Supporting government cost planning of industrial wastewater treatment

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INTRODUCTION

The 1972 Federal Water Pollution Control Act Amendments established a series of national goals with the purpose of reducing and eliminating water borne pollution in the United States. One of these goals requires the implementation of best practicable control technology by all industrial dischargers by 1977.

The purpose of this paper is to describe a computer based system designed to estimate the costs of achieving these Federal Standards on non-thermal discharges by industry. The costs are estimated for each of 250,000 establishments in 14 major industry groups affected by the new standards. The computer system can then aggregate these results to the desired level of detail, supporting management decisions at federal, regional, and state levels for any of the 14 industry groups or their subsets.

A major purpose of the development of the Industrial Cost Model is to produce national cost estimates by industry for inclusion in the 1973 Economics of Clean Water report to Congress. Thus, one goal of the models developed was to attempt to achieve as high a level of compatibility as possible with previous Economics of Clean Water reports. The other goals of the model and the constraints under which it was developed are discussed in more detail in a later section of this paper.

The model was developed by EPA Headquarters in Washington, D.C. However, the information from the model is available to state and local government institutions as well as to selected private sector organizations. It is hoped that the full utility of the system can be taken advantage of.

Later sections of the paper discuss the concepts underlying the model development, an overview of the model itself and some summary data and suggested applications for the model results.

CONCEPT OF THE MODEL

Some of the basic outward features of the Industrial Model were mentioned briefly in the introduction. It is the purpose of this section to discuss the development of the model from the standpoint of the goals to be achieved by the model and the information and resources available to support the model's development.

Model goals

The major goals of the model as seen during its planning stages were as follows:

- To produce information on the cost impact of 1977 Federal standards on industry, by industry type, for publication in 1973 Economics of Clean Water.
- The most current available data on water use, industrial plants, and costs of control alternatives were to be used.
- To support economic impact analyses to be made by industry type.
- To produce cost summary reports in breakdowns other than major industry type* including EPA region** and state, as aggregates or by major or minor industry type.
- To achieve compatibility where possible with the previous versions of Economics of Clean Water, particularly the 1972 edition.
- All of the existing industrial sources in those industries under study were to be represented in the total cost figures developed.***

While the goals above refer to specific information outputs, it is important to realize that the study focused on producing results which would be meaningful as management tools. Some examples of how the model results can be used at various levels of government and by the private sector are discussed in a later section.

* Reference to major industry type or industry type is to 2 digit Standard Industrial Classification (SIC) code. Minor industry type refers to 3 or 4 digit SIC code.

** The 10 EPA regions are shown in Figure 1.

*** This ruled out use of the EPA Refuse Act Permit Program (RAPP) system and successor which has detailed information on industrial sources but contains only a small fraction of the total number of sources.
Model constraints

The resources available for the project were limited considering the scope of the goals to be achieved by the project. The effort was restricted to using information and data currently available to the Agency; there was not adequate time to undertake any sort of large data collection effort.

Some software was available from the Industrial Model developed for the 1972 Report but it had been developed for a different computer system. In addition, the formats and contents of the input files had to be changed significantly. Thus, although the existing programs were available, those which were used had to be almost completely rewritten.

The time constraint primarily served to limit the number of detailed reports which were produced by the system and the thorough analysis of those which were. The computer runs for the project were being made during a time of both hardware and software difficulties by the Agency computer services contractor. Most of the major runs had a large time requirement and were submitted for overnight turnaround. However, the various computer difficulties often dictated more than one attempt at each run.

Overall, the project team was able to meet the final deadlines for production and analysis of the model and its outputs. In addition to the summary information published in Economics of Clean Water, there is a variety of other more detailed information which could be useful to management and planners at state and local levels.

MODEL OVERVIEW

Several steps are required to achieve the desired calculation of costs of meeting Federal standards in 1977. The steps required are shown below:

1. Compute the cost of abatement facilities to meet 1977 standards on the current stock of plants (i.e., retrofit costs).
2. Apply growth factors to compute the costs of the 1977 standards on the plants to be built between now and 1977.
3. Compute the replacement cost of all abatement facilities adequate to meet 1977 standards on existing plants.

The costs represented by calculation 1 are the total investment required for existing plants. The costs represented by the difference of 1 and 3 represent the new retrofit investment required by 1977. Finally, the costs represented by calculations 1 plus 2 minus 3 is the total to be invested by 1977 including new plants.

In addition to the capital (or fixed) costs required, the annual operations and maintenance (O&M) costs for the facilities is also computed. Knowing capital and O&M costs, a "total annual cost" (TAC) can be computed assuming an annualizing factor to convert capital cost to an annual charge.

