
 645  FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE CORRECT
     * YOUR ALTERNATIVE')
      GO TO 495
 585  CALL TECP(IFLAG,DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),SQ(IT),SBOD(IT),Q1
     *(IT),BOD1(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
 595  CALL PESM(IFLAG,DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),RMBOD,Q2(IT),BOD2(
     *IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
 605  CALL SEMP(IFLAG,PQ(IT),PBOD(IT),Q3(IT),BOD3(IT),TDP(IT),RMBOD)
      IF (IFLAG.EQ.1),GO TO 495
      GO TO 655
 615  CALL TPCWM(IFLAG,DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),SQ(IT),SBOD(IT),Q
     *1(IT),BOD1(IT),Q3(IT),BOD3(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
 625  CALL PPCWM(IFLAG,DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),RMBOD,Q2(IT),BOD2
     *(IT),Q3(IT),BOD3(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
 635  CALL WDUMP(IFLAG,PQ(IT),PBOD(IT),Q4(IT),BOD4(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
 665  CALL TPSR (IFLAG,DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),SQ(IT),SBOD(IT),Q
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     *1(IT),BOD1(IT),Q4(IT),BOD4(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
      GO TO 655
  666 CALL WPDUMP(IFLAG,PQ(IT),PBOD(IT),Q4(IT),BOD4(IT),TDP(IT))
      IF (IFLAG.EQ.1) GO TO 495
  655 CALL SALT(IS,Q1(IT),BOD1(IT),Q2(IT),BOD2(IT),Q3(IT),BOD3(IT),Q4(IT
     *),BOD4(IT))
      PRINT 675
  675 FORMAT(1X,'IS THIS CORRECT')
  161 PRINT 685
  685 FORMAT(1X,'ENTER 1 IF CORRECT')
      PRINT 695
  695 FORMAT(1X,'ENTER 2 IF WANT TO DELETE CHOSEN ALTERNATIVE AND SELECT
     * ANOTHER ALTERNATIVE')
      READ*,IC
      IF (IC.EQ.1) GO TO 735
      IF (IC.EQ.2) GO TO 715
      PRINT 705,IC
  705 FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 161
  715 PRINT 725
  725 FORMAT(1X,'ENTER ALTERNATIVE NUMBER TO BE SELECTED')
      GO TO 162

      DECIDE TO UPGRADE EXISTING PLANT
  735 PRINT 745
  745 FORMAT(1X,'DO YOU WANT TO UPGRADE EXISTING PLANT')
      CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 765
      CALL UPGRAD(IFLAG,DQ(IT),DBOD(IT),FQ(IT),FBOD(IT),SQ(IT),SBOD(IT))
  765 CALL INFO(AR,IT,IJ,IP,PR(IT),DQ(IT),DBOD(IT),PQ(IT),PBOD(IT),UQ1(I
     *T),UBOD1(IT),TDP(IT),SBOD(IT),CBOD(IT))
      IF (IJ.EQ.2) GO TO 104
      CALL SALT(IS,Q1(IT),BOD1(IT),Q2(IT),BOD2(IT),Q3(IT),BOD3(IT),Q4(IT
     *),BOD4(IT))
  104 IF (IA.EQ.2) GO TO 775
      IF (IFLAG.EQ.1) GO TO 775
      CALL SHUPGR(FQ(IT),FBOD(IT))
  775 PRINT 785
  785 FORMAT(' THIS WILL BE STORED AS YOUR DECISION FOR THIS PERIOD IN A
     * DATA FILE.')
      PRINT 795
  795 FORMAT(' IF YOU WANT TO INPUT ALL THE DATA AGAIN, PLEASE TYPE -1 O
     *THERWISE TYPE 0')
      READ*,IFLG
      IF (IFLG.GE.0) GO TO 805
      GO TO 101

      PRINT OUTPUT FOR STUDENT DECISION FILE
  805 WRITE(11,50) AR,IT,IJ,IS,IP,PR(IT),PQ(IT),PBOD(IT),Q1(IT),BOD1(IT)
     *,Q2(IT),BOD2(IT),Q3(IT),BOD3(IT),Q4(IT),BOD4(IT),UQ1(IT),UBOD1(IT)
     *,FQ(IT),FBOD(IT),SBOD(IT),CBOD(IT)
   50 FORMAT(A1,4I1,F6.3,6(F6.3,F5.1)/F6.3,3F5.1)
      IF(FQ(IT).LE.0) GO TO 815
      PTINT OUTPUT FOR PLANT FILE
      WRITE(20,806) IT,FQ(IT),FBOD(IT)
  806 FORMAT(I2,1X,F6.3,F5.1)
      GO TO 501
  815 WRITE(20,806) IT,DQ(IT),DBOD(IT)
  501 STOP
      END

      THIS SUBROUTINE IS USED FOR INITIALIZATION
      SUBROUTINE INTALT(LFLAG,Q1IT,BOD1IT,Q2IT,BOD2IT,Q3IT,BOD3IT,Q4IT,B
     *OD4IT,UQ1IT,UBODIT,FQIT,FBODIT)
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      IFLAG=0
      Q1IT=0.
      BOD1IT=0.
      Q2IT=0.
      BOD2IT=0.
      Q3IT=0.
      BOD3IT=0.
      Q4IT=0.
      BOD4IT=0.
      UQ1IT=0.
      UBODIT=0.
      FQIT=0.
      FBODIT=0.
      RETURN
      END

C     THIS SUBROUTINE IS USED FOR SELECTING MUNICIPAL PLANT WASTEWATER B
C     OD EFFLUENT CONCENTRATION
      SUBROUTINE MPEBOD(DBODIT,CBODIT,SBODIT)
      PRINT 105,DBODIT
  105 FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION
     *          :',F5.1,' MG/L')
      PRINT 115,SBODIT
  115 FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
     *HE RIVER :',F5.1,' MG/L')
  155 PRINT 125
  125 FORMAT(1X,'ENTER EXPECTED BOD EFFLUENT CONCENTRATION (MG/L)')
      READ*,CBODIT
C     SHOW RESTRICTION ITEMS
      IF (CBODIT.GE.DBODIT) GO TO 135
      PRINT 145,CBODIT,DBODIT
  145 FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
     *OWERS THE DESIGN BOD EFFLUENT CONCENTRATION',F5.1,'MG/L')
      GO TO 155
  135 IF (CBODIT.LE.SBODIT) GO TO 165
      PRINT 175,CBODIT,SBODIT
  175 FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L E
     *XCEED THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L')
  165 RETURN
      END

C     THIS SUBROUTINE IS USED FOR PRINTING BASIC INFORMATION
      SUBROUTINE INFO(AR,IT,IJ,IP,PRIT,DQIT,DBODIT,PQIT,PBODIT,UQ1IT,UBO
     *DIT,TDPIT,SBODIT,CBODIT)
      PRINT 105
  105 FORMAT(1X,'THIS IS THE INFORMATION YOU HAVE')
      PRINT 114,AR
  114 FORMAT(1X,'  REGION                          :',1X,A1)
      PRINT 115,IT
  115 FORMAT(1X,'1.TEAM NUMBER                     :',I2)
      PRINT 125,IP
  125 FORMAT(1X,'2.PERIOD NUMBER                   :',I2)
      PRINT 135,DQIT
  135 FORMAT(1X,'CURRENT DESIGN CAPACITY           :',F7.3,'MGD')
      PRINT 145,DBODIT
  145 FORMAT(1X,'CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'MG/L
     *')
      PRINT 146,SBODIT
  146 FORMAT(1X,'CURRENT MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATIO
     *N TO THE RIVER:',F6.1,'MG/L')
      IF (TDPIT) 104,106,107
  104 PRINT 147, ABS(TDPIT)
  147 FORMAT(1X,'NUMBER OF PERMITS SOLD            :',F6.2)
      GO TO 106
  107 PRINT 148,TDPIT
  148 FORMAT(1X,'NUMBER OF PERMITS BOUGHT          :',F6.2)
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106   IF (IJ.GT.1) GO TO 101
      PRINT 155
155   FORMAT(1X,'  THIS IS INDUSTRIAL FIRM')
      GO TO 102
101   PRINT 165
165   FORMAT(1X,'  THIS IS MUNICIPAL TREATMENT PLANT')
      PRINT 175,UQ1IT
175   FORMAT(1X,'3.EXPECTED RESIDENTIAL WASTEWATER FLOW RATE
     *          :',F7.3,'MGD')
      PRINT 185,UBODIT
185   FORMAT(1X,'4.EXPECTED RESIDENTIAL WASTEWATER BOD INFLUENT CONCENTR
     *ATION    :',F5.1,'MG/L')
      PRINT 186,CBODIT
186   FORMAT(1X,'5.EXPECTED MUNICIPAL PLANT WASTEWATER BOD EFFLUENT CONC
     *ENTRATION :',F5.1,'MG/L')
      GO TO 103
102   PRINT 195,PRIT
195   FORMAT(1X,'3.PRODUCTION FORCAST                  :',F7.3)
      PRINT 205,PQIT
205   FORMAT(1X,'   EXPECTED WASTEWATER FLOW RATE    :',F7.3,'MGD')
      PRINT 215,PBODIT
215   FORMAT(1X,'   EXPECTED BOD INFLUENT CONCENTRATION      :',F5.1,'MG/
     *L')
103   RETURN
      END

