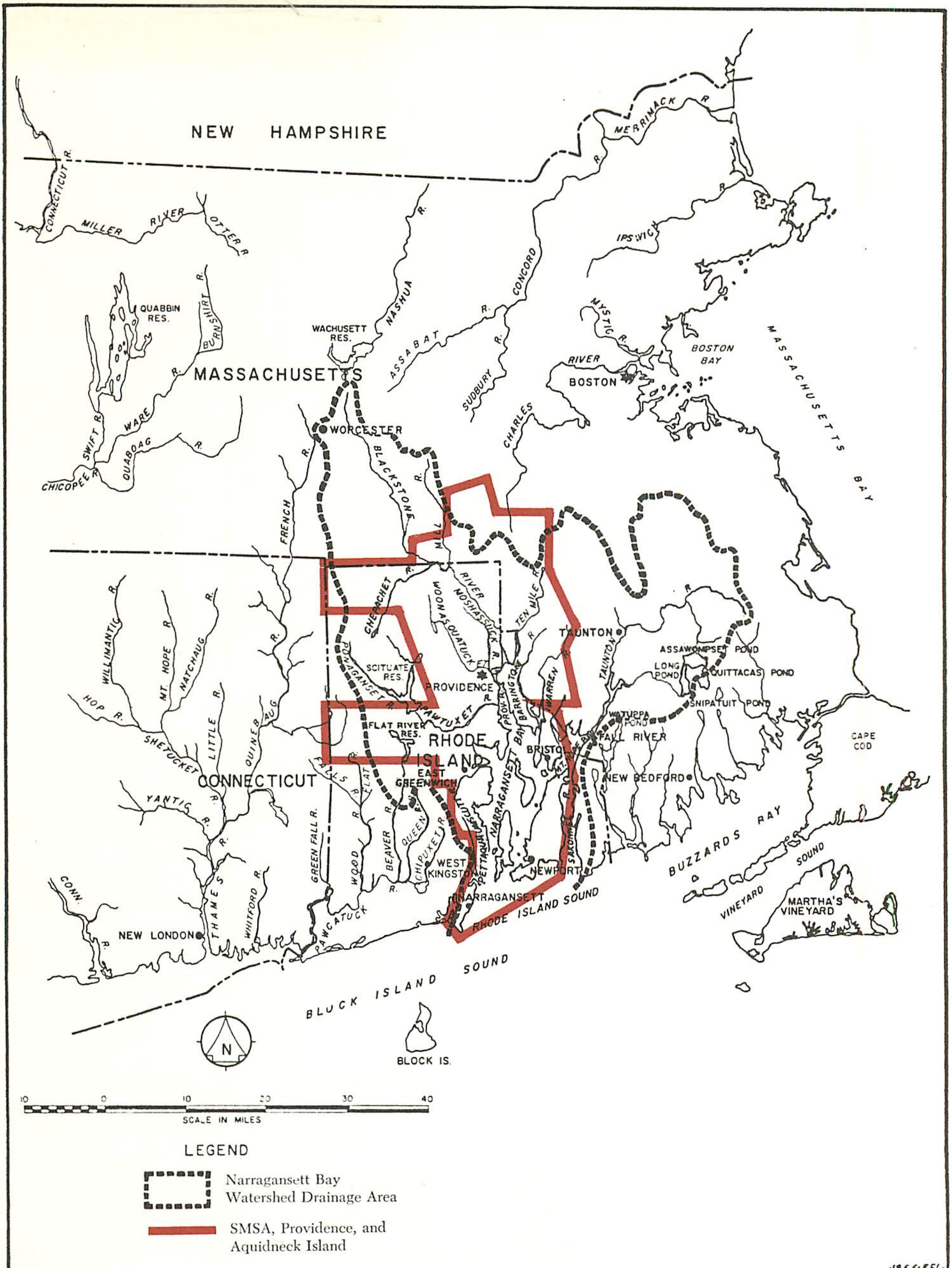
Economic Growth and the Generation of Waterborne Wastes

Sidney Feld and Niels Rorholm

Sea Grant
Resource Economics

University of Rhode Island
Marine Technical Report No. 12



The study area for this report is the Providence Standard Metropolitan Statistical Area and Aquidneck Island, which are outlined in color on the map.

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Acknowledgments

This publication is based on the senior author's Ph.D. thesis submitted to the graduate economics faculty, University of Rhode Island. In the process of writing the thesis, valuable counsel was received from Thomas A. Grigalunas and Harlan C. Lampe of the Department of Resource Economics and from Scott W. Nixon of the Graduate School of Oceanography.

The research underlying the publication was supported, jointly, by Office of Sea Grant, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and the University of Rhode Island Agricultural Experiment Station. It is a part of efforts in ocean engineering, oceanography, and resource economics to understand and to characterize physical, biological, and economic interaction in and around Narragansett Bay. The ultimate objective of the work is to provide tools for making better decisions in the coastal zone.

The Agricultural Experiment Station contribution number is 1502.

Additional copies of Marine Technical Report No. 12 are available at $1.00 each from the URI Marine Advisory Service, Narragansett Bay Campus, Narragansett, Rhode Island 02882. Please make checks payable to the University of Rhode Island.