The industries covered by the study (by 2 digit SIC code) are shown below:

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<tr>
<th>SIC</th>
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<tbody>
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<td>20</td>
<td>Food and Kindred Products</td>
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<td>Leather and Leather Products</td>
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<td>Non-Electric Machinery</td>
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<td>36</td>
<td>Electric Machinery</td>
</tr>
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<td>37</td>
<td>Transportation</td>
</tr>
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</table>

Figure 2 shows the overall flow of the industrial cost model system. This series of program and files is executed for com-
The blocks of Figure 2 are explained below. All programs were written in FORTRAN IV.

1. **Water Use Data.** This is basic data taken from the report *Water Use in Manufacturing* which indicates the water used by minor industry types in 20 water use regions.** Table II from *Water Use in Manufacturing* provided the following detail required for the model.***

   —Water intake by purpose, Gross Water Used, and Water Discharged: 1968
   A—Industry Group and Industries
   employees
   water intake
   process water intake
   gross water used
   total water discharged

   —Water intake by purpose, Gross Water Used, and Water Discharged: 1968
   B—Water Use Regions, Major Industry Groups, and Industries
   employees
   water intake
   process water intake
   gross water used
   total water discharged

2. **WUSE Program.** This program converts the basic data from *Water Use in Manufacturing* to data by minor industry type and water use region. The model operates as follows:†

   The model forms ratios of regional to national totals to define variability between major classes of manufacturers geographically and also looks at the variability between industrial classes within a major manufacturing class. The water use per employee values define the process water per employee coming into contact with the product stream as follows:

   \[
   \text{WT}_{4R(o)} = \frac{\text{WP}}{\text{E}_4} \times \frac{\text{WU}}{\text{W}_4} \times \text{WU}_{2R} \times \text{WU}_{2R} 
   \]

   Where the process water to be treated is constrained to be no greater than the total amount of water discharged.

   The parameters are defined as follows:

   E—employment
   WI—water intake
   WP—water intake specifically used in product processing

   WD—water discharged
   WU—water used (gross used in plant including recirculation and reuse)
   WT—total water in contact with product stream

   Also,

   4—four-digit SIC Code
   2—two-digit SIC Code
   R—water use region designator—(If no R exists the parameter is assumed to be a national value)
   (e) —designates a per employee value
   primes—represent ratios calculated between regional and national values

   The following calculations are performed to yield the result above:

   (a) process water per employee ratio; regional defined ratio at the major industrial class level

   \[
   \text{WP}_{2R} = \frac{\text{WP}_{2R}/\text{E}_{2R}}{\text{WP}_{2}/\text{E}_2}
   \]

   (b) recirculation ratio; regionally defined ratio at the major industrial class level

   \[
   \text{WU}_{2R} = \frac{\text{WU}_{2R}/\text{W}_2}{\text{WU}_{2}/\text{W}_2}
   \]

   (c) water discharged per employee: represents the maximum water to be treated per employee for each industrial category, regionally defined

   \[
   \text{WD}_{4R(o)} = \frac{\text{WD}_4}{\text{E}_4} \times \frac{\text{WD}_{2R}/\text{E}_{2R}}{\text{WD}_{2}/\text{E}_2}
   \]

   (d) process water per employee coming into contact with the product stream defined by industrial category and region

   \[
   \text{WT}_{4R(o)} = \frac{\text{WP}}{\text{E}_4} \times \frac{\text{WP}_{2R}/\text{WU}_{2R} \times \text{WU}_4}{\text{W}_4}
   \]

   Where:

   \[
   \text{WT}_{4R(o)} = \text{WD}_{4R(o)}
   \]

   If:

   \[
   \text{WD}_{4R(o)} < \text{WT}_{4R(o)}
   \]

   Since the computations above were based on data which represented water use policies of some time ago (1968), the program produced six different water use scenarios based on different improvements in water use efficiency. The details of these scenarios is not repeated here.* One scenario was selected as most appropriate and used in most computations. Outputs from other scenarios are available to test model sensitivity and validity.

3. **Water use per employee.** This file contains the water to

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be treated per manufacturing employee by major and minor industry type and by 17 water use regions.

4. Duns Market Indicators* Extract. The following data elements were extracted from the Dun's Market Indicators (DMI) file for each of the approximately 250,000 establishments with the desired SIC codes.

- SIC code
- manufacturing employment
- state code
- county code
- SMSA code

5. Convert Program. The convert program was used to add two fields to the DMI extract. The fields added were:

- water use region (based on state and county codes)
- EPA region (based on state code)

6. Added DMI. The DMI extract file that contains the new fields discussed above.

7. Cost Data. The basic cost data were determined for the following twelve types of treatment:

- Oil Separation
- Equalization
- Coagulation
- Neutralization
- Air Flotation
- Sedimentation
- Aeration
- Natural Stabilization
- Chlorination
- Evaporation
- Incineration
- Activated Sludge

The basic cost data were taken primarily from a report by an EPA contractor.*** Three or four points were available for each treatment type based on the costs for different water flows.