      THIS SUBROUTINE IS USED FOR ALTERNATIVE "TREAT EVERYTHING IN THE
      COMPANY PLANT AND RELEASE"
      SUBROUTINE TECP(IFLAG,DQIT,DBODIT,PQIT,PBODIT,SQIT,SBODIT,Q1IT,BOD
     *1IT,TDPIT)
      IFLAG=0
      SHOW BASIC INFORMATION
      PRINT 105
105   FORMAT(' TREAT EVERYTHING IN THE COMPANY PLANT & RELEASE.')
      PRINT 115,DQIT
115   FORMAT(' CURRENT DESIGN CAPACITY                   :',F7.3,'MGD')
      PRINT 125,DBODIT
125   FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
     *')
      IF (TDPIT) 126,127,128
126   PRINT 129, ABS(TDPIT)
129   FORMAT(' NUMBER OF PERMITS SOLD                    :',F6.2)
      GO TO 127
128   PRINT 130,TDPIT
130   FORMAT(' NUMBER OF PERMITS BOUGHT                  :',F6.2)
127   PRINT 135,PQIT
135   FORMAT(' EXPECTED WASTEWATER FLOW RATE             :',F7.3,'MGD')
      PRINT 145,PBODIT
145   FORMAT(' EXPECTED BOD INFLUENT CONCENTRATION       :',F5.1,'  MG/L
     *')
      PRINT 146,SQIT
146   FORMAT(' THE MAXIMUM LIMITATION OF WASTEWATER FLOW RATE TO THE RIV
     *ER      :',F7.3,'MGD')
      PRINT 147,SBODIT
147   FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
     *HE RIVER :',F5.1,'  MG/L')
      SHOW RESTRICTION ITEMS
      IF (PQIT.LE.DQIT) GO TO 160
      PRINT 155,PQIT,DQIT
155   FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE',F9.5,'MGD EXCEEDS
     *THE DESIGN CAPACITY',F9.5,'MGD')
      PRINT 156
156   FORMAT('          SORRY THIS IS INFEASIBLE SOLUTION, PLEASE CONSID
     *ER ALTERNATIVE 3,4,5,6')
      GO TO 102
160   IF (PQIT.LE.SQIT) GO TO 164
      PRINT 157,PQIT,SQIT
157   FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE',F9.5,'MGD EXCEEDS
     *THE MAXIMUN LIMITATION OF WASTEWATER FLOW RATE TO THE RIVER',F9.5,
     *'MGD')
      PRINT 156
      GO TO 102
164   CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
175   Q1IT=PQIT
C      PERMIT SOLD IS NEGATIVE SIGN IN THE INPUT FILE
101   BOD1IT=(SBODIT*SQIT)/Q1IT+TDPIT/8.34
C     GET INPUT DATA
C     PRINT 185
C185  FORMAT(1X,'ENTER DESIRED BOD EFFLUENT CONCENTRATION (MG/L)')
C     READ*,BOD1IT
      PRINT 100
100   FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      PRINT 195,Q1IT
195   FORMAT(1X,'TREATED WASTEWATER FLOW RATE          :',F7.3,'MGD')
      PRINT 205,BOD1IT
205   FORMAT(1X,'EXPECTED BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L')
C     MAKE CORRECTION
107   PRINT 215
215   FORMAT(' IS THIS CORRECT')
103   PRINT 225
225   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 235
235   FORMAT(' ENTER 2 IF WANT TO CHANGE BOD EFFLUENT CONCENTRATION')
      PRINT 245
245   FORMAT(' ENTER 3 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (265,175,102),IC
      PRINT 255,IC
255   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 103
102   IFLAG=1
      Q1IT=0.
      BOD1IT=0.
      GO TO 335
305   Q1IT=FLG
      GO TO 101
265   IF (Q1IT.LE.DQIT) GO TO 335
      PRINT 325,Q1IT,DQIT
325   FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE ',F7.3,'MGD EXCEEDS
     *THE DESIGN WASTEWATER CAPACITY ',F7.3,'MGD')
      PRINT 326
326   FORMAT(' PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO  SELECT DI
     *FFERENT ALTERNATIVE')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 305
      GO TO 102
335   RETURN
      END

C     THIS SUBROUTINE IS USED FOR ALTERNATIVE "PRETREAT EVERYTHING IN
C     THE COMPANY PLANT & SEND TO THE MUNICIPAL TREATMENT"
      SUBROUTINE PESM(IFLAG,DQIT,DBODIT,PQIT,PBODIT,RMBOD,Q2IT,BOD2IT,TD
     *PIT)
      IFLAG=0
      PRINT 105
105   FORMAT(' PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO THE MU
     *NICIPAL PLANT.')
      IF (TDPIT.LE.0.) GO TO 104
      PRINT 114,TDPIT
114   FORMAT(' NUMBER OF PERMITS BOUGHT IS',F5.0,'SORRY THIS IS INFEASIB
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     *LE SOLUTION, PLEASE CONSIDER ALTERNATIVE 1,4')
      GO TO 102
      SHOW BASIC INFORMATION
 104  PRINT 115,DQIT
 115  FORMAT(' CURRENT DESIGN CAPACITY                    :',F7.3,'MGD')
      PRINT 125,DBODIT
 125  FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
     *')
      PRINT 135,PQIT
 135  FORMAT(' EXPECTED WASTEWATER FLOW RATE              :',F7.3,'MGD')
      PRINT 145,PBODIT
 145  FORMAT(' EXPECTED BOD INFLUENT CONCENTRATION        :',F5.1,'  MG/L
     *')
      PRINT 146,RMBOD
 146  FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
     *HE MUNICIPAL TREATMENT PLANT :',F5.1,' MG/L')
      SHOW RESTRICTION ITEMS
      IF (PQIT.LE.DQIT) GO TO 161
      PRINT 155,PQIT,DQIT
 155  FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE',F9.5,'MGD EXCEED T
     *HE DESIGN CAPACITY',F9.5,'MGD')
      PRINT 156
 156  FORMAT('          SORRY THIS IS INFEASIBLE SOLUTION, PLEASE CONSID
     *ER ALTERNATIVE 3,4,5,6')
      GO TO 102
 161  IF (DBODIT.LE.RMBOD) GO TO 164
      PRINT 162,RMBOD,DBODIT
 162  FORMAT(' WARNING: THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG
     */L LOWERS THE DESIGN BOD EFFLUENT CONCENTRATION LIMITS',F5.1,'MG/L
     *')
      PRINT 163
 163  FORMAT('           SORRY THIS INFEASIBLE SOLUTION, PLEASE CONSIDER
     * ALTERNATIVE 3,6')
      GO TO 102
 164  CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
      Q2IT=PQIT
      GET INPUT DATA
 175  PRINT 185
 185  FORMAT(1X,'ENTER DESIRED BOD EFFLUENT CONCENTRATION (MG/L)')
      READ*,BOD2IT
 101  PRINT 100
 100  FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      PRINT 195,Q2IT
 195  FORMAT(1X,'PRETREATED WASTEWATER FLOW RATE     :',F7.3,'MGD')
      PRINT 205,BOD2IT
 205  FORMAT(1X,'EXPECTED BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L')
      MAKE CORRECTION
      PRINT 215
 215  FORMAT(' IS THIS CORRECT')
 103  PRINT 225
 225  FORMAT(' ENTER 1 IF CORRECT')
      PRINT 235
 235  FORMAT(' ENTER 2 IF WANT TO CHANGE BOD EFFLUENT CONCENTRATION')
      PRINT 245
 245  FORMAT(' ENTER 3 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (265,175,102),IC
      PRINT 255,IC
 255  FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 103
 265  IF (BOD2IT.LE.RMBOD) GO TO 285
      PRINT 275,BOD2IT,RMBOD
 275  FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
     *OWERS THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L PLEASE IN
     * PUT A REASONABLE VALUE OR ENTER -1 TO  SELECT DIFFERENT ALTERNATI
     *VE')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 305
 102  IFLAG=1
      BOD2IT=0.
      GO TO 335
 305  BOD2IT=FLG
      GO TO 101
 285  IF (BOD2IT.GE.DBODIT) GO TO 335
      PRINT 325,BOD2IT,DBODIT
 325  FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
     *OWERS THE DESIGN BOD EFFLUENT CONCENTRATION LIMITATION',F5.1,'MG/L
     *')
      PRINT 326
 326  FORMAT(' PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO  SELECT DI
     *FFERENT ALTERNATIVE')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 305
      GO TO 102
 335  RETURN
      END

C     THIS SUBROUTINE IS USED FOR ALTERNATIVE "SEND ALL WASTE TO THE
C     MUNICIPAL TREATMENT WITHOUT TREATMENT"
      SUBROUTINE SEMP(IFLAG,PQIT,PBODIT,Q3IT,BOD3IT,TDPIT,RMBOD)
      IFLAG=0
      PRINT 105
 105  FORMAT(1X,'SEND ALL WASTE TO THE MUNICIPAL PLANT WITHOUT TREATMENT
     *.')
      BOD3IT=PBODIT
      IF (TDPIT.LE.0.) GO TO 103
      PRINT 115,TDPIT
 115  FORMAT(' NUMBER OF PERMITS BOUGHT IS',F5.0,'SORRY THIS IS INFEASIB
     *LE SOLUTION, PLEASE CONSIDER ALTERNATIVE 1,4')
      GO TO 102
 103  IF (BOD3IT.LE.RMBOD) GO TO 104
      PRINT 125,BOD3IT,RMBOD
 125  FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
     *OWERS THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L')
      PRINT 135
 135  FORMAT('           SORRY THIS INFEASIBLE SOLUTION, PLEASE CONSIDER
     * ALTERNATIVE 1,2,6')
      GO TO 102
 104  CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
      Q3IT=PQIT
      PRINT 100
 100  FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      PRINT 145,Q3IT
 145  FORMAT(1X,'SEND WASTEWATER FLOW RATE TO THE MUNICIPAL PLANT
     *     :',F6.2,'MGD')
      PRINT 155,BOD3IT
 155  FORMAT(1X,'EXPECTED BOD  EFFLUENT CONCENTRATION TO THE MUNICIPAL P
     *LANT :',F6.2,'MG/L')
C     MAKE CORRECTION
      PRINT 165
 165  FORMAT(' IS THIS CORRECT')
 101  PRINT 175
 175  FORMAT(' ENTER 1 IF CORRECT')
      PRINT 185
 185  FORMAT(' ENTER 2 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (205,102),IC
      PRINT 195,IC
 195  FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
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      * REASONABLE VALUE')
        GO TO 101
  102   IFLAG=1
        Q3IT=0.
        BOD3IT=0.
  205   RETURN
        END