Abstract

The primary objective of this study is to demonstrate how to quantify the interaction among economic activities and water effluent loadings for the area surrounding Narragansett Bay, Rhode Island. A second objective is to discuss some uses of an economic waste generation model in public decision-making.

The study focuses on economic activity and its waterborne residuals within the Narragansett Bay Drainage Basin. This region accounts for over 90 percent of the economic activity of Rhode Island and slightly less than 10 percent of that of Massachusetts.

The bases for the study are an input-output framework for the area's economy disaggregated into 59 endogenous sectors and 4 exogenous final-demand sectors, and a matrix of effluent coefficients and water usage coefficients for the endogenous sectors. The effluent data were obtained primarily from permit applications submitted by Rhode Island firms to the U.S. Army Corps of Engineers. Some were from appropriate industries studied in other regions of the country (1,2,3). The economic model was constructed by updating, expanding and resectoring an earlier input-output model of the greater metropolitan Providence area (4).

The study concludes that much as the multiplier effects caused by economic interdependencies are of critical importance in regional economic development, so are the waste products generated by these interdependencies of substantial importance to the regional ecology. Upon reflection, it is not surprising that this should be so. However, recognition of these "waste multipliers" seems even less widespread in local and state economic development circles than is the general recognition of the pervasive role played by economic interdependencies. The policy implication is that the cost savings in pollution control or, conversely, the abatement effect of a given public outlay may be significantly increased by selective rather than by broad controls. These gains or savings to society may be great enough to overcome the political difficulties associated with selective controls.

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Introduction

Research sponsored by the federal government indicates that manufacturing firms are the most significant contributors of waterborne waste.[1] For example, waste water from manufacturing firms is almost two and one-half times that generated by the nation's municipal population. In addition, biochemical oxygen demand (B.O.D.) and suspended solids—both important indicators of water quality—exceed municipality loads by three and two and one-half times, respectively. Furthermore, the waste's composition is potentially much more harmful. In many instances, specific wastes emitted by firms are highly complex in nature; moreover, the number of different residuals discharged far exceeds those generated from other sources. Consequently, treatment is hampered, and the potential effect on the environment considerably more severe.

The outflow of these kinds of residuals constitutes a major societal concern. Legislation and government controls are being developed to ensure that industrial wastes entering the environment are either reduced in amount or, if necessary, transformed into less noxious forms. However, a prerequisite to optimum regulation is an awareness of the basic economic-environmental interactions.

It bears emphasis that this study is primarily an economic one with the principal interest being economic interrelationships and how these generate waterborne wastes. The study in no way attempts to evaluate the effect these waste loadings have on the environment, but rather quantifies the discharges and shows how economic interactions precipitate their generation. In addition, data on water usage by specific economic sectors are included to provide some measure of natural resource services required by each of the economic sectors.

The Study Area

The drainage basin for which Narragansett Bay is the receptacle encompasses most of Rhode Island and sizable portions of Massachusetts. In Rhode Island alone, the wastes from approximately 90 percent of the households and practically all manufacturing plants drain into the Bay, although not all are untreated.[2] Technically, the study area should include the entire Narragansett Bay drainage basin because much of the waste entering the waters, in any part of the watershed, will ultimately come out in Narragansett Bay (fig., inside front cover).

However, while the drainage basin is easily definable, it is not a usable study area. Economic data normally are aggregated in accordance with some political subdivision or specific socio-economic characteristic. The watershed follows no such demarcations. Because of the demanding economic data needed for this model, some compromise was necessary to define a workable study area.

The area ultimately chosen encompasses the Providence Standard Metropolitan Statistical Area (SMSA) plus Aquidneck Island (fig., inside front cover). This area coincides very closely with the Rhode Island portion of the drainage basin; however, relatively large sections of Massachusetts which are within the watershed are not part of the Providence SMSA. Although the discrepancy exists, a model including these areas would not significantly improve this study for two reasons. First, of all effluents generated from the Mount Hope Bay area, approximately 30 percent will bypass Narragansett Bay altogether, entering the ocean via the Sakonnet River.[3] Second, because the area excluded lies at the periphery of the watershed, wastes have to go many miles down rivers and streams before entering the Bay. Because B.O.D. is subject to biological activity and decomposition as a result of water's regenerative powers, it should be significantly reduced upon its entrance into the Bay.

Population and the Economy

The Rhode Island portion of the study area accounts for 91.5 percent of the State's total population as of the 1970 Census, and 93.5 percent of its firms and 96.5 percent of its employment as of 1968.[4] Table 1 shows the distribution of land area and people in the study between Rhode Island and Massachusetts.

[1] *U.S. Department of the Interior,* The Cost of Clean Water, Vol. I, Summary Report *(Washington, D.C.: U.S. Government Printing Office, 1968), p. 20.*

[2] *Governor's Technical Committee on the Coastal Zone,* State of Rhode Island Report of the Governor's Committee on the Coastal Zone *(Providence, Rhode Island: State House, 1970), p. 63.*

[3] *Nixon, Scott, personal communication.*

[4] *Griffiths, Lucy,* Indicators of Economic Changes for Rhode Island Cities & Towns, 1957-1968, *Resource Economics Occasional Paper No. 70-59 (Kingston, Rhode Island: University of Rhode Island, 1970).*

Table 1. Towns and cities in the study area, population and land area.