8. COSTCOMP. The cost points were converted to coefficients of equations of the form

\[
\log(COST) = A + B [\log(FLOW)] + C [\log(FLOW)^2]
\]

where

- \(\log\) = base 10 logarithim
- COST = cost in millions of dollars
- FLOW = flow in millions of gallons per day
- \(A, B, C\) = coefficients from COSTCOMP program

Both linear (coefficient \(C = 0\)) and quadratic (coefficient \(C \neq 0\)) regressions were run on the basic cost data. The type of equation with the highest F test value was selected. In some cases, the curve was divided into separate equations based on level of flow.

9. Cost Coefficients. The values of \(A, B,\) and \(C\) for each of the twelve treatment types (and segments) for both capital (fixed) and operating and maintenance costs.

10. INDUST, Cost Calculator Model. This is the key program in the system. It operates on each of the establishments from block 6 and, using files from blocks 3 and 9 and other data described below, produces the treated water flow and capital and O&M cost requirements in 1972 dollars for each of the twelve treatment types which may be imposed. In addition, a filter is applied which eliminates all establishments with less than one million gallons per year of treatable wastewater since these establishments are undoubtedly either using municipal facilities or applying wastes to land; 100,000 establishments were rejected in this way.

The inputs are:

- water use per employee (block 3)
- list of establishments to model (block 6)
- cost coefficient (\(A, B,\) and \(C\)) of the form:

\[
\log(COST) = A + B [\log(FLOW)] + C [\log(FLOW)^2]
\]

(block 9)

- factors for accommodating differences in O&M costs for each state
- factors for estimating the capital cost differences for each water use region.
- the percentage of plant water use that is treated by each of the various treatment processes. This information was compiled for each SIC code considered.
- average operating days per year for each SIC.
- waste strength scale factor relative to municipal wastes of the form \(SF = 0.4 + 0.6 \times \) (waste strength relative to municipal waste)
- where \(SF\) is greater than or equal to 1.0
- a factor for accommodating differences in the cost of the same effluent treatment process in different SIC industries.

11. Establishments with Cost. This file consists of a subset of the added DMI file (block 6). The subset is all establishments with a computed water usage greater than one million gallons per year (equivalent to the domestic waste from thirty people). The file contains all of the elements from block 6 and the following additions:

- the annual process water requiring some type of treatment
- the capital cost of treatment facilities for each of the twelve treatment types
- the operating and maintenance costs for each of the twelve treatment types.

12. Output Program. This program performs data aggregations and computes summary statistics for the aggregated groups. Before running the program, the output file from block 11 is sorted on the appropriate fields. The following

* Computer file maintained by Dun and Bradstreet Inc. and available to EPA under contract.
types of aggregations may be generated

- state
- EPA region
- industry type (2, 3, or 4 digit SIC)

The third category, industry type, can be generated by itself is supplemented with data from an annual survey of pollution control expenditures. This section discusses the variety of potential applications at federal, state, and local levels for the information produced.

12. Output Reports. Figure 3 shows page from an output report as described in block 11.

To compute the value of facilities in place, the Added DMI file (block 6) is replaced by a summary of plants with facilities derived from Water Use Manufacturing. The output is supplemented with data from an annual survey of pollution control expenditures.

MODEL APPLICATIONS

This section discusses the variety of potential applications at federal, state, and local levels for the information produced.

Figure 3—Sample output report
by the Industrial Cost Model. The section is divided into two parts, the first discusses some of the applications to which the model can be put, the second presents an example of how the model outputs were used to perform a relative impact analysis for states and EPA regions.

Potential applications

One of the benefits from the methodology used in developing the Industrial Cost Model is the variety of aggregations which can be performed. The flexibility of uses for the model outputs are considerably enhanced by this capability of the model. At the present time, aggregations have been produced by EPA region, state, and major industry type. The model can easily produce additional aggregation by minor industry type, SMSA, or counties. Of course, the less aggregated the analysis is, the more likely that it may vary from the actual situations.

The mechanisms used in producing the control cost estimates are designed to account for the specific differences in control costs for each plant based on such factors as manufacturing plant type, water use, state difference, for operations and maintenance costs, and regional differences for capital costs. However, each plant has a certain amount of latitude in controlling water pollution. For example, there is considerable flexibility in the specific set of treatment types which are possible and there are additional tradeoffs between capital costs and operations and maintenance costs. The model outputs are based on estimations of the most likely overall abatement measures to be adopted; however, these measures will not necessarily apply to each specific plant. Thus, discrepancies between the model estimates and actual occurrences are more likely to be noticed at low level aggregations. Conclusions based on specific model outputs may be affected by this phenomenon.