        THIS SUBROUTINE IS USED FOR ALTERNATIVE "TREAT PART IN THE COMPANY
        PLANT & RELEASE, SEND THE OTHER PART WITHOUT TREATMENT TO THE
        MUNICIPAL PLANT"
        SUBROUTINE TPCWM(IFLAG,DQIT,DBODIT,PQIT,PBODIT,SQIT,SBODIT,Q1IT,BO
       *D1IT,Q3IT,BOD3IT,TDPIT)
        IFLAG=0
        SHOW BASIC INFORMATION
        PRINT 105
  105   FORMAT(' TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OTHER
       * PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT')
        PRINT 115,DQIT
  115   FORMAT(' CURRENT DESIGN CAPACITY                   :',F7.3,'MGD')
        PRINT 125,DBODIT
  125   FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
       *')
        IF (TDPIT) 126,127,128
  126   PRINT 129, ABS(TDPIT)
  129   FORMAT(' NUMBER OF PERMITS SOLD                    :',F6.2)
        GO TO 127
  128   PRINT 130,TDPIT
  130   FORMAT(' NUMBER OF PERMITS BOUGHT                  :',F6.2)
  127   PRINT 135,PQIT
  135   FORMAT(' EXPECTED WASTEWATER FLOW RATE             :',F7.3,'MGD')
        PRINT 145,PBODIT
  145   FORMAT(' EXPECTED BOD INFLUENT CONCENTRATION       :',F5.1,'  MG/L
       *')
        PRINT 154,SQIT
  154   FORMAT(' THE MAXIMUM LIMITATION OF WASTEWATER FLOW RATE TO THE RIV
       *ER      :',F7.3,'MGD')
        PRINT 155,SBODIT
  155   FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
       *HE RIVER :',F7.3,'MG/L')
        SHOW RESTRICTION ITEMS
  101   CALL YESNO(IA)
        IF (IA.EQ.2) GO TO 102
        GET INPUT DATA
  106   IN=0
  385   PRINT 185
  185   FORMAT(1X,'ENTER TREATED WASTEWATER FLOW RATE IN THE COMPANY PLANT
       * (MGD)')
        READ*,Q1IT
  104   IF (Q1IT.LE.PQIT) GO TO 201
        PRINT 195,Q1IT,PQIT
  195   FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
       *T',F7.3,'MGD EXCEEDS THE PRODUCTION WASTEWATER FLOW RATE',F7.3,'MG
       *D')
        PRINT 196
  196   FORMAT('             SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT
       *A REASONABLE VALUE')
        GO TO 385
  201   IF (Q1IT.LE.DQIT) GO TO 205
        PRINT 197,Q1IT,DQIT
  197   FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
       *T',F7.3,'MGD EXCEEDS THE DESIGN CAPACITY',F7.3,'MGD')
        PRINT 198
  198   FORMAT('            SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT A
       * REASONABLE VALUE OR ENTER -1 TO SELLECT DIFFERENT ALTERNATIVE')
        READ*,FLG
        IF (FLG.GE.0.) GO TO 325
  102   IFLAG=1
        Q1IT=0.
        BOD1IT=0.
        GO TO 475
  325   Q1IT=FLG
        GO TO 104
C202    IF (Q1IT.LE.SQIT) GO TO 205
C       PRINT 199,Q1IT,SQIT
C199    FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
C      *T',F7.3,'MGD EXCEEDS THE MAXIMUM LIMITATION OF WASTEWATER FLOW RAT
C      *E',F7.3,'MGD')
C       PRINT 198
C       READ*,FLG
C       IF (FLG.GE.0.) GO TO 325
C       GO TO 102
  205   Q3IT=PQIT-Q1IT
        IF (IN.EQ.1) GO TO 108
        PRINT 175
  175   FORMAT(1X,'ENTER DESIRED BOD EFFLUENT CONCENTRATION FROM THE COMPA
       *NY PLANT & RELEASE TO THE RIVER (MG/L)')
        READ*,BOD1IT
C       MEASURE THE TDP'S EFFECT ON ALLOWED BOD EFFLUENT CONCENTRATION
C       Q1IT*BOD1IT=SBODIT*SQIT+TDPIT
        BOD3IT=PBODIT
  107   PRINT 215
  215   FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
        PRINT 225,Q1IT
  225   FORMAT(1X,'1.TREATED WASTEWATER FLOW RATE          :',F7.3,'MGD')
        PRINT 235,BOD1IT
  235   FORMAT(1X,'2.TREATED WASTEWATERE BOD EFFLUENT CONCENTRATION :',F5.
       *1,'MG/L')
        PRINT 245,Q3IT
  245   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER FLOW RATE :',F7.3,'MGD')
        PRINT 255,BOD3IT
  255   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATI
       * :',F5.1,'MG/L')
C       IF (DTBOD) 110,111,112
C 110   PRINT 256, ABS(DTBOD)
C 256   FORMAT(1X,'THE ALLOWED BOD EFFLUENT CONCENTRATION WILL BE DECREASE
C      D BY',F6.1,'MG/L BY SELLING PERMITS')
C       GO TO 113
C 112   PRINT 257,DTBOD
C 257   FORMAT(1X,'THE ALLOWED BOD EFFLUENT CONCENTRATION WILL BE INCREASE
C      D BY',F6.1,'MG/L BY BUYING PERMITS')
C 113   PRINT 258,SBODIT
C 258   FORMAT(1X,'THE CURRENT MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTR
C      ATION TO THE RIVRE IS',F6.1,'MG/L BY TRADING PERMITS')
C       MAKE CORRECTION
        PRINT 265
  265   FORMAT(' IS THIS CORRECT')
  103   PRINT 275
  275   FORMAT(' ENTER 1 IF CORRECT')
        PRINT 285
  285   FORMAT(' ENTER 2 IF NEED TO MAKE A CHANGE')
        PRINT 295
  295   FORMAT(' ENTER 3 IF WANT TO INPUT DATA AGAIN')
        PRINT 305
  305   FORMAT(' ENTER 4 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
        READ*,IC
        GO TO (475,345,106,102),IC
        PRINT 315,IC
  315   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
       * REASONABLE VALUE')
        GO TO 103
  345   PRINT 355
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 55  FORMAT(' TYPE VARIABLE NUMBER TO BE CHANGED')
     PRINT 365
;65  FORMAT(' FOR EXAMPLE: TYPE 2 FOR TREATED BOD EFFLUENT CONCENTRATIO
    *N TO THE RIVER')
     READ*,IN
     GO TO (385,109),IN
     PRINT 375,IN
 75  FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
    * REASONABLE VALUE')
     GO TO 345
.09  PRINT 175
     READ*,BOD1IT
:08  PRINT 395
:95  FORMAT(' ENTER 1 IF CORRECT')
     PRINT 405
;05  FORMAT(' ENTER 2 IF NEED TO MAKE MORE CORRECTION')
     READ*,IB
     IF (IB.EQ.1) GO TO 107
     IF (IB.EQ.2) GO TO 345
     PRINT 415,IB
.15  FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
    * REASONABLE VALUE')
:25  IF (BOD1IT.LE.SBODIT) GO TO 455
     PRINT 425,BOD1IT,SBODIT
;25  FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
    *OWERS THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L')
     PRINT 426
.26  FORMAT('           PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO
    *SELECT DIFFERENT ALTERNATIVE')
     READ*,FLG
     IF (FLG.GE.0.) GO TO 435
     GO TO 102
:35  BOD1IT=FLG
     GO TO 107
:55  IF (BOD1IT.GE.DBODIT) GO TO 475
     PRINT 465,BOD1IT,DBODIT
;65  FORMAT(' WARNING: TREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L L
    *OWERS THE DESIGN BOD EFFLUENT CONCENTRATION LIMITATION',F5.1,'MG/L
    *')
     PRINT 466
:66  FORMAT(' PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO  SELECT DI
    *FFERENT ALTERNATIVE')
     READ*,FLG
     IF (FLG.GE.0.) GO TO 305
     GO TO 108
:75  RETURN
     END