Towns and Cities	Population 1970*	Land Area (Sq. Miles)
Rhode Island Portion (total)	868,888	517.9
Bristol County	45,937	24.9
Barrington (town)	17,554	8.9
Bristol (town)	17,860	10.2
Warren (town)	10,523	5.8
Kent County	140,541	122.0
Warwick (city)	83,694	34.9
Coventry (town)	22,947	62.2
East Greenwich (town)	9,577	16.6
West Warwick (town)	24,323	8.3
Newport County	79,284	53.6
Jamestown (town)	2,911	9.7
Middletown (town)	29,621	12.9
Newport (city)	34,231	7.7
Portsmouth (town)	12,521	23.3
Providence County	566,195	260.0
Central Falls (city)	18,716	1.2
Cranston (city)	74,287	28.6
East Providence (city)	48,207	13.3
Pawtucket (city)	76,984	8.8
Providence (city)	179,116	18.1
Woonsocket (city)	46,820	7.9
Burrillville (town)	10,087	55.8
Cumberland (town)	26,605	27.1
Johnston (town)	22,037	23.7
Lincoln (town)	16,182	18.6
North Providence (town)	24,337	5.7
North Smithfield (town)	9,349	24.5
Smithfield (town)	13,468	26.7
Massachusetts Portion (total)	122,331	209.0
Bristol County	69,200	112.9
Attleboro (city)	32,907	27.2
North Attleboro (town)	18,665	19.4
Rehoboth (town)	6,512	47.6
Seekonk (town)	11,116	18.7
Norfolk County	44,065	79.8
Bellingham (town)	13,967	18.8
Franklin (town)	17,830	26.6
Plainville (town)	4,953	11.4
Wrentham (town)	7,315	23.0
Worcester County	9,066	16.3
Blackstone (town)	6,566	11.4
Millville (town)	2,500	4.9
Total study area	991,219	726.9

**U.S. Department of Commerce, Bureau of Census,* 1970 Census of Population—Rhode Island *(Washington, D.C.: U.S. Government Printing Office, 1970).*

The Narragansett Bay study area is a relatively important economic region. In 1967, the base year used here, gross regional product was estimated at $4.238 billion. Of that amount, personal income constituted $3.126 billion, and wages, salaries and profits amounted to $2.499 billion. An indication of the productive mix of the economy is given in table 2, where sectors primarily responsible for the generation of revenues are listed.

Table 2. Total output of 12 leading sectors for Narragansett Bay study area—1967.

Sector	Millions of Dollars
Finance, insurance and real estate	864.5
Wholesale and retail trade	557.2
Jewelry manufacturing	506.2
Primary nonferrous metal manufacturing	389.4
Construction and mining	329.0
Medical, education and non-profit organizations (services)	278.6
Broad and narrow fabrics (manufacturing)	253.4
U.S. Navy	226.8
Government industry	225.0
Food and kindred products (manufacturing)	166.6
Business services	158.7
Rubber and miscellaneous plastics (manufacturing)	155.8

The Economic Model

The model depicts economic activity within the study region for the year 1967. The data are set within an input-output framework so that for each of the 59 endogenous sectors input and output flows are systematically presented.[5] Algebraically, the basic input-output format can be expressed as a system of linear equations. The example that follows is for a three-sector economy.

A transactions table for a three-sector economy is represented as a system of equations:

$$\begin{aligned} X_1 &= x_{11} + x_{12} + x_{13} + Y_1 \\ X_2 &= x_{21} + x_{22} + x_{23} + Y_2 \\ X_3 &= x_{31} + x_{32} + x_{33} + Y_3 \end{aligned} \qquad (1)$$

where X_i = total gross output of the ith sector

x_{ij} = intermediate demands for gross output, i.e., purchases made by the jth sector from the ith sector

and Y_i = final demand

Technical coefficients are calculated as the ratio of purchases made by sector j of sector i's output over the gross output of sector j.

$$a_{ij} = \frac{x_{ij}}{X_j} = \text{technical coefficient} \qquad (2)$$

Substituting $a_{ij}X_j$ for x_{ij} in the set of equations (1) and rearranging terms produces:

$$\begin{aligned} Y_1 &= X_1 - a_{11}X_1 - a_{12}X_2 - a_{13}X_3 \\ Y_2 &= X_2 - a_{21}X_1 - a_{22}X_2 - a_{23}X_3 \\ Y_3 &= X_3 - a_{31}X_1 - a_{32}X_2 - a_{33}X_3 \end{aligned}$$

Rewriting these equations in matrix form produces:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} = \begin{bmatrix} 1-a_{11} & -a_{12} & -a_{13} \\ -a_{21} & 1-a_{22} & -a_{23} \\ -a_{31} & -a_{32} & 1-a_{33} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix}$$

[5] *Detailed explanations for data development as well as the more than 50 pages of data matrices are not included in this report. For such details write for a copy of the thesis underlying the report from Chairman, Department of Resource Economics, University of Rhode Island, Kingston, Rhode Island 02881. Enclose check of $10.00 payable to the University of Rhode Island.*

or

$$Y = (I - A)X$$

where

Y = the final demand matrix

$(I - A)$ = an identity matrix less a matrix of technical coefficients

and X = the matrix of gross outputs.

