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A WATER QUALITY MANAGEMENT SIMULATION GAME

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ABSTRACT

This paper describes a simulation game that is designed to introduce students to decision making for waste treatment. The game may also be used to research regulatory issues in water quality management. For example, the game may be used to assess the effect of having a marketable discharge permit system. It may also be used to determine the effect of a tax system for water quality management decisions.

INTRODUCTION

Simulation gaming has been a popular technique to introduce students to the decision-making process in various areas of a business. The games have been reasonably successful in training students and have also been used with mixed results [3] in researching one or the other characteristics of the decision making process. One function, however, which does not seem to have received much attention is the water quality management function. Timely and efficient disposal of the waste generated by a 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 authority. Typically these permits allow companies to release a specified maximum amount of waste bearing certain chemical characteristics. The companies may also have the choice of releasing the waste into the city sewer system and paying the municipality user charge. Obviously the decisions on proper disposition of the waste can involve evaluation of several alternatives based on economic considerations. The decision to install a waste treatment plant also has to consider production forecasts. Thus this decision problem is similar to other unstructured problems where tradeoffs have to be considered in evaluating alternatives and where simulation gaming has proven to be a good teaching tool. This paper de- scribes WQM, a game for introducing students to such business decisions. The game is suitable for training current and future water quality managers.

DESCRIPTION OF WQM

Basic Game Structure

The flowchart shown in Figure 1 illustrates the basic structure of the game. The game participants are given a detailed description of the firm or the municipality they are supposed to represent. This narrative for firms includes data on planned production, cost of production, relationships between output and emission of various pollutants. For municipal managers, the information contains data on expected city waste loads from firms in the area for treatment. The participants are also informed about the water quality standards that the firm or the municipal plant must meet. Some firm participants receive information on whether their firm could get away with releasing effluent without treatment. This includes the estimated penalties and probability of getting fined. The narrative also includes their corporate culture and concern for corporate citizenship.

Besides the production data, the manager is also given a complete description of waste disposal alternatives. These alternatives are described later in detail. Relevant cost/capacity effectiveness figures are provided for each alternative. Costs are provided for various levels of treatment using different plant capacities.

The manager/participant considers all of the relevant information, evaluates the alternatives and makes a decision. The decision is in terms of an alternative and appropriate size-cost data. The decision may also include investment in a new treatment plant. If selected, the new plant would be available two periods after the decision is made.

When each of the participants representing a firm has made a decision, they then enter the data into the computer simulation game. The game program then prepares two reports. Based on the decisions of all the firms, the production-pollution relationships determine the amount of pollution generated. The abatement options selected by teams are used to calculate their costs and the quality of effluents. The game also prepares a water quality report for the entire part of the hypothetical river.

Each participant is provided a report which summarizes the effects of his/her decisions. This includes the actual costs incurred, fines levied for not meeting standards, achievement of pollution clean-up objectives and so on. The participant also receives information that a firm/city would be able to get in general, such as overall quality of water in the stream at different locations.