     THIS SUBROUTINE IS USED FOR SUBROUTINE "PRETREAT PART IN THE
     COMPANY PLANT & SEND TO THE MUNICIPAL PLANT, SEND THE OTHER PART
     WITHOUT TREATMENT TO THE MUNUCIPAL PLANT"
     SUBROUTINE PPCWM(IFLAG,DQIT,DBODIT,PQIT,PBODIT,RMBOD,Q2IT,BOD2IT,Q
    *3IT,BOD3IT,TDPIT)
     IFLAG=0
     SHOW BASIC INFORMATION
     PRINT 105
:05  FORMAT(' PRETREAT PART IN THE COMPANY PLANT & SEND TO THE MUNICIPA
    *L PLANT, SEND THE OTHER PART WITHOUT TREATMENT TO THE MUNICIPAL PL
    *ANT')
     IF (TDPIT.LE.0.) GO TO 110
     PRINT 114,TDPIT
:14  FORMAT(' NUMBER OF PERMITS BOUGHT IS',F5.0,'SORRY THIS IS INFEASIB
    *LE SOLUTION, PLEASE CONSIDER ALTERNATIVE 1,4')
     GO TO 102
:10  PRINT 115,DQIT
:15  FORMAT(' CURRENT DESIGN CAPACITY                 :',F7.3,'MGD')
     PRINT 125,DBODIT
 125 FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
    *')
     PRINT 135,PQIT
 135 FORMAT(' EXPECTED WASTEWATER FLOW RATE            :',F7.3,'MGD')
     PRINT 145,PBODIT
 145 FORMAT(' EXPECTED BOD INFLUENT CONCENTRATION      :',F5.1,'  MG/L
    *')
     PRINT 146,RMBOD
 146 FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
    *HE MUNICIPAL TREATMENT PLANT :',F5.1,'MG/L')
C    SHOW RESTRICTION ITEMS
     IF (DBODIT.LE.RMBOD) GO TO 101
     PRINT 147,RMBOD,DBODIT
 147 FORMAT(' WARNING: THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG
    */L LOWERS THE DESIGN BOD EFFLUENT CONCENTRATION LIMITATION',F5.1,'
    *MG/L')
     PRINT 148
 148 FORMAT('           SORRY THIS IS INFEASIBLE SOLUTION, PLEASE CONSID
    *ER ALTERNATIVE 3,6')
     GO TO 102
 101 CALL YESNO(IA)
     IF (IA.EQ.2) GO TO 102
C    GET INPUT DATA
 106 IN=0
 385 PRINT 185
 185 FORMAT(1X,'ENTER TREATED WASTEWATER FLOW RATE IN THE COMPANY PLANT
    * (MGD)')
     READ*,Q2IT
 104 IF (Q2IT.LE.PQIT) GO TO 201
     PRINT 195,Q2IT,PQIT
 195 FORMAT(' WARNING: PRETREATED WASTEWATER FLOW RATE IN THE COMPANY P
    *LANT',F7.3,'MGD EXCEEDS THE PRODUCTION WASTEWATER FLOW RATE',F7.3,
    *'MGD')
     PRINT 196
 196 FORMAT('           SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT
    *A REASONABLE VALUE')
     GO TO 385
 201 IF (Q2IT.LE.DQIT) GO TO 205
     PRINT 197,Q2IT,DQIT
 197 FORMAT(' WARNING: PRETREATED WASTEWATER FLOW RATE IN THE COMPANY P
    *LANT',F7.3,'MGD EXCEEDS THE DESIGN CAPACITY',F7.3,'MGD')
     PRINT 198
 198 FORMAT('           SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT A
    * REASONABLE VALUE OR ENTER -1 TO SELLECT DIFFERENT ALTERNATIVE')
     READ*,FLG
     IF (FLG.GE.0.) GO TO 325
 102 IFLAG=1
     Q2IT=0.
     BOD2IT=0.
     GO TO 475
 325 Q2IT=FLG
     GO TO 104
 205 Q3IT=PQIT-Q2IT
     IF (IN.EQ.1) GO TO 108
     PRINT 175
 175 FORMAT(1X,'ENTER DESIRED BOD EFFLUENT CONCENTRATION FROM THE COMPA
    *NY PLANT & RELEASE TO THE RIVER (MG/L)')
     READ*,BOD2IT
     BOD3IT=PBODIT
 107 PRINT 215
 215 FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
     PRINT 225,Q2IT
 225 FORMAT(1X,'1.PRETREATED WASTEWATER FLOW RATE       :',F7.3,'MGD')
     PRINT 235,BOD2IT
 235 FORMAT(1X,'2.PRETREATED WASTEWATER BOD EFFLUENT CONCENTRATION :',F
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     *5.1,'MG/L')
      PRINT 245,Q3IT
245   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER FLOW RATE :',F7.3,'MGD')
      PRINT 255,BOD3IT
255   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION
     * :',F5.1,'MG/L')
      MAKE CORRECTION
      PRINT 265
265   FORMAT(' IS THIS CORRECT')
103   PRINT 275
275   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 285
285   FORMAT(' ENTER 2 IF NEED TO MAKE A CHANGE')
      PRINT 295
295   FORMAT(' ENTER 3 IF WANT TO INPUT DATA AGAIN')
      PRINT 305
305   FORMAT(' ENTER 4 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (335,345,106,102),IC
      PRINT 315,IC
315   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 103
345   PRINT 355
355   FORMAT(' TYPE VARIABLE NUMBER TO BE CHANGED')
      PRINT 365
365   FORMAT(' FOR EXAMPLE: TYPE 1 FOR PRETREATED WASTEWATER FLOW RATE')
      READ*,IN
      GO TO (385,109),IN
      PRINT 375,IN
375   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * RESONABLE VALUE')
      GO TO 345
109   PRINT 175
      READ*,BOD2IT
108   PRINT 395
395   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 405
405   FORMAT(' ENTER 2 IF NEED TO MAKE MORE CORRECTION')
      READ*,IB
      IF (IB.EQ.1) GO TO 107
      IF (IB.EQ.2) GO TO 345
      PRINT 415,IB
415   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 108
335   IF (BOD2IT.LE.RMBOD) GO TO 455
      PRINT 425,BOD2IT,RMBOD
425   FORMAT(' WARNING: PRETREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/
     *L LOWERS THE ALLOWED BOD EFFLUENT CONCENTRATION',F5.1,'MG/L')
      PRINT 426
426   FORMAT('           PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO S
     *ELECT DIFFERENT ALTERNATIVE')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 435
      GO TO 102
435   BOD2IT=FLG
      GO TO 107
455   IF (BOD2IT.GE.DBODIT) GO TO 475
      PRINT 465,BOD2IT,DBODIT
465   FORMAT(' WARNING: PRETREATED BOD EFFLUENT CONCENTRATION',F5.1,'MG/
     *L LOWERS THE DESIGN BOD EFFLUENT CONCENTRATION LIMITS',F5.1,'MG/L'
     *)
      PRINT 466
466   FORMAT('           PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TOS
     *ELECT DIFFERENT ALTERNATIVE')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 435
      GO TO 102
475   RETURN
      END

C     THIS SUBROUTINE IS USED FOR SUBROUTINE "DISCHARGE WITHOUT PERMIT"
      SUBROUTINE WDUMP(IFLAG,PQIT,PBODIT,Q4IT,BOD4IT,TDPIT)
      IFLAG=0
C     SHOW BASIC INFORMATION
      PRINT 105
105   FORMAT(1X,'DISCHARGE WITHOUT PERMIT')
      IF (TDPIT.LE.0.) GO TO 103
      PRINT 115,TDPIT
115   FORMAT(' NUMBER OF PERMITS BOUGHT IS',F5.0,'SORRY THIS IS INFEASIB
     *LE SOLUTION, PLEASE CONSIDER ALTERNATIVE 1, 4, 7  OR 8')
      GO TO 102
103   CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
      Q4IT=PQIT
      BOD4IT=PBODIT
      PRINT 100
100   FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      PRINT 145,Q4IT
145   FORMAT(1X,'DISCHARGE WASTEWATER FLOW RATE      :',F7.3,'MGD')
      PRINT 155,BOD4IT
155   FORMAT(1X,'EXPECTED BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L')
C     MAKE CORRECTION
      PRINT 165
165   FORMAT(' IS THIS CORRECT')
101   PRINT 175
175   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 185
185   FORMAT(' ENTER 2 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (205,102),IC
      PRINT 195,IC
195   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 101
102   IFLAG=1
      Q4IT=0.
      BOD4IT=0.
205   RETURN
      END

C     THIS SUBROUTINE IS USED FOR ALTERNATIVE "TREAT PART IN THE COMPANY
C     PLANT & RELEASE, SEND THE OTHER PART WITHOUT TREATMENT TO THE
C     RIVER"
      SUBROUTINE TPSR (IFLAG,DQIT,DBODIT,PQIT,PBODIT,SQIT,SBODIT,Q1IT,BO
     *D1IT,Q4IT,BOD4IT,TDPIT)
      IFLAG=0
C     SHOW BASIC INFORMATION
      PRINT 105
105   FORMAT(' TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OTHER
     * PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT')
      PRINT 115,DQIT
115   FORMAT(' CURRENT DESIGN CAPACITY                    :',F7.3,'MGD')
      PRINT 125,DBODIT
125   FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
     *')
      IF (TDPIT) 126,127,128
126   PRINT 129, ABS(TDPIT)
129   FORMAT(' NUMBER OF PERMITS SOLD                     :',F6.2)
      GO TO 127
128   PRINT 130,TDPIT
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30  FORMAT(' NUMBER OF PERMITS BOUGHT                 :',F6.2)
27  PRINT 135,PQIT
35  FORMAT(' EXPECTED WASTEWATER FLOW RATE            :',F7.3,'MGD')
    PRINT 145,PBODIT
45  FORMAT(' EXPECTED BOD INFLUENT CONCENTRATION      :',F5.1,'  MG/L
   *')
    PRINT 154,SQIT
54  FORMAT(' THE MAXIMUM LIMITATION OF WASTEWATER FLOW RATE TO THE RIV
   *ER       :',F7.3,'MGD')
    PRINT 155,SBODIT
55  FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
   *HE RIVER :',F7.3,'MG/L')
    SHOW RESTRICTION ITEMS
.01 CALL YESNO(IA)
    IF (IA.EQ.2) GO TO 102
    GET INPUT DATA
06  IN=0
85  PRINT 185
85  FORMAT(1X,'ENTER TREATED WASTEWATER FLOW RATE IN THE COMPANY PLANT
   * (MGD)')
    READ*,Q1IT
04  IF (Q1IT.LE.PQIT) GO TO 201
    PRINT 195,Q1IT,PQIT
95  FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
   *T',F7.3,'MGD EXCEEDS THE PRODUCTION WASTEWATER FLOW RATE',F7.3,'MG
   *D')
    PRINT 196
96  FORMAT('           SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT
   *A REASONABLE VALUE')
    GO TO 385
:01 IF (Q1IT.LE.DQIT) GO TO 205
    PRINT 197,Q1IT,DQIT
.97 FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
   *T',F7.3,'MGD EXCEEDS THE DESIGN CAPACITY',F7.3,'MGD')
    PRINT 198
98  FORMAT('           SORRY THIS IS INFEASIBLE SOLUTION PLEASE INPUT A
   * REASONABLE VALUE OR ENTER -1 TO SELLECT DIFFERENT ALTERNATIVE')
    READ*,FLG
    IF (FLG.GE.0.) GO TO 325
.02 IFLAG=1
    Q1IT=0.
    BOD1IT=0.
    GO TO 475
.25 Q1IT=FLG
    GO TO 104
'02 IF (Q1IT.LE.SQIT) GO TO 205
    PRINT 199,Q1IT,SQIT
99  FORMAT(' WARNING: TREATED WASTEWATER FLOW RATE IN THE COMPANY PLAN
   *T',F7.3,'MGD EXCEEDS THE MAXIMUM LIMITATION OF WASTEWATER FLOW RAT
   *E',F7.3,'MGD')
    PRINT 198
    READ*,FLG
    IF (FLG.GE.0.) GO TO 325
    GO TO 102
05  Q4IT=PQIT-Q1IT
    IF (IN.EQ.1) GO TO 108
    PRINT 175
.75 FORMAT(1X,'ENTER DESIRED BOD EFFLUENT CONCENTRATION FROM THE COMPA
   *NY PLANT & RELEASE TO THE RIVER (MG/L)')
    READ*,BOD1IT
    MEASURE THE TDP'S EFFECT ON ALLOWED BOD EFFLUENT CONCENTRATION
    BOD4IT=PBODIT
.07 PRINT 215
:15 FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
    PRINT 225,Q1IT
:25 FORMAT(1X,'1.TREATED WASTEWATER FLOW RATE        :',F7.3,'MGD')
```