Solving for X produces:

$$X = (I - A)^{-1}Y$$

where

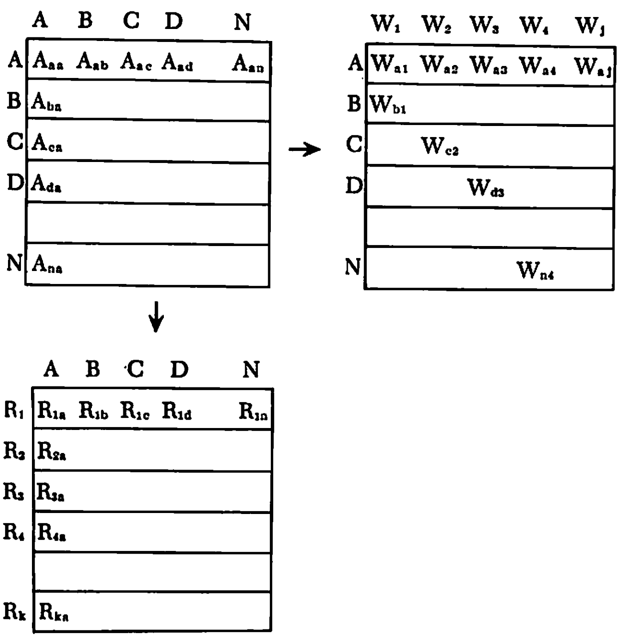
$(I - A)^{-1}$ = the Leontief Inverse, or the matrix of interdependency coefficients. This final equation shows the total impact on output of a unit change in final demand.

The economic data for the model relies heavily on an earlier input-output study of the Providence Standard Metropolitan Statistical Area (4). Basically, the technical relationships developed in 1963 and 1964 were assumed valid for the 1967 economy. The size of the economy was, however, updated to 1967 and in certain instances differences in sector aggregations were made to better reflect the economic characteristics of the region. For example, many activities were disaggregated into distinct sectors in the earlier study, even though they are not important economically. Consequently, in this model, these sectors were combined with other activities which displayed similar economic characteristics. New technical coefficients were developed by summing the existing technical coefficients, taking care to weight each coefficient according to its respective output total. In addition, in two instances more detail was sought for this model than for the earlier study. Jewelry manufacturing and the U.S. Navy were judged sufficiently important to the region to warrant separate sector classification. In each case, technical coefficients had to be developed from other sources (5,6). Finally, the models differ in the treatment of the residential sector. This sector was internalized within this study because concern exists about the wastes generated by this sector, and also because the effect on the economy of successive rounds of re-spending generated by additions to personal income can readily be seen when households are endogenous.

Environmental Linkage

The economic model was then linked to environmental data to show how the economic interdependencies relate to waste generation. Schematically, the linkage operation is presented in the flow diagram below.

Matrix 1. Interindustry. Matrix 2. Waste coefficients.



Matrix 3. Natural resource usage.

Flow diagram of an economic-environmental linkage model.

The primary matrix, appearing in the upper left-hand corner of the figure, is an interindustry matrix that accounts for the transactions among the different sectors of the economy. Its columns and rows represent the specific sectors into which the economy is disaggregated. At its right is the matrix depicting waste coefficients. Its column headings denote specific wastes generated, while rows correspond to the rows of the primary matrix to its left. Starting at the extreme left and reading across a row, one can outline the distributional pattern of a sector's output. For example, from matrix 1, one may envision sector A discharging output to itself, to other endogenous economic sectors and to final demand sectors. Data in the same row in matrix 2 indicate that the sector also discharges wastes. A third matrix, with its columns aligned with those of the primary matrix, appears directly below it. This matrix incorporates data on environmental resource use; each row corresponds to a specific natural resource and each column corresponds to an economic sector. Thus, starting at the extreme top and reading down a column, one can observe the inputs required by a sector to produce its output. For example, reference to matrix 1 makes evident that sector A receives inputs from itself and other economic sectors, but data in column A of matrix 3 indicate that it requires inputs from the environment as well. In this case, only water is accounted for. Thus, the interactions existing between the environment and the economy can be systematically accounted for within this scheme.

The model can be condensed into two matrices by incorporating the data contained in matrices 2 and 3 to form a new matrix containing all environmental goods. Discharges to the environment (wastes) are then given negative values. A simple mathematical formulation follows.

Assume a basic interindustry flow matrix with each cell containing a dollar value represented by X_{ij}.

$$\begin{matrix} X_{11} & \cdots & X_{1j} \\ \vdots & & \vdots \\ X_{i1} & \cdots & X_{ij} \end{matrix}$$

From this matrix, technical coefficients can be calculated in this manner:

$$\frac{X_{ij}}{X_j} = a_{ij} \quad (i,j = 1 \ldots n)$$

The matrix of technical coefficients is a square matrix of n by n dimensions where n is the number of endogenous economic sectors.

$$\begin{matrix} a_{11} & \cdots & a_{1n} \\ \vdots & & \vdots \\ a_{n1} & \cdots & a_{nn} \end{matrix}$$

Total output and final demand values are depicted as two distinct column vectors each of the dimension n by 1.