### TABLE I—Percentage of National Totals by States

<table>
<thead>
<tr>
<th>State</th>
<th>Capital cost of industrial water treatment*</th>
<th>Total industrial capital expenditure*</th>
<th>Annual cost of industrial water treatment</th>
<th>Value added by manufacturer</th>
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</thead>
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<td></td>
<td>(Percent)</td>
<td>(Percent)</td>
<td>(Percent)</td>
<td>(Percent)</td>
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* From 1973 Economics of Clean Water.

### TABLE II—Percentage of National Totals by EPA Region

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<th>Capital cost of industrial water treatment*</th>
<th>Total industrial capital cost</th>
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<th>Value added by manufacturer†</th>
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<td>3.4</td>
<td>4.3</td>
<td>4.7</td>
</tr>
<tr>
<td>VIII</td>
<td>2.1</td>
<td>1.1</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>IX</td>
<td>8.4</td>
<td>8.4</td>
<td>6.3</td>
<td>9.5</td>
</tr>
<tr>
<td>X</td>
<td>6.9</td>
<td>2.8</td>
<td>7.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

* From 1973 Economics of Clean Water
Some of the potential applications which would be meaningful at national, regional, state, and local levels are discussed below.

- The specific areal requirements which include the number and size of plants affected as well as the required outlays can aid government officials in evaluating specific plant by plant implementation plans in light of overall requirements.
- The alternative water use scenarios produce information which can be used to determine overall and average cost savings possible through greater water recycling or process changes. These savings vary greatly in the various geographical areas due to differing hydraulic efficiencies.
- Local cost data could be used to validate the model outputs for a particular geographic area. Also, differing types of treatment can be modeled if they apply in a specific area.
- Relating model outputs to other economic indicators can support analysis of relative impacts in different geographic areas or industrial subcategories.
- Much industrial wastewater is currently not treated at all. In some parts of the country, publicly owned treatment facilities may provide some of the required treatment. The model outputs can help aid local planning of industrial loading of publicly owned treatment works.

**Sample application**

One of the requirements of the Economics of Clean Water is the analysis of relative impacts of industrial water pollution control costs in states and EPA regions. To develop this impact, the capital requirements for water pollution control were compared with total capital expenditures and annual costs of water pollution control were compared to value added by manufacturing.

The percentage of the national requirement in each state and region for both capital and annual industrial wastewater treatment costs are based primarily on both the size and type of industry found in the state. The geographically-determined capital cost factor also makes a difference. The range by state is from less than 0.1 percent to 9.0 percent of total capital requirements and from less than 0.1 percent to 8.9 percent of total annual costs. Regional values for the former range from 2.1 percent to 24.9 percent and from 2.5 percent to 24.6 percent for the latter. Table I contains the percentages by state and Table II contains them by EPA region.

The relative share of industrial capital invested in a state or region is based on the growth rate for the area, the type of industry (capital intensive or not), and the age of existing facilities. Also reflected in the total capital expenditures are those expenditures for pollution control. The relative share of value added is also based on the size and type of industry.

While no direct relationship necessarily exists, it would seem that those areas with a larger share of capital requirements for pollution control than of capital expenses in general might encounter a greater burden in diverting capital to the construction of pollution control facilities. Examples of areas with this characteristic are Regions VIII and X and the following states:

- Alaska
- Hawaii
- Idaho
- Maine
- Montana

Other areas might encounter less of a burden in diverting capital to construction of pollution control facilities given the capital cost and overall level of investment. Regions II, IV, and V fall into this category as well as the following states:

- Arizona
- Connecticut
- Indiana
- Iowa
- Kentucky
- Maryland

A similar comparison can be made between annual costs of pollution control and value added by industry. In those areas with relatively higher annual pollution control costs than value added, there may be greater changes in wages, prices, and dividends than in other areas. Areas with relatively high annual pollution control in comparison to value added are Regions VI, VIII, and X and the following states:

- Alaska
- Hawaii
- Idaho
- Louisiana
- Maine

Those with relatively high value added in comparison with annual costs are Regions II, V, and IX and the following states:

- Arizona
- California
- Connecticut
- Delaware
- Indiana
- Kentucky

While no detailed set of effects by State or region can be developed from the data presented in Tables I and II, it is clear that significant differences are present between pollution control capital requirements and capital expended and between annual pollution control costs and value added. In fact, the two sets of measures generally reinforce each other.
which strengthens the hypothesis that there will be a differ­ential burden.

CONCLUSIONS

The information made available by the Industrial Cost Model is useful to the Federal government in its planning and evaluation roles. In addition, it has potential applications at regional, state, and local levels of government and in the private sector. These other potential applications would primarily fall into the realms of planning and management.

The data and manpower resources required to develop the Industrial model are generally not available to state or local government. Thus, the development of the system by the Federal government and its being made available to other users present smaller units of government with a tool otherwise unavailable to them.