```
      PRINT 235,BOD1IT
  235 FORMAT(1X,'2.TREATED WASTEWATERE BOD EFFLUENT CONCENTRATION :',F5.
     *1,'MG/L')
      PRINT 245,Q4IT
  245 FORMAT(1X,'DISCHARGED WASTEWATER FLOW RATE TO THE RIVER:',F7.3,'M
     *GD')
      PRINT 255,BOD4IT
  255 FORMAT(1X,'DISCHARGED WASTEWATER BOD EFFLUENT CONCENTRATION:',F5.
     *1,'MG/L')
C     MAKE CORRECTION
      PRINT 265
  265 FORMAT(' IS THIS CORRECT')
  103 PRINT 275
  275 FORMAT(' ENTER 1 IF CORRECT')
      PRINT 285
  285 FORMAT(' ENTER 2 IF NEED TO MAKE A CHANGE')
      PRINT 295
  295 FORMAT(' ENTER 3 IF WANT TO INPUT DATA AGAIN')
      PRINT 305
  305 FORMAT(' ENTER 4 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (475,345,106,102),IC
      PRINT 315,IC
  315 FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 103
  345 PRINT 355
  355 FORMAT(' TYPE VARIABLE NUMBER TO BE CHANGED')
      PRINT 365
  365 FORMAT(' FOR EXAMPLE: TYPE 2 FOR TREATED BOD EFFLUENT CONCENTRATIO
     *N TO THE RIVER')
      READ*,IN
      GO TO (385,109),IN
      PRINT 375,IN
  375 FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 345
  109 PRINT 175
      READ*,BOD1IT
  108 PRINT 395
  395 FORMAT(' ENTER 1 IF CORRECT')
      PRINT 405
  405 FORMAT(' ENTER 2 IF NEED TO MAKE MORE CORRECTION')
      READ*,IB
      IF (IB.EQ.1) GO TO 107
      IF (IB.EQ.2) GO TO 345
      PRINT 415,IB
  415 FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 108
  475 RETURN
      END

C     THIS SUBROUTINE IS USED FOR SUBROUTINE "DISCHARGE WITH PERMIT"
      SUBROUTINE WPDUMP(IFLAG,PQIT,PBODIT,Q4IT,BOD4IT,TDPIT)
      IFLAG=0
C     SHOW BASIC INFORMATION
      PRINT 105
  105 FORMAT(1X,'DISCHARGE WITH PERMIT')
      IF (TDPIT.GT.0.) GO TO 114
  111 PRINT 112, ABS(TDPIT)
  112 FORMAT(' NUMBER OF PERMITS SOLD IS',F5.0,' SORRY THIS IS INFEASIBL
     * SOLUTION, PLEASE CONDIDER OTHER ALTERNATIVE')
      GO TO 102
  114 PRINT 115,TDPIT
  115 FORMAT(' NUMBER OF PERMITS BOUGHT IS',F5.0)
```

```
      CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
      Q4IT=PQIT
      BOD4IT=PBODIT
      PRINT 100
100   FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      PRINT 145,Q4IT
145   FORMAT(1X,'DISCHARGED WASTEWATER FLOW RATE      :',F7.3,'MGD')
      PRINT 155,BOD4IT
155   FORMAT(1X,'DISCHARGED BOD CONCENTRATION :',F5.1,'  MG/L')
      MAKE CORRECTION
      PRINT 165
165   FORMAT(' IS THIS CORRECT')
101   PRINT 175
175   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 185
185   FORMAT(' ENTER 2 IF WANT TO SELECT DIFFERENT ALTERNATIVE')
      READ*,IC
      GO TO (205,102),IC
      PRINT 195,IC
195   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 101
102   IFLAG=1
      Q4IT=0.
      BOD4IT=0.
205   RETURN
      END

      THIS SUBROUTINE IS USED FOR PRINTING ALTERNATIVE
      SUBROUTINE SALT(IS,Q1IT,BOD1IT,Q2IT,BOD2IT,Q3IT,BOD3IT,Q4IT,BOD4IT
     *)
      PRINT 201
201   FORMAT(1X,'THIS IS YOUR ALTERNATIVE')
      GO TO (101,102,103,104,106,107,108,109),IS
101   PRINT 105
105   FORMAT(' 1.TREAT EVERYTHING IN THE COMPANY PLANT & RELEASE.')
      PRINT 115,Q1IT
115   FORMAT(' TREATED WASTEWATER FLOW RATE        :',F7.3,' MGD')
      PRINT 125,BOD1IT
125   FORMAT(' EXPECTED BOD EFFLUENT CONCENTRATION :',F5.1,'   MG/L')
      GO TO 325
102   PRINT 135
135   FORMAT(' 2.PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO THE
     *MUNICIPAL PLANT.')
      PRINT 145,Q2IT
145   FORMAT(' PRETREATED WASTEWATER FLOW RATE     :',F7.3,' MGD')
      PRINT 155,BOD2IT
155   FORMAT(' EXPECTED BOD EFFLUENT CONCENTRATION :',F5.1,'   MG/L')
      GO TO 325
103   PRINT 165
165   FORMAT(' 3.SEND ALL WASTEWATER TO THE MUNICIPAL PLANT WITHOUT TREA
     *TMENT.')
      PRINT 175,Q3IT
175   FORMAT(1X,'SEND WASTEWATER FLOW RATE          :',F7.3,' MGD')
      PRINT 185,BOD3IT
185   FORMAT(1X,'SEND WASTEWATER BOD CONCENTRATION  :',F5.1,'   MG/L')
      GO TO 325
104   PRINT 195
195   FORMAT(' 4. TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OT
     *HER PART WITHOUT TREATMENT TO THE MUNICIPAL PLANT.')
      PRINT 205,Q1IT
205   FORMAT(1X,'TREATED WASTEWATER FLOW RATE           :',F7.3,'MGD')
      PRINT 215,BOD1IT
215   FORMAT(1X,'TREATED WASTEWATER BOD EFFLUENT CONCENTRATION :',F5.1,'
     *MG/L')
      PRINT 225,Q3IT
225   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER FLOW RATE :',F7.3,'MGD')
      PRINT 235,BOD3IT
235   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION
     * :',F5.1,'MG/L')
      GO TO 325
106   PRINT 245
245   FORMAT(' 5. PRETREAT PART IN THE COMPANY PLANT & SEND TO MUNICIPAL
     * PLANT, SEND THE OTHER PART WITHOUT TREATMENT TO THE MUNICIPAL PLA
     *NT')
      PRINT 255,Q2IT
255   FORMAT(1X,'PRETREATED WASTEWATER FLOW RATE        :',F7.3,'MGD')
      PRINT 265,BOD2IT
265   FORMAT(1X,'PRETREATED WASTEWATER BOD EFFLUENT CONCENTRATION  :',F5
     *.1,'MG/L')
      PRINT 275,Q3IT
275   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER FLOW RATE :',F7.3,'MGD')
      PRINT 285,BOD3IT
285   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION
     * :',F5.1,'MG/L')
      GO TO 325
107   PRINT 295
295   FORMAT(' 6. DISCHARGE WITHOUT PERMIT')
      PRINT 305,Q4IT
305   FORMAT(1X,'DISCHARGE WASTEWATER FLOW RATE        :',F7.3,'MGD')
      PRINT 315,BOD4IT
315   FORMAT(1X,'EXPECTED BOD EFFLUENT CONCENTRATION   :',F5.1,'  MG/L')
      GO TO 325
108   PRINT 335
335   FORMAT(' 7. TREAT PART IN THE COMPANY PLANT & RELEASE, SEND THE OT
     *HER PART WITHOUT TREATMENT TO RIVER.')
      PRINT 345,Q1IT
345   FORMAT(1X,'TREATED WASTEWATER FLOW RATE           :',F7.3,'MGD')
      PRINT 355,BOD1IT
355   FORMAT(1X,'TREATED WASTEWATER BOD EFFLUENT CONCENTRATION :',F5.1,'
     *MG/L')
      PRINT 365,Q4IT
365   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER FLOW RATE :',F7.3,'MGD')
      PRINT 375,BOD4IT
375   FORMAT(1X,'WITHOUT TREATMENT WASTEWATER BOD EFFLUENT CONCENTRATION
     * :',F5.1,'MG/L')
      GO TO 325
109   PRINT 385
385   FORMAT(' 8. DISCHARGE WITH PERMIT')
      PRINT 395,Q4IT
395   FORMAT(1X,'DISCHARGE WASTEWATER FLOW RATE        :',F7.3,'MGD')
      PRINT 405,BOD4IT
405   FORMAT(1X,'EXPECTED BOD EFFLUENT CONCENTRATION   :',F5.1,'  MG/L')
325   RETURN
      END

C     THIS SUBROUTINE IS USED FOR UPGRADING EXISTING PLANT
      SUBROUTINE UPGRAD(IFLAG,DQIT,DBODIT,FQIT,FBODIT)
      IFLAG=0
      IN=0
C     SHOW BASIC INFORMATION
      PRINT 105
105   FORMAT(' UPGRADE EXISTING PLANT')
      PRINT 115,DQIT
115   FORMAT(' CURRENT DESIGN CAPACITY                   :',F7.3,'MGD')
      PRINT 125,DBODIT
125   FORMAT(' CURRENT DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L
     *')
      PRINT 135,SQIT
135   FORMAT(' THE MAXIMUM LIMITATION OF WASTEWATER FLOW RATE TO THE RIV
     *ER      :',F7.3,'MGD')
```

```
      PRINT 136,SBODIT
.36   FORMAT(' THE MAXIMUM LIMITATION OF BOD EFFLUENT CONCENTRATION TO T
     *HE RIVER :',F5.1,'  MG/L')
      CALL YESNO(IA)
      IF (IA.EQ.2) GO TO 102
      GET INPUT DATA
 04   PRINT 145
 45   FORMAT(1X,'ENTER FUTURE DESIGN CAPACITY (MGD)')
      READ*,FQIT
      IF (IN.EQ.1)  GO TO 109
:07   PRINT 155
:55   FORMAT(1X,'ENTER FUTURE DESIGN BOD EFFLUENT CONCENTRATION (MG/L)')
      READ*,FBODIT
      IF (IN.EQ.2)  GO TO 109
:01   PRINT 100
.00   FORMAT(' THIS IS YOUR UPGRADE PLAN')
      PRINT 165,FQIT
.65   FORMAT(' 1.FUTURE DESIGN CAPACITY                :',F7.3,'MGD')
      PRINT 175,FBODIT
.75   FORMAT(' 2.FUTURE DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/
     *L')
      MAKE CORRECTION
.08   PRINT 185
.85   FORMAT(' IS THIS CORRECT')
.03   PRINT 195
.95   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 205
:05   FORMAT(' ENTER 2 IF NEED TO MAKE A CHANGE')
      PRINT 215
:15   FORMAT(' ENTER 3 IF WANT TO GIVE UP UPGRADE PLAN')
      READ*,IC
      GO TO (265,106,102),IC
      PRINT 225,IC
:25   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 103
.06   PRINT 235
:35   FORMAT(1X,'TYPE VARIABLE NUMBLE TO BE CHANGED')
      PRINT 245
245   FORMAT(1X,'FOR EXAMPLE: TYPE 1 FOR FUTURE DESIGN CAPACITY')
      READ*,IN
      IF (IN.EQ.1) GO TO 104
      IF (IN.EQ.2) GO TO 107
      PRINT 255,IN
:55   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 106
.09   PRINT 335
:35   FORMAT(' ENTER 1 IF CORRECT')
      PRINT 345
345   FORMAT(' ENTER 2 IF NEED TO MAKE MORE CORRECTION')
      READ*,IB
      IF (IB.EQ.1) GO TO 101
      IF (IB.EQ.2) GO TO 106
      PRINT 355,IB
:55   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 109
:65   IF (FQIT.GE.DQIT) GO TO 285
      PRINT 275,FQIT,DQIT
:75   FORMAT(' WARNING: FUTURE DESIGN CAPACITY',F7.3,'MGD LESS THAN THE 
     *CURRENT DESIGN CAPACITY',F7.3,'MGD')
      PRINT 276
:76   FORMAT('             PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO Q
     *UIT UPGRADE PLAN')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 295
102   IFLAG=1
      FQIT=0.
      FBODIT=0.
      GO TO 325
295   FQIT=FLG
      GO TO 101
285   IF (FBODIT.LE.DBODIT) GO TO 325
      PRINT 305,FBODIT,DBODIT
305   FORMAT(' WARNING: FUTURE DESIGN BOD EFFLUENT CONCENTRATION',F5.1,'
     *MG/L LARGER THAN CURRENT DESIGN BOD EFFLUENT CONCENTRATION',F5.1,'
     *MG/L')
      PRINT 306
306   FORMAT('             PLEASE INPUT A REASONABLE VALUE OR ENTER -1 TO Q
     *UIT UPGRADE PLAN')
      READ*,FLG
      IF (FLG.GE.0.) GO TO 315
      GO TO 102
315   FBODIT=FLG
      GO TO 101
325   RETURN
      END