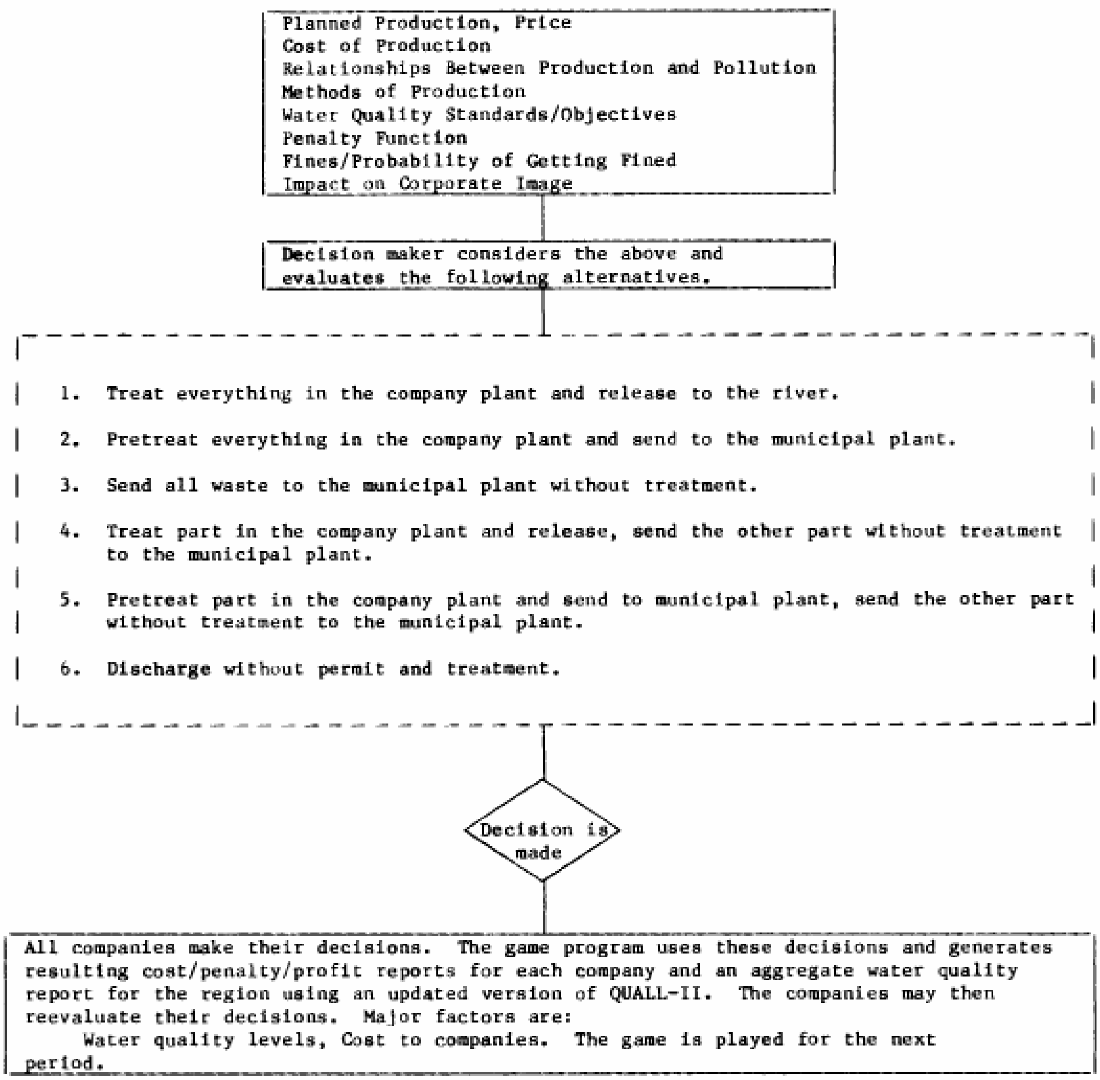
The game is then played again for the next period, i.e., next quarter. Details of these steps follow.

Participant Characteristics

In its current version, the game simulates a region consisting of five industrial firms and two municipalities. Each player represents either a firm or a municipality. Using teams of two or more members for each industry or municipality allows one to include more participants in each region. A schematic of the region is given in Figure 2. As shown in Figure 2, the industries and cities are located along a river and its tributaries. The numbered elements in the figure are supposed to represent a ‘mile-marker.’ Thus, for example, team 2 is located 4 miles downstream from team 1. It is also assumed that the first three industrial firms are located in Paladine City and the other two are in Eddyville. The five industries selected in this game represent industries which generate significant biochemical waste. This version of the game only considers biochemical waste; it does not consider toxic waste substances. Future revisions of the game could include treatment of toxic wastes as well.

The industrial firms represent respectively a cotton processing plant, a poultry processing plant, a meat

FIGURE 1
WATER QUALITY MANAGEMENT GAME



processing plant, a potato chip factory and a pulp- and-paper mill. These plants range from small to medium in size within their respective industries. A narrative is given to each participant describing the production process of the firm. It includes the production forecast for four quarters, associated expected waste water flow rates in million gallons per day (MGD), and influent Biochemical Oxygen Demand (SOD) in milligrams per liter (mg/l). The narrative specifies the permitted discharge into the river in terms of maximum flow (MGI)) with limits on BOD concentration in the effluent. A description of the capacity of the available waste water treatment plant is also provided. This is followed by a statement about the estimated fixed cost as well as variable costs of operating the waste treatment plant at various levels. Estimated user charges at different flow rates and pretreatment levels are also included, should a firm decide to use the municipal plant for disposal of waste water. A table containing costs of larger plant sizes is provided to aid in making decisions on upgrading the plant, should a company/city decide to enhance its waste treatment facilities.

Plant sizes, permits and production forecasts exhibit a wide range among the five industrial firms and the two municipal teams. Table 1 includes a summary of starting values of permits, plant sizes and production forecasts. The wide range appears to be quite realistic based on our interviews with representatives of many of the regulatory agencies in the State of Oklahoma. In any ease, these numbers can easily be changed.