Total Output = X = X_1 Final Demand = Y = Y_1

$$X = \begin{matrix} X_1 \\ \cdot \\ \cdot \\ \cdot \\ X_n \end{matrix} \qquad Y = \begin{matrix} Y_1 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{matrix}$$

Assume also an environmental matrix similar to the one just discussed which contains both positive and negative values. Its dimensions would be m by n where m equals the number of environmental parameters under review and n is again the number of endogenous sectors. Coefficients within this matrix are expressed in pounds or gallons per dollar of output.

A generalized form of an environmental matrix follows:

$$\begin{matrix} E_{11} \ldots\ldots\ldots\ldots E_{1n} \\ \cdot \\ \cdot \\ \cdot \\ E_{m1} \ldots\ldots\ldots\ldots E_{mn} \end{matrix}$$

By definition, total output equals intermediate demands plus final demand. In matrix form, the equation is:

$$X = AX + Y$$

However, each sector is recognized as producing not only economically viable output, but also a whole host of negative environmental goods. Thus, total output for any specific sector should be thought of as containing a subset of different types of output. This can be represented by the equation:

$$X = AX + Y + E$$

Performing matrix algebra on this equation produces:

$$(1)\ X - AX = Y + E$$

$$(2)\ X[I - A] = Y + E$$

$$(3)\ X = [I - A]^{-1} Y + E [I - A]^{-1}$$

In equation three $[I - A]^{-1}$ is the matrix of interdependency coefficients and $[I - A]^{-1} Y$ shows the total production of economic output after taking into account the structural interdependencies of the different economic sectors. The total production of byproducts is indicated by $E [I - A]^{-1}$.

Environmental Data

The application of the model discussed above requires that direct environmental coefficients be specified.[6] These values should reflect the direct input or output to or from the environment per dollar of output by each of the endogenous economic sectors. Initially, it was hoped that secondary data could be used (1,2,3). Unfortunately, coefficients reported in other regions often were not applicable to the Narragansett Bay model because of differences in sector aggregations. Consequently, primary sources were used extensively in the development of these coefficients. The methodologies follow.

Permit applications

The permit applications required under the Federal Refuse Act provide a relatively new source of data on wastes entering navigable waters (7). One of the first steps was to convert the permit data, which were either expressed as a measure of weight per unit of time, or level of concentration, to pounds per dollar of output.

First, each firm submitting a permit application was identified by Standard Industrial Classification (SIC) number and then assigned to its respective sector. Because employment in the firm and in the sector, as well as the sector's total output, were known, the firm's output was estimated by utilizing an employment ratio.[7] It was then assumed that the firm's output would be proportionate to the sector's in the same way that employment was.

$$\frac{\text{Firm's Output}}{\text{Sector's Output}} = \frac{\text{Firm's Employment}}{\text{Sector's Employment}}$$

Combining output data and effluent data converted to pounds then resulted in the calculation of a coefficient reflecting pounds of waste loading per dollar of output.

Typically, a sample of several firms comprising a minimum of 40 percent of a sector's output was

[6] *Appendix table 1 indicates the sources of effluent data for all the sectors of the model.*

[7] *(A) Employment in the firm is specified on the permit applications; (B) employment in the sector can be estimated from unpublished data provided by the Rhode Island Department of Employment Security, and (C) total output by sector can be calculated from Census of Manufacturing and Business etc. (see References).*

available to calculate sector coefficients. In these instances, the final coefficient for each parameter was calculated as an average of the reporting firms, each weighted by its respective outputs. There were cases, however, where data for a sector were limited to just one firm. The decision to use the data was then based on the firm's importance relative to the sector. A coverage factor of at least 20 percent was deemed necessary to extrapolate coefficients for the entire sector. It is recognized that the samples used throughout this analysis are consistently small; however, the number of Rhode Island firms submitting usable detailed applications was such that larger samples were not possible.

There are, of course, many variables which may cause distortions between calculated and actual coefficients. For example, each sector can be a highly aggregated unit with many different production processes and products coexisting. To some extent, the weighting procedure handles this. In addition, different firms may be operating with varying levels of in-plant treatment, and if the sample is biased in this respect, the coefficients will be biased. The use of this data is based on the assumption that for each sector the sample of firms used is representative of that sector in terms of its mix, its level of treatment and, for that matter, any other characteristic common to an industry. Although some distortions probably exist, there is no reason to conclude that the sample of firms drawn upon is anything other than typical.

After discussing the problem of data quality with officials of the Division of Water Supply and Pollution Control of the Rhode Island Department of Health, the authors concluded that no systematic bias was likely to exist and that, even though there are concerns about accuracy, permit applications constituted the best available source of data on waste loadings.[8]

The permit applications provided the source for coefficients for more than 33 percent of the economic sectors specified in the model. More important, those sectors are the most critical industries in generation of waterborne wastes.[9] In addition, the level of detail far exceeds what is available from other sources with as many as 28 specific parameters quantified for individual sectors. In most instances, the number of coefficients developed per sector averages 15 to 20.