C     THIS SUBROUTINE IS USED FOR PRINTING UPGRADE PLAN
      SUBROUTINE SHUPGR(FQIT,FBODIT)
      PRINT 105
105   FORMAT(' THIS IS YOUR UPGRADE PLAN')
      PRINT 115,FQIT
115   FORMAT(' FUTURE DESIGN CAPACITY                :',F7.3,'MGD')
      PRINT 125,FBODIT
125   FORMAT(' FUTURE DESIGN BOD EFFLUENT CONCENTRATION :',F5.1,'  MG/L'
     *)
      RETURN
      END

C     THIS SUBROUTINE IS USED FOR CORRECTING INPUT
      SUBROUTINE CORT(IB)
155   PRINT 105
105   FORMAT(1X,'ENTER 1 IF CORRECT')
      PRINT 115
115   FORMAT(1X,'ENTER 2 IF NEED TO MAKE A CHANGE')
      READ*,IB
      IF (IB.EQ.1) GO TO 135
      IF (IB.EQ.2) GO TO 135
      PRINT 145,IB
145   FORMAT(' WARNING:',I2,'  EXCEEDS THE BOUNDARY VALUE PLEASE INPUT A
     * REASONABLE VALUE')
      GO TO 155
135   RETURN
      END

C     THIS SUBROUTINE IS USED FOR OPTION " YES OR NO "
      SUBROUTINE YESNO(IX)
      CHARACTER*3 AD
      PRINT 105
105   FORMAT(1X,'ENTER "YES" OR "NO" TO CONFIRM YOUR CHOICE')
101   READ(5,31) AD
 31   FORMAT(A3)
      IF (AD.EQ.'YES') GO TO 102
      IF (AD.EQ.'NO ') GO TO 103
      PRINT 115
115   FORMAT(1X,'PLEASE TYPE "YES" OR "NO"')
      GO TO 101
102   IX=1
      GO TO 104
```

# APPENDIX G

# INTERACTIVE FORTRAN PROGRAM FOR PROCTOR INPUT

```
* TSO FOREGROUND HARDCOPY ****
AME=U11502C.QUAI.CNTL

   THIS IS AN INTERACTIVE INPUT PROGRAM FOR INSTRUCTORS. THE
   INSTRUCTOR HAS ONLY TO CHOOSE A SEASON INDEX ( 1 FOR SPRING 2 FOR
   SUMMER 3 FOR FALL AND 4 FOR WINTER ) AND THE PROGRAM WILL CHOOSE
   THE SUITABLE TEMPERATURE, BOD CONCENTRATION AND FLOW RATE
   AUTOMATICALLY. THIS PROGRAM WILL READ POINT SOURCE FLOW RATE AND
   BOD CONCENTRATION FROM STUDENT DECISION FILES. THE PROGRAM WILL BE
   CREATED AS A LOAD MODULE AND EXECUTED BY  TSO COMMAND LANGUAGE (
   SQUAL.CLIST ). THE PROGRAM WILL GENERATE A WATER QUALITY FILE.
   THIS DATA FILE WILL BE FED INTO QUAL-II PACKAGE TO PRODUCE WATER
   QUALITY OF THE WHOLE REACH.


   INITIAL CONDITIONS     :
        TMPI(I,J) -> TEMPERATURE (*C) REACH I, SEASON J.
        BODIN(I)  -> BOD CONCENTRATION (MG/L) REACH I.
        DOIN(I)   -> DO CONCENTRATION (MG/L) REACH I.
   INCREMENTAL CONDITIONS :
        TMP(J)    -> TEMPERATURE (*C) SEASON J.
        FLI(I,J)  -> FLOW RATE (CMS) REACH I, SEASON J.
        BODIC(I)  -> BOD CONCENTRATION (MG/L) REACH I.
        DOIC(I)   -> DO CONCENTRATION (MG/L) REACH I.
   HEADWATER CONDITIONS   :
        TMPH(I,J) -> TEMPERATURE (*C) HEADWATER I, SEASON J.
        FLH(I,J)  -> FLOW RATE (CMS) HEADWATER I, SEASON J.
        BODH(I)   -> BOD CONCENTRATION (MG/L) HEADWATER I.
        DOH(I)    -> DO CONCENTRATION (MG/L) HEADWATER I.
   POINT SOURCE CONDITIONS:
        TMPP(I,J) -> TEMPERATURE (*C) POINT SOURCE I, SEASON J.
   DTP(J) -> DRY BULB TEMPERATURE (*C) SEASON J.
   WTP(J) -> WET BULB TEMPERATURE (*C) SEASON J.
   CH     -> CONVERSION FACTOR 1 MGD IS EQUAL TO 1.55 CFS.
   CVH    -> CONVERSION FACTOR 1 CFS IS EQUAL TO 0.0283 CMS.


   DIMENSION IS(7),Q1(7),BOD1(7),Q2(7),BOD2(7),Q3(7),BOD3(7),Q4(7),
  *BOD4(7),UQ(7),UBOD(7),PFL(7),PBOD(7),FQ(7),FBOD(7),TMPI(5,4),
  *BODIN(5),TMP(4),FLI(5,4),BODIC(5),TMPH(3,4),FLH(3,4),BODH(3),
  *TMPP(7,4),DTP(4),WTP(4),SBOD(7),CBOD(7),DOIN(5),DOIC(5),DOH(3),
  *PDO(7)

   CHARACTER*1 AR,AP
   DATA TMPI/5*22.,5*26.,5*9.,5*6./
   DATA BODIN/20.,43.,46.,37.,27./
   DATA DOIN/20.,43.,46.,47.,27./
   DATA TMP/20.,24.,7.,4./
   DATA FLI/0.16,0.08,0.03,0.02,0.02,0.09,0.05,0.019,0.12,0.12,
  *0.13,0.07,0.024,0.016,0.016,0.11,0.06,0.021,0.014,0.014/
   DATA BODIC/5*60./
   DATA TMPH/3*22.,3*26.,3*9.,3*6./
   DATA FLH/1.3,0.11,0.23,0.78,0.07,0.14,0.14,0.09,0.18,0.9,0.08,0.16
  */
   DATA BODH/3*20./
   DATA TMPP/23.,22.,23.,22.,23.,22.,22.,27.,26.,27.,26.,27.,26.,26.,
  *10.,9.,10.,9.,10.,9.,9.,7.,6.,7.,6.,7.,6.,6./
   DATA WTP/22.,26.,9.,6./
   DATA DTP/26.,30.,13.,10./
   CH=1.55

   CONVERT FROM METRIC UNIT YO ENGLISH UNIT
      DO 15 I=1,4
      TMP(I)=TMP(I)*1.8+32
      DTP(I)=DTP(I)*1.8+32
      WTP(I)=WTP(I)*1.8+32
      DO 16 J=1,3
      TMPH(J,I)=TMPH(J,I)*1.8+32
      FLH(J,I)=FLH(J,I)*0.03
   16 CONTINUE
      DO 17 J=1,5
      TMPI(J,I)=TMPI(J,I)*1.8+32
      FLI(J,I)=FLI(J,I)*35.3
   17 CONTINUE
      DO 18 J=1,7
      TMPP(J,I)=TMPP(J,I)*1.8+32
   18 CONTINUE
   15 CONTINUE