<u>Decisions and Alternatives</u>

In each period, participants have to make two types of decisions. They first decide on how to dispose of the waste expected to be generated in the current period. Then they decide on whether to upgrade the treatment plant. In the former decision, six alternatives are normally available. These 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.

FIGURE 2
A TYPICAL RIVER REGION CONSISTING OF INDUSTRIES AND CITIES

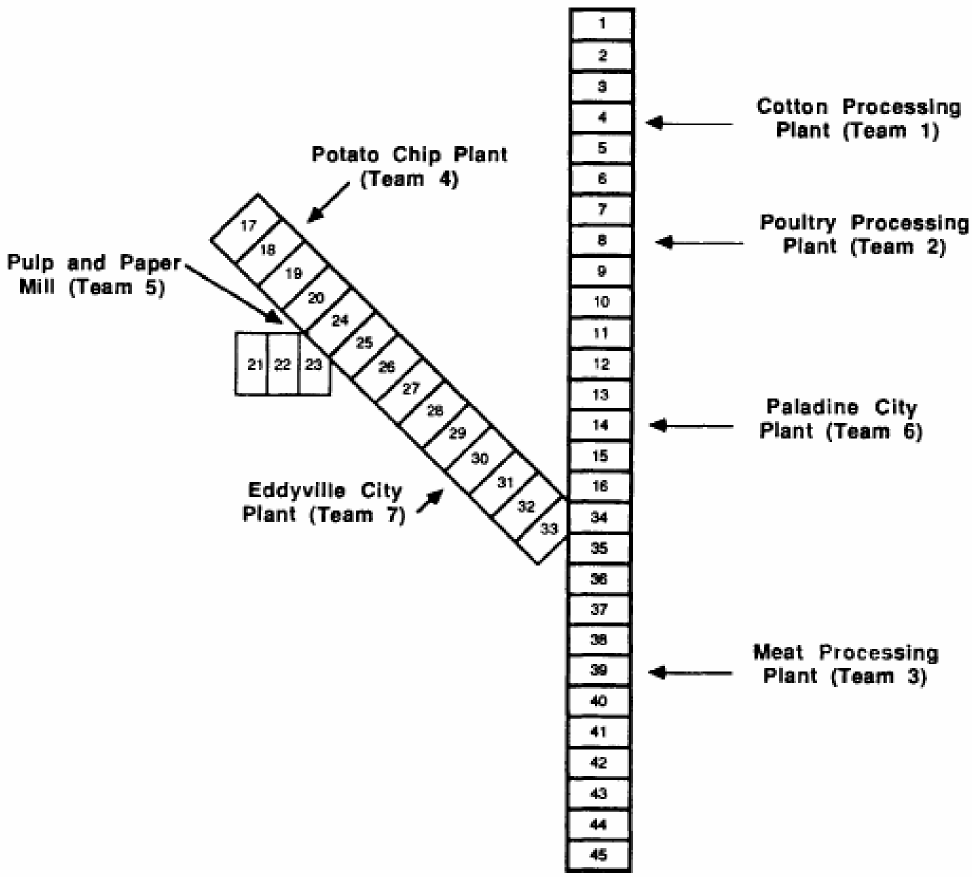


TABLE 1
SOME INITIAL PARAMETERS FOR PARTICIPANTS

Team No.	Description	Max. Permitted Discharge		Plant Capacity		Production Data*	
		Flow (MGD)	BOD (Mg/l)	Flow (MGD)	BOD (Mg/l)	Flow (MGD)	BOD (mg/l)
1	Cotton Processing Plant	1.70	30	1.50	20	1.20	200
2	Poultry Processing Plant	0.38	24	0.45	24	0.50	300
3	Meat Processing Plant	0.03	40	0.05	70	0.04	400
4	Potato Chip Factory	0.04	20	0.05	20	0.04	100
5	Pulp and Paper Mill	2.00	20	2.00	40	2.00	400
6	Paladine City	26.70	45	20.00	40		
7	Eddyville City	5.60	10	8.00	10		

*These are based on production forecasts for first quarter. These can be changed by the students.

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

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

6. Discharge without permit and treatment.

The first alternative involves treating the waste fully in the company plant. It results in the company incurring capital as well as operating costs of a treatment plant. The next four alternatives make use of the municipal plant to some extent and thus involve the expense of a user charge. The last alternative is really an unacceptable one. 'If a company selects this alternative and is caught, a heavy fine is imposed which is to simulate a penalty as well as bad publicity.