Similar economic sectors

Similarities exist among certain sectors and, in some cases, coefficients already developed have application to some of these industries.

A review of the sectors revealed five manufacturing activities for which data could be extrapolated from previously developed coefficients. This source also was used to supply data for parts of four other sectors. The sectors are identified in Appendix table 1.

Per capita effluent loadings

Use of permit data and extrapolation from similar industries still left two manufacturing sectors and most of the nonmanufacturing sectors without residual coefficients. For all but one of these sectors, four parameters were calculated based on per-capita-per-day values for human wastes. For the nonmanufacturing sectors, human wastes probably constitute the bulk, if not all, of the waterborne wastes generated; however, this is certainly not the case for the manufacturing sectors. Unfortunately, no other data could be uncovered for these industries and, consequently, the waste loadings are somewhat understated. However, these two sectors, agriculture and maintenance, are not economically significant to the region.

For human wastes, secondary data were converted into four basic residual parameters. The values appearing in table 3 reflect the average number of grams discharged per day.

The conversion of these values to coefficients consistent with the matrix of direct loadings was accomplished by assuming waste generation to be a linear function of time.

To test the effect of possible inaccuracies in effluent data, percentage fluctuations of up to 100 percent were applied to coefficients in selected sectors in the matrix of direct waste loadings. Matrices further on in the analysis were, of course, affected but the percentage changes in these coefficients were on

[8] *Klazer, P. and H. Boghosian of the Rhode Island Department of Health, Division of Water Supply and Pollution Control, interview, Providence, Rhode Island, Dec. 1972.*

[9] *U.S. Department of the Army, Corps of Engineers, Permit Application Form 4345-1 (Washington, D.C.: U.S. Government Printing Office, 1972), p. 3.*

Table 3. Per capita per day human wastes.[*]

$B.O.D._5$	64.8 grams†
Total solids	250.0 grams
Suspended solids	90.0 grams
Dissolved solids	160.0 grams

[*] *Fair, G. M. and J. C. Geyer,* Water Supply and Waste Disposal *(New York: John Wiley and Sons, 1956), p. 563.*

† *64.8 grams represent an average of two different estimates given for the same value. $B.O.D._5$ is reported as 54 grams in the source cited in the above footnote and is calculated at 75.6 grams. Source: U.S., Department of the Interior,* The Cost of Clean Water, *Vol. I,* Summary Report *(Washington, D.C.: Government Printing Office, 1968), p. 21.*

the whole significantly less than the initial change. If, for example, direct coefficients in a typical sector were adjusted upward by 50 percent, the matrix of direct and indirect linkages per dollar change in final demand and the matrix of direct and indirect linkages per dollar of local income would reflect increases varying from 0-40 percent. Most coefficients varied less than 5 percent, but for those in which the direct component was significantly large relative to the indirect contribution, increases of 30-40 percent were registered.

Analysis of the Data

Waste from Present Economy

Direct Loadings

It is now possible to construct the matrix of direct waste loadings, which provides the basic effluent data in a form acceptable to the economic model. The matrix has 59 columns and 37 rows.[10] This matrix may be reduced considerably by adding vertically, but such simplification may destroy its usefulness. That is to say, 500 pounds of alkalinity may not in a given place constitute pollution, but an equal amount of nitrogen might. Table 4 should be examined with this warning in mind.

Each sector in table 4 is assigned a value of 1 to 8 to designate its relative importance as a contributor of waterborne waste loadings. The industries with a ranking of 1 are among the five heaviest direct generators of wastes, while those with a ranking of 8 are among the five smallest. The table also shows the number of pounds generated per dollar of output and ranks this value in a similar fashion. The two approaches produce somewhat different results, because in the second column each sector is divided by its level of economic output, and this varies widely among sectors. For example, sector 9 (lumber and wood products) has a ranking of 1 in wastes generated per dollar of output, but is ranked only 3 as a contributor to total waste loadings. This occurs because very little of this type of activity takes place in the region. For the 40 sectors reviewed in this table, 22, or 55 percent, have similar shifts in rank.

Direct and Indirect Loadings

Multiplying the table of direct waste loadings by the table of interdependency coefficients produces a matrix of direct and indirect waste generation. This matrix shows how economic interactions affect the generation of by-products. The causality implied here is that each sector demands inputs from other sectors within the region, some of which are major contributors of residuals. In order for the given sector to increase output, activity in these supplying sectors must also increase, producing waste elements without which the sector could not increase output. These indirect emissions often increase manyfold a sector's direct emissions. As a result, many economic activities that directly discharge no more than a few pounds of residuals per 1,000 dollars of output are in actuality stimulating the generation of hundreds of pounds of by-products for that same level of economic activity. The results of such a comparison for emissions per 1,000 dollars appear in table 5.