C     GET SEASON INDEX
      PRINT 49
   49 FORMAT(' ENTER SEASON INDEX --> 1 FOR SPRING 2 FOR SUMMER 3 FOR FA
     *LL AND 4 FOR WINTER')
      READ*,J
C     READ STUDENT DECISION FILES
      DO 23 I=1,7
      READ(14+I,45) AR,IT,IJ,IS(I),AP,PR,PC,PRBOD,Q1(I),BOD1(I),Q2(I),
     * BOD2(I),Q3(I),BOD3(I),Q4(I),BOD4(I),UQ(I),UBOD(I),FQ(I),FBOD(I),
     *SBOD(I),CBOD(I)
   45 FORMAT(A1,3I1,A1,F6.3,6(F6.3,F5.1)/F6.3,3F5.1)
   23 CONTINUE
      WRITE (11,50)
   50 FORMAT('TITLE01',14X,'WATER QUALITY SIMULATION GAME')
      WRITE(11,51) AR,AP
   51 FORMAT('TITLE02',14X,'REGION',1X,A1,3X,'PERIOD',1X,A1)
      WRITE(11,52)
   52 FORMAT('TITLE03',3X,'NO',9X,'CONSERVATIVE MINERAL   I')
      WRITE(11,53)
   53 FORMAT('TITLE04',3X,'NO',9X,'CONSERVATIVE MINERAL  II')
      WRITE(11,54)
   54 FORMAT('TITLE05',3X,'NO',9X,'CONSERVATIVE MINERAL III')
      WRITE(11,55)
   55 FORMAT('TITLE06',2X,'YES',9X,'TEMPERATURE')
      WRITE(11,56)
   56 FORMAT('TITLE07',2X,'YES',9X,'BIOCHEMICAL OXYGEN DEMAND IN MG/L')
      WRITE(11,57)
   57 FORMAT('TITLE08',3X,'NO',9X,'ALGAE AS CHL A IN UG/L')
      WRITE(11,58)
   58 FORMAT('TITLE09',3X,'NO',9X,'PHOSPHORUS AS P IN MG/L')
      WRITE(11,59)
   59 FORMAT('TITLE10',3X,'NO',9X,'AMMONIA AS N IN MG/L')
      WRITE(11,60)
   60 FORMAT('TITLE11',3X,'NO',9X,'NITRITE AS N IN MG/L')
      WRITE(11,61)
   61 FORMAT('TITLE12',3X,'NO',9X,'NITRATE AS N IN MG/L')
      WRITE(11,62)
   62 FORMAT('TITLE13',2X,'YES',9X,'DISOLVED OXYGEN IN MG/L')
      WRITE(11,63)
   63 FORMAT('TITLE14',3X,'NO',9X,'COLIFORMS IN NO/100 ML')
      WRITE(11,64)
   64 FORMAT('TITLE15',3X,'NO',9X,'ARBITRARY NON-CONSERVATIVE')
      WRITE(11,65)
   65 FORMAT('ENDTITLE')
      WRITE(11,66)
   66 FORMAT('LIST DATA INPUT')
      WRITE(11,67)
   67 FORMAT('WRITE OPTIONAL SUMMARY')
      WRITE(11,68)
```

```
 68   FORMAT('NO FLOW AUGMENTATION')
      WRITE(11,69)
 69   FORMAT('STEADY STATE')
      WRITE(11,70)
 70   FORMAT('NO TRAPEZOIDAL X-SECTION')
      WRITE(11,71)
 71   FORMAT('INPUT METRIC (YES=1)',4X,'=',9X,'0',10X,'OUTPUT METRIC (YE
     *S=1)',3X,'=',9X,'0')
      WRITE(11,72)
 72   FORMAT('NUMBER OF REACHES',7X,'=',9X,'5',10X,'NUMBER OF JUNCTIONS'
     *,5X,'=',9X,'2')
      WRITE(11,73)
 73   FORMAT('NUM OF HEADWATERS',7X,'=',9X,'3',10X,'NUMBER OF POINT LOAD
     *S',3X,'=',9X,'7')
      WRITE(11,74)
 74   FORMAT('TIME STEP (HOURS)',7X,'=',20X,'LNTH  COMP  ELEMENT (MI)=',
     *9X,'1')
      WRITE(11,75)
 75   FORMAT('MAXIMUM ROUTE TIME (HRS)=',8X,'30',10X,'TIME INC. FOR RPT2
     * (HRS)=')
      WRITE(11,120)
120   FORMAT('LATITUDE OF BASIN (DEG) =',6X,'42.5',10X,'LONGITUDE OF BAS
     *IN (DEG)=',6X,'83.3')
      WRITE(11,121)
121   FORMAT('STANDARD MERIDIAN (DEG) =',6X,'75.0',10X,'DAY OF YEAR STAR
     *T TIME  =',5X,'180.0')
      WRITE(11,122)
122   FORMAT('EVAP. COEF. (AE)',8X,'=',2X,'.0000062',10X,'EVAP. COEF. (B
     *E)',8X,'=',2X,'.0000055')
      WRITE(11,123)
123   FORMAT('ELEV. OF BASIN (METERS)',1X,'=',6X,'250.',10X,'DUST ATTENU
     *ATION COEF.',2X,'=',6X,'0.13')
      WRITE(11,76)
 76   FORMAT('ENDATA1')
      WRITE(11,77)
 77   FORMAT('ENDATA1A')
      WRITE(11,78)
 78   FORMAT('STREAM REACH',5X,'1.0RCH=',19X,'FROM',9X,'46.0',4X,'TO',10
     *X,'30.')
      WRITE(11,79)
 79   FORMAT('STREAM REACH',5X,'2.0RCH=',19X,'FROM',9X,'14.0',4X,'TO',10
     *X,'10.')
      WRITE(11,80)
 80   FORMAT('STREAM REACH',5X,'3.0RCH=',19X,'FROM',10X,'3.0',4X,'TO',11
     *X,'0.')
      WRITE(11,81)
 81   FORMAT('STREAM REACH',5X,'4.0RCH=',19X,'FROM',9X,'10.0',4X,'TO',11
     *X,'0.')
      WRITE(11,82)
 82   FORMAT('STREAM REACH',5X,'5.0RCH=',19X,'FROM',9X,'30.0',4X,'TO',10
     *X,'18.')
      WRITE(11,83)
 83   FORMAT('ENDATA2')
      WRITE(11,84)
 84   FORMAT('ENDATA3')
      WRITE(11,85)
 85   FORMAT('FLAG FIELD RCH=',2X,'1.0',6X,'16.0',10X,'1.2.2.6.2.2.2.6.2
     *.2.2.2.2.6.2.3.')
      WRITE(11,86)
 86   FORMAT('FLAG FIELD RCH=',2X,'2.0',7X,'4.0',10X,'1.6.2.3.')
      WRITE(11,87)
 87   FORMAT('FLAG FIELD RCH=',2X,'3.0',7X,'3.0',10X,'1.6.2.')
      WRITE(11,88)
 88   FORMAT('FLAG FIELD RCH=',2X,'4.0',6X,'10.0',10X,'4.2.2.2.2.2.6.2.2
     *.2.')
      WRITE(11,89)
 89   FORMAT('FLAG FIELD RCH=',2X,'5.0',6X,'12.0',10X,'4.2.2.2.2.6.2.2.2
     *.2.2.5.')
      WRITE(11,90)
 90   FORMAT('ENDATA4')
      WRITE(11,91)
 91   FORMAT('HYDRAULICS RCH=',2X,'1.0',15X,'.2500',5X,'0.300',5X,'0.44 
     *',6X,'0.55',5X,'0.040')
      WRITE(11,92)
 92   FORMAT('HYDRAULICS RCH=',2X,'2.0',15X,'.3800',5X,'0.370',5X,'0.510
     *',6X,'0.61',5X,'0.040')
      WRITE(11,93)
 93   FORMAT('HYDRAULICS RCH=',2X,'3.0',15X,'.2800',5X,'0.350',5X,'0.480
     *',6X,'0.58',5X,'0.040')
      WRITE(11,94)
 94   FORMAT('HYDRAULICS RCH=',2X,'4.0',15X,'.3800',5X,'0.370',5X,'0.510
     *',6X,'0.61',5X,'0.040')
      WRITE(11,95)
 95   FORMAT('HYDRAULICS RCH=',2X,'5.0',15X,'.2200',5X,'0.330',5X,'0.430
     *',6X,'0.38',5X,'0.040')
      WRITE(11,96)
 96   FORMAT('ENDATA5')
      WRITE(11,97)
 97   FORMAT('REACT COEF RCH=',2X,'1.0',6X,'0.60',7X,'0.0',7X,'2.0')
      WRITE(11,98)
 98   FORMAT('REACT COEF RCH=',2X,'2.0';6X,'0.60',7X,'0.0',7X,'2.0')
      WRITE(11,99)
 99   FORMAT('REACT COEF RCH=',2X,'3.0',6X,'0.60',7X,'0.0',7X,'2.0')
      WRITE(11,100)
100   FORMAT('REACT COEF RCH=',2X,'4.0',6X,'0.60',7X,'0.0',7X,'2.0')
      WRITE(11,101)
101   FORMAT('REACT COEF RCH=',2X,'5.0',6X,'0.60',7X,'0.0',7X,'2.0')
      WRITE(11,102)
102   FORMAT('ENDATA6')
      WRITE(11,103)
103   FORMAT('ENDATA6A')
      WRITE(11,104)
104   FORMAT('ENDATA6B')
C     INITIAL CONDITIONS
      DO 21 I=1,5
      WRITE(11,105) I,TMPI(I,J),DOIN(I),BODIN(I)
105   FORMAT('INITIAL CONDITIONS',3X,'RCH=',4X,I1,F10.3,F5.1,F5.1)
 21   CONTINUE
      WRITE(11,106)
106   FORMAT('ENDATA7')
      WRITE(11,107)
107   FORMAT('ENDATA7A')
C     INCREMENTAL INFLOW
      DO 29 I=1,5
      WRITE(11,150) I,FLI(I,J),TMP(J),DOIC(I),BODIC(I)
150   FORMAT('INCREMENTAL INFLOW',3X,'RCH=',4X,I1,F5.3,F5.1,F5.1,F5.1)
 29   CONTINUE
      WRITE(11,108)
108   FORMAT('ENDATA8')
      WRITE(11,109)
109   FORMAT('ENDATA8A')
      WRITE(11,110)
110   FORMAT('STREAM JUNCTION',7X,'1.0',5X,'JNC=',23X,'20.',7X,'24.',7X,
     *'23.')
      WRITE(11,111)
111   FORMAT('STREAM JUNCTION',7X,'2.0',5X,'JNC=',23X,'16.',7X,'34.',7X,
     *'33.')
      WRITE(11,112)
112   FORMAT('ENDATA9')
      DO 22 I=1,3
      WRITE(11,113) I,FLH(I,J),TMPH(I,J),DOH(I),BODH(I)
113   FORMAT('HEADWATER',10X,I1,'HDW=',16X,F10.3,F5.1,F5.1,F5.1)
```

```
 22  CONTINUE
     WRITE(11,114)
114  FORMAT('ENDATA10')
     WRITE(11,115)
115  FORMAT('ENDATA10A')
     POINT SOURCE LOADING
     DO 24 I=1,5
     GO TO (131,132,132,131,132,133,134,133),IS(I)
131  PFL(I)=Q1(I)
     PBOD(I)=BOD1(I)
     GO TO 24
132  PFL(I)=0.
     PBOD(I)=0.
     GO TO 24
133  PFL(I)=Q4(I)
     PBOD(I)=BOD4(I)
     GO TO 24
134  PFL(I)=Q1(I)+Q4(I)
     PBOD(I)=(Q1(I)*BOD1(I)+Q4(I)*BOD4(I))/(Q1(I)+Q4(I))
 24  CONTINUE