The decision to select an alternative from these is not an easy one. One needs to calculate the total cost of each alternative. In some alternatives involving partial treatment, one also needs to consider the extent of treatment and its effect on total cost. Some of the alternatives may not be feasible, given the capacity of the treatment plant and/or the permitted flow discharges to the river. For example, if a firm has a waste treatment plant with a design capacity of 0.08 MGD and expects 0.07 MGD flow this quarter, but its permit allows a discharge of only 0.06 MGD, the company cannot select the alternative of treating everything in the company plant and releasing to the river. Thus the decision maker has to select the feasible set of alternatives first, analyze their implications and make a decision. Another factor to consider is the continuity from quarter-to-quarter. Realistically, one does not change such decisions month to month. Thus the long term effect of a strategy also has to be considered.

A similar reasoning also applies to the decision to upgrade the plant. If the water quality manager expects significant growth in either the flow or the influent concentration, one way to treat them is by having a plant with higher flow capacity and/or higher BUD removal rate. This decision may affect future decisions as well. One has to weigh the benefits of a larger plant against its costs as well as costs of alternatives such as "pretreat the waste and release to the city sewer" or "treat only part of the waste and release to the river and send the other part to the city plant." Both of these decisions involve a good deal of analysis of marginal costs of each alternative.

<u>Inputs by Game Administrator</u>

Once the participants have made their decisions and entered them into a computer dataset, the instructor can specify the expected ambient temperature, other flow conditions in the region and so on. In the simplest form, all such environmental conditions can automatically be generated through a computer program if the instructor specifies a season for the quarter under consideration. Thus four sets of environmental conditions are built in, one for each season.

<u>Game Program Calculations</u>

When game participants and the administrator have entered their information, a main program is called to simulate the economic as well as water quality effects of the decisions. A financial report is generated for each team, summarizing their decisions, their plant report, and a cost analysis of their decision. Reports for industrial firms also include a highly simplified income statement, based on their production decisions and fixed relationships between production, price and cost of goods sold variables. A sample financial report is exhibited in Figure 3.

Considerable effort was made to ensure the accuracy of the relationships included in the game program. For example, fixed and variable cost formulae for operation of a waste treatment plant are based on statistical analyses reported by Fraas and Munley [2]. The relationships were developed over a sample of 62 and 178 plants, respectively. User fees for use of a municipal plant are calculated using formulae proposed by Dyer et al. [1], again based on a statistical analysis. We modified this formula a little because it establishes user charges on the basis of BOD, nitrogen and phosphorous contents of the waste water and we assume BOD as the only metric for measurement of water quality.

If a team decides to release untreated water without the appropriate number of permits, the game program attempts to simulate reality by randomly deciding whether the team is caught by inspectors. This is accomplished by generating a random number between 0 and 1. Assuming that there is a 607. probability of getting caught, this random number is translated into a fine or no fine. Thus the game program attempts to achieve some reality.

A second component of the game program is responsible for simulating the water quality of the whole region, based on various point discharges and environmental conditions. We use a program called QUAL-II [4] for this purpose. This program, or versions of it, has been used by the Environmental Protection Agency (EPA) and local regulatory agencies in simulating steady state water quality as well as in establishing point loads for various dischargers. This program is an extension of the Streeter-Phelps equations and is able to consider multiple input sources and ambient conditions in determining the spatial distribution of water quality as measured by BOD, dissolved oxygen (DO), nitrogen and phosphorous. The game program has achieved an 'aura' of reality by being able to use QUAL-Il in simulating water quality effects of individual decisions.

COMPUTER SUPPORT OF THE GAME

While the participants make the decisions based on economic principles, the computer is used to record those decisions and analyze their effects. number of computer programs, command procedures and datasets comprise the overall game program. A schematic of these programs and datasets is given in Figure 4.

There are two command procedures for interaction in the game. One of these is used by each participant to enter their decisions. This command procedure allocates appropriate datasets and calls the student input program. This input program prompts the student for decisions, allows one to make corrections and finally records the decisions in two datasets. One dataset keeps track of the decision for disposal of the current period's waste. The other dataset records the plant size available two periods later based on the upgrade decision. It is assumed that it takes two periods to upgrade a plant.

A second command procedure is invoked by the instructor. This procedure allocates student decision datasets which are read by another program to prepare input for the QUAL-Il program. The instructor also specifies the season index. The program then automatically selects environmental conditions. A dataset is finally prepared for the QUAL-II program. The command procedure then submits two batch jobs, one for execution of the cost program, and the other for the QUAL-II program. The programs also write all pertinent information to an archival dataset for any further analysis. Thus the whole process has been automated. The instructor only needs to logon to the computer once a week and enter the season index. The rest is fairly straightforward.