Waste Generation Related to Income Generation

The analysis so far depicts total waste loadings related to output. A more meaningful comparison would relate the flow of direct and indirect waste loadings to local income. This would permit the regional benefits of economic activity to be contrasted with the related output of waterborne wastes.

In order to develop this matrix, one must use the local income multipliers from the matrix of interdependency coefficients. Each multiplier equals the total local income (direct, indirect and induced) generated as a result of a one dollar increase in that sector's output. These values are reproduced in Appendix table 2. The local income multipliers are then divided into the direct and indirect linkages (table 5, column 2) to show the relationship between the generation of income and of specific wastes.

Table 6 shows the "waste-income tradeoffs." For example, for the construction and mining sector, dividing table 5, column 2 (239) by the value for this sector in Appendix table 2 (.755326) yields 317 as listed in table 6. In other words, each 1,000 dollars of personal income generated by construction and mining also generates 317 pounds of waterborne waste. Without further waste treatment, if society wants the income, it must also take the waste.

In table 6 all manufacturing and selected nonmanufacturing sectors are ranked in an ascending order based on their composite waterborne waste loadings per 1,000 dollars of local income generated by each. Among sectors wide disparities exist in waste loadings per 1,000 dollars of income. Such differences are important considerations in planning for the industrial development of a region, although it should be repeated that the values in table 6 represent a summation of the many residuals reported for each sector. These values may contain double counting and different chemical elements,

[10] *The complete matrices—3 that were 60 x 60 and 3 that were 37 x 59—are not reproduced here. Individuals who are interested in that level of detail may proceed as in footnote number 5.*

Table 4. Composite of all waterborne wastes generated by selected sectors—absolute and per dollar amounts.*

Ranking	Millions of Pounds	Sector	Pounds Per Dollar of Output	Ranking
1	722.92	Chemicals, drugs and paints	8.544	1
1	386.67	Paper and allied products	9.618	1
1	264.31	Electric, gas and sanitary services	2.255	1
1	251.84	Residential households	0.101	3
1	229.07	Primary iron and steel manufacturing	4.012	1
2	168.79	Hotels and personal services (laundries)	2.048	2
2	131.66	Apparel	1.767	2
2	89.60	Food and kindred products	0.538	3
2	83.06	Miscellaneous textile products	1.188	2
2	39.96	Broad and narrow fabrics	0.158	3
3	25.34	Lumber and wood products	2.345	1
3	19.26	Plastics and synthetics	0.485	3
3	13.40	Miscellaneous fabricated textile products	0.957	2
3	10.66	Petroleum refining and related industries	0.881	2
3	6.71	Glass, stone and clay products	0.124	3
4	6.19	Electric lighting and wiring equipment	0.047	4
4	3.97	Other miscellaneous manufacturing	0.056	4
4	2.97	Electric machinery	0.030	4
4	2.67	United States Navy	0.012	4
4	2.65	Construction and mining	0.008	6
5	2.35	Primary nonferrous metal manufacturing	0.006	6
5	2.22	Paperboard cartons and boxes	0.077	4
5	1.74	Rubber and miscellaneous plastics	0.011	5
5	1.48	Heating, plumbing and other metal products	0.010	6
5	0.63	Scientific controlling equipment	0.011	5
6	0.57	Stamp, screw, and bolt products	0.010	5
6	0.38	Electronic components	0.011	5
6	0.28	Printing and publishing	0.003	8
6	0.27	Metalworking machinery and equipment	0.003	7
6	0.21	Jewelry manufacturing	0.001	8
7	0.19	Optical and photographic equipment	0.011	5
7	0.14	Leather products	0.004	6
7	0.13	Special industry equipment	0.001	8
7	0.06	Motor vehicles and equipment	0.004	7
7	0.06	Other transportation equipment	0.006	6
8	0.05	General industrial equipment	0.003	7
8	0.04	Machine shop products	0.002	8
8	0.04	Furniture and fixtures	0.003	8
8	0.02	Equipment and machines (not elsewhere classified)	0.003	7
8	0.002	Aircraft and parts	0.003	7

* *Total pounds of waste should not be used as direct measure of pollution. The damage caused by waste production in an aquatic environment depends on the specific composition of the waste and on the nature of the environment.*

and have varying degrees of environmental significance due to the different composition of wastes within each sector. Thus, a better approach would be to view each residual separately.

An analysis by specific residual can be performed by viewing each row in the matrix of waste interdependencies separately (matrix not reproduced here). As an example, such an analysis was performed for B.O.D. per 1,000-dollar change in local income. The selection of B.O.D. is predicated on its common use as an environmental index. The results appear in table 7.