     CALCULATE FLOW RATES AND BOD CONCENTRATION FOR MUNICIPAL TREATMENT
     PLANTS
     DO 25 I=1,3
     PFL(6)=Q2(I)+Q3(I)+PFL(6)
 25  CONTINUE
     DO 26 I=4,5
     PFL(7)=Q2(I)+Q3(I)+PFL(7)
 26  CONTINUE
     DO 27 I=6,7
     PFL(I)=PFL(I)+UQ(I)
     PBOD(I)=CBOD(I)
 27  CONTINUE
     DO 28 I=1,7
     PFL(I)=PFL(I)*CH
 28  CONTINUE

     CONVERT TEAM SEQUENCE TO POINT LOAD SEQUENCE
     P=PFL(3)
     PFL(3)=PFL(6)
     PFL(6)=PFL(7)
     PFL(7)=P
     P=PBOD(3)
     PBOD(3)=PBOD(6)
     PBOD(6)=PBOD(7)
     PBOD(7)=P
     T=TMPP(3,J)
     TMPP(3,J)=TMPP(6,J)
     TMPP(6,J)=TMPP(7,J)
     TMPP(7,J)=T

     CONVERT 1CFS TO 1 CMS
     DO 201 I=1,7
     PFL(I)=PFL(I)*0.0283
201  CONTINUE
     DO 30 I=1,7
     WRITE(11,116) I,PFL(I),TMPP(I,J),PDO(I),PBOD(I)
116  FORMAT('POINT LOAD',4X,I1,'PTL=',18X,'0.0',F10.3,F5.1,F5.1,F5.1)
 30  CONTINUE
     WRITE(11,117)
117  FORMAT('ENDATA11')
     WRITE(11,118)
118  FORMAT('ENDATA11A')
     WRITE(11,119) DTP(J),WTP(J)
119  FORMAT('LOCAL CLIMATOLOGY',28X,'0.2',3X,F5.1,3X,F5.1,2X,'1000.0',5
    *X,'3.0')
```

# APPENDIX H

# ALPHABETICAL LIST OF VARIABLES AND THEIR DEFINITIONS IN WATER QUALITY SIMULATION GAME

| | |
|---|---|
| AR | Region index |
| ALM (I) | Labor and Material cost, Firm I |
| ABOD (I) | BOD Effluent concentration to the treatment plant, Team I |
| BOD1 (I) | BOD effluent concentration treated from the industrial treatment plant to the river, Firm I |
| BOD2 (I) | BOD effluent concentration treated from the industrial treatment plant to the municipal treatment plant, Firm I |
| BOD3 (I) | BOD concentration sent without treatment from the industrial firm to the municipal treatment plant, Firm I |
| BOD4 (I) | BOD concentration discharged without treatment from the industrial firm to the river, Firm I |
| BQ (I) | Wastewater flow rate to the treatment plant, Team I |
| C1 (I) | Quarterly investment and fixed operation costs, Firm I |
| CBOD (I) | Municipal plant wastewater BOD effluent concentration, Team I |
| DBOD (I) | Current design BOD effluent concentration, Team I |
| DQ (I) | Current design capacity, Team I |
| FBOD (I) | Future design BOD effluent concentration, Team I |
| FQ (I) | Future design capacity, Team I |
| I | Dummy team number index |
| IJ | Industrial firm or municipal treatment plant index |
| IP | Period number index |
| IS | Alternative index |
| NRG | Seed of the uniformly distributed pseudo-random numbers |
| OE (I) | Other expenses of the industrial firm, Firm I |
| PBOD (I) | Wastewater BOD concentration produced, Firm I |
| PC (I) | Discharge without permit -> penalty costs, Firm I |
| POE (I) | Price of other expenses per unit products, Firm I |
| PLA (I) | Price of labor and material costs per unit product, Firm I |

| | |
|---|---|
| PQ (I) | Wastewater flow rate produced, Firm I |
| Q1 (I) | Wastewater flow rate pretreated from the industrial treatment plant to the river, Firm I |
| Q2 (I) | Wastewater flow rate pretreated from the industrial treatment plant to the municipal treatment plant, Firm I |
| Q3 (I) | Wastewater flow rate sent without treatment from the industrial firm to the municipal treatment plant, Firm I |
| Q4 (I) | Wastewater flow rate discharged from the industrial firm to the river, Firm I |
| RANF | Uniform distributed pseudo-random number function |
| RAT (I) | Design BOD removal rate, Team I |
| SR (I) | Total sales revenue, Firm I |
| TC (I) | Total expenses, Firm I |
| TCI (I) | Tax on current income, Firm I |
| TNE (I) | Total net earning, Firm I |
| TPP (I) | Total price of permits |
| TTI (I) | Total taxable income, Firm I |
| UBOD (I) | Residential wastewater BOD concentration, Team I |
| UC (I) | Industrial wastewater user charges, Team I |
| UQ (I) | Residential wastewater flow rate, Team I |
| VC (I) | Operation costs, Team I |
| WC (I) | Total water quality related costs, Team I. |

APPENDIX I

TRANSACTION RECORDS OF PERMITS

Period 5

The market model is based on multiple-price auction, negotiation between bidders and rationale bidder behavior.

| Team | # of Permits Bought | Buying Price | # of Permits Sold | Selling Price |
|---|---|---|---|---|
| 1 | <-1577 | <-18.19 | <-224 | 18.19-> |
| 2 | <-14.2 | <-38.67 | <-76 | 38.67-> |
| 3 | <-123 | <-17.8 | <-10 | 17.8-> |
| 4 | <-26.66 | <-43.88 | <-6.66 | 43.88-> |
| 5 | <-333.6 | <-95.8 | <-333.6 | 95.8-> |
| 6 | --- | --- | <-625.5 | 5.0-> |
| 7 | --- | --- | --- | --- |

Based on the above information, the administration decides the following trading transaction.

Team 1 will buy 10.0 permits at $18 from Team 3

Team 1 will buy 250.7 permits at $18 from Team 6

Team 2 will buy 14.2 permits at $19 from Team 6

Team 3 will sell 10.0 permits at $18 to Team 1

Team 4 will buy 26.7 permits at $39 from Team 6

Team 5 will buy 333.6 permits at $44 from Team 6

Team 6 will sell 250.7 permits at $18 to Team 1

Team 6 will sell 14.2 permits at $19 to Team 2

Team 6 will sell 26.7 permits at $39 to Team 4

Team 6 will sell 333.6 permits at $44 to Team 5

Period 6

| Team | # of Permits Bought | Buying Price | # of Permits Sold | Selling Price |
|---|---|---|---|---|
| 1 | <-1678 | <-17.73 | <-213.7 | 17.73-> |
| 2 | <-14.2 | <-38.67 | <-76 | 38.67-> |
| 3 | <-157 | <-17.8 | <-10 | 17.8-> |
| 4 | <-33 | <-43.88 | <-6.66 | 43.88-> |
| 5 | <-333.6 | <-85.8 | <-333.6 | 85.8-> |
| 6 | --- | --- | <-592. | 5.0-> |
| 7 | --- | --- | --- | --- |

Based on the above information, the administration decides the following trading transactions.

Team 1 will buy 64.2 permits at $17.78 from Team 6

Team 2 will buy 14.2 permits at $18 from Team 6

Team 3 will buy 147.0 permits at $17.78 from Team 6

Team 4 will buy 33.0 permits at $39 from Team 6

Team 5 will buy 333.6 permits at $44 from Team 6

Team 6 will sell 64.2 permits at $17.78 to Team 1

Team 6 will sell 14.2 permits at $18 to Team 2

Team 6 will sell 147.0 permits at $17.78 to Team 3

Team 6 will sell 33.0 permits at $39 to Team 4

Team 6 will sell 333.6 permits at $44 to Team 5

Period 7

| Team | # of Permits Bought | Buying Price | # of Permits Sold | Selling Price |
|---|---|---|---|---|
| 1 | <-1839 | <-17.73 | <-197.7 | 17.73-> |
| 2 | <-14.2 | <-38.67 | <-76 | 38.67-> |
| 3 | <-180 | <-17.8 | <-10 | 17.8-> |
| 4 | <-34.2 | <-43.88 | <-6.66 | 43.88-> |
| 5 | <-333.6 | <-85.8 | <-333.6 | 85.8-> |
| 6 | --- | --- | <-572. | 5.0-> |
| 7 | <-8.34 | <-470.2 | --- | --- |

Based on the above information, the administration decides the following trading transactions.

Team 2 will buy 14.2 permits at $18 from Team 6

Team 3 will buy 180.0 permits at $17.78 from Team 6

Team 4 will buy 34.2 permits at $39 from Team 6

Team 5 will buy 333.6 permits at $44 from Team 6

Team 7 will buy 8.34 permits at $46 from Team 6

Team 6 will sell 14.2 permits at $18 to Team 2

Team 6 will sell 180.0 permits at $17.78 to Team 3

Team 6 will sell 34.2 permits at $39 to Team 4

Team 6 will sell 333.6 permits at $44 to Team 5

Team 6 will sell 8.34 permits at $46 to Team 7

Period 8

| Team | # of Permits Bought | Buying Price | # of Permits Sold | Selling Price |
|---|---|---|---|---|
| 1 | <-1910 | <-17.13 | <-181.4 | 17.73-> |
| 2 | <-14.2 | <-38.67 | <-76 | 38.67-> |
| 3 | <-200.2 | <-17.8 | <-10 | 17.8-> |
| 4 | <-40.7 | <-43.88 | <-6.66 | 43.88-> |
| 5 | <-333.6 | <-85.8 | <-333.6 | 85.8-> |
| 6 | --- | --- | <-558. | 5.0-> |
| 7 | <-8.34 | <-470.2 | --- | --- |

Based on the above information, the administration decides the following trading transactions.

Team 2 will buy 14.2 permits at $18 from Team 6

Team 3 will buy 161.16 permits at $17.78 from Team 6

Team 3 will buy 39.04 permits at $17.78 from Team 1

Team 4 will buy 40.7 permits at $39 from Team 6

Team 5 will buy 333.6 permits at $44 from Team 6

Team 7 will buy 8.34 permits at $86 from Team 6

Team 6 will sell 14.2 permits at $18 to Team 2

Team 6 will sell 161.16 permits at $17.78 to Team 3

Team 1 will sell 39.04 permits at $17.78 to Team 3

Team 6 will sell 40.7 permits at $39 to Team 4

Team 6 will sell 333.6 permits at $44 to Team 5

Team 6 will sell 8.34 permits at $86 to Team 7

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