The programs have been developed using a VS FORTRAN compiler running on IBM 3081K. Only ANSI standard FORTRAN statements have been used. The QUAL-II program was developed in standard FORTRAN at EPA. The command procedures are CLISTs available on the IBM mainframes under MVS/TSO environment. None of the programs are claimed to be particularly efficient.

GAME ADMINISTRATION

The game simulates a region of seven teams. Two of these teams represent municipalities; the others are industrial firms. Depending upon the class size, multiple independent regions can be simulated in the same class. The names of the datasets are such that the administrator can easily keep track of multiple regions. Another way to accommodate large class sizes is to let a group of two or three students represent an industrial or municipal entity. We have played the game with each student representing one team and the entire section simulating three regions.

The game has been played in a Natural Resource Economics class. This course is an elective taken by economics, business and civil engineering majors. The class normally meets on a Monday, Wednesday, Friday schedule for fifty minutes. After the instructor covers the topics relevant to water quality management, the game is introduced. The students are provided a description of the firm they are supposed to represent. Their decisions are required to be entered into the computer by Friday each week. When all teams have entered their decisions, the instructor calls the appropriate command procedure to submit the jobs. Output containing a cost report as well as water quality data is then distributed back to students, normally on Mondays. How the three regions are performing in terms of water quality is discussed in the class. Also discussed is how the teams are managing their water quality costs.

Grading of a student's performance is quite difficult in this case. Since the students are playing two different roles, namely industrial and municipal managers, their decision strategies are difficult to compare. The industrial manager's objective is presumably to minimize the cost of waste treatment whereas the municipal manager ought to be more sensitive to water quality issues. This difference in their expected performance makes grading quite subjective. We award a significant part of the case grade on their entering timely decisions, even if the decisions are not the best. The administrator currently determines what the best strategy would be under each case. If the participant selects the same alternative, full credit is given. Otherwise partial credit is given depending on the cost performance.

FIGURE 3
SAMPLE FINANCIAL STATEMENT

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     WATER QUALITY SIMULATION GAME

 REGION                                 : A
 GAME PERIOD                            : 1
 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                      :  1.000 MILLION POUNDS OF PRODUCT
 EXPECTED WASTEWATER FLOW RATE          :  0.038 MGD
 EXPECTED BOD INFLUENT CONCENTRATION    :400.0   MG/L

     THIS IS YOUR ALTERNATIVE
PRETREAT EVERYTHING IN THE COMPANY PLANT & SEND TO THE MUNICIPAL PLANT.
PRETREATED WASTEWATER FLOW RATE         :  0.038 MGD
EXPECTED BOD EFFLUENT CONCENTRATION     :280.0   MG/L

DESIGN BOD REMOVAL RATE                 :    0.82

     THIS IS YOUR UPGRADE PLAN
FUTURE DESIGN CAPACITY                  :  0.050 MGD
FUTURE DESIGN BOD EFFLUENT CONCENTRATION : 60.0   MG/L

     WATER QUALITY-RELATED COSTS
QUARTERLY  INVESTMENT AND FIXED OPERATING COSTS OF PLANTL:     7081. DOLLARS
OPERATION COSTS                         :     3707. DOLLARS
INDUSTRIAL USER CHARGES                 :     1391. DOLLARS
PRICE OF PERMIT                         :        0. DOLLARS
TOTAL CURRENT COSTS                     :    12179. DOLLARS

     PROFIT & LOSS STATEMENT
TOTAL SALES REVENUE                     :  1800000. DOLLARS
LABOR AND MATERIAL COSTS                :  1080000. DOLLARS
OTHER EXPENSES                          :   180000. DOLLARS
TOTAL EXPENSES                          :  1272179. DOLLARS
TOTAL TAXABLE INCOME                    :   527821. DOLLARS
TAX ON CURRENT INCOME                   :   242798. DOLLARS
NET EARNING                             :   285023. DOLLARS
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CONCLUSION

The game described in this paper is perhaps one of the first to apply simulation gaming to introduce students to decision making for waste treatment. The game may also be used to research the regulatory issues in water quality management. For example, the game may be used to assess the effect of having a marketable discharge permit system. It may also be used to determine the effect of a tax system for discharge permits. Thus it offers a rich teaching and research tool.

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[4] Roesner, L. A., Giguere, P. R. arid Evenson, D. E., User’s Manual for the Stream Quality Model QUAL-II, EPA Report No. 600/9-81-015, U.S. Environmental Protection Agency, Athens, Georgia.

FIGURE 4
COMPUTER SUPPORT AND DATASETS FOR THE GAME PROGRAM