A comparison of tables 6 and 7 points out one of the dangers in using composite waste loading val-

Table 5. Comparison of direct emissions with direct and indirect emissions per $1000 of output for all manufacturing and selected nonmanufacturing sectors.*

Sector	Pounds Generated Per $1000 of Output: Direct Emissions	Pounds Generated Per $1000 of Output: Direct and Indirect Emissions	Absolute Change
Construction and mining	8	239	231
Food and kindred products	538	673	135
Broad and narrow fabrics	158	621	463
Miscellaneous textile goods	1188	1361	173
Apparel	1767	1936	169
Miscellaneous fabricated textile products	957	1161	204
Lumber and wood products	2345	2934	589
Furniture and fixtures	3	304	301
Paper and allied products	9618	9748	130
Paperboard containers and boxes	77	767	690
Printing and publishing	3	189	186
Chemicals, drugs, and paints	8544	8740	196
Plastics and synthetics	485	587	102
Petroleum refining and related industries	881	1088	207
Rubber and miscellaneous plastics	11	163	152
Leather	4	377	373
Glass, stone and clay	124	406	282
Primary iron and steel	4012	4214	202
Primary nonferrous metal manufacturing	6	120	114
Heating, plumbing, and other metal products	10	249	239
Stamp, screw and bolt products	10	564	554
Equipment and machines	3	278	275
Metal working machinery and equipment	3	215	212
Special industry machinery	1	177	176
General industrial equipment	3	231	228
Machine shop equipment	2	267	265
Electric machinery	30	219	189
Electric lighting and wiring equipment	47	246	199
Electronic components	11	196	185
Motor vehicles and equipment	4	304	300
Aircraft and parts	3	231	228
Other transportation equipment	6	307	301
Scientific controlling equipment	11	316	305
Optical and photographic equipment	11	228	217
Jewelry	1	132	131
Other miscellaneous manufacturing	56	273	217
Electric, gas, and sanitary services	2255	2474	219
Hotels and personal services	2048	2344	296
U.S. Navy	12	346	334
Residential households	101	335	234

* *Total pounds of waste should not be used as direct measure of pollution. The damage caused by waste production in an aquatic environment depends on the specific composition of the waste and on the nature of the environment.*

ues. For example, economic activity in the primary iron and steel sector results in 7,525 pounds of wastes, the third highest level of total loadings per 1,000 dollars of income. However, of that amount only 49 pounds is identified as B.O.D. which, when compared to other sectors, is a relatively low level. Thus, whenever interest is directed toward a specific parameter, such as a type of toxic metal or a particular nutrient, a correct approach is to evaluate only coefficients corresponding to that residual.

Table 6. Total waterborne waste accompanying each 1000 dollars of local income for all manufacturing sectors and selected nonmanufacturing sectors.*

Sector	Pounds Resulting from $1000 of Local Income
Jewelry manufacturing	267
U.S. Navy	270
Printing and publishing	285
Metalworking machinery and equipment	297
Aircraft and parts manufacturing	297
Maintenance and repair	306
Special industrial machinery	315
Construction and mining	317
Electronic components	348
Controlling and scientific instruments	354
Machine shop products	359
Rubber and miscellaneous plastics	363
Optical and photographic equipment	364
Agriculture	380
Primary nonferrous metals	392
Heating, plumbing and other metal products	399
General industrial machinery	408
Equipment and machines	448
Electric machinery	512
Other miscellaneous manufacturing	520
Furniture and fixtures	522
Glass, stone and clay products	641
Electric lighting and wiring equipment	643
Motor vehicle equipment	647
Leather	835
Stamp, screw and bolt products	870
Other transportation equipment	948
Paperboard containers and boxes	1317
Broad and narrow fabrics	1364
Plastics and synthetics	1517
Food and kindred products	1626
Miscellaneous textile goods	2706
Miscellaneous fabricated textile products	2751
Petroleum refining and related industries	3150
Electric, gas, water and sanitary services	3359
Hotels: personal services	4030
Apparel	4288
Lumber and wood products	4858
Primary iron and steel	7525
Chemicals, drugs and paints	22107
Paper and allied products	22347

* *Total pounds of waste should not be used as an index of pollution. The damage caused by waste production in an aquatic environment depends on the specific composition of the waste and on the nature of the environment.*

Table 7. Biochemical oxygen demand (B.O.D.) accompanying 1000 dollars of local income generated by manufacturing sectors and selected nonmanufacturing sectors.

Sector	Pounds of B.O.D. Resulting from $1000 of Local Income
Special industry machinery	32
Jewelry manufacturing	33
Construction and mining	33
Machine shop products	33
Electric, gas, water and sanitary services	33
Maintenance and repair	34
Electronic components	34
U.S. Navy	34
Metalworking machinery and equipment	35
General industrial machinery	35
Aircraft and parts	35
Rubber and miscellaneous plastics	35
Controlling and scientific instruments	36
Optical and photographic equipment	36
Stamp, screw, and bolt products	36
Printing and publishing	36
Equipment and machinery	37
Electrical machinery	37
Electric lighting and wiring equipment	37
Primary nonferrous metals	37
Agriculture	38
Petroleum refining and related industries	38
Motor vehicles and equipment	39
Other miscellaneous manufacturing	41
Heating, plumbing and other metal products	46
Glass, stone and clay products	47
Primary iron and steel	49
Leather products	51
Plastics and synthetics	110
Hotels: personal repairs and services	116
Furniture and fixtures	131
Paperboard boxes and containers	183
Broad and narrow fabrics	198
Apparel	199
Other transportation equipment	227
Miscellaneous fabricated textile products	238
Miscellaneous textile goods	240
Chemicals, drugs and paints	449
Food and kindred products	549
Paper and allied products	555
Lumber and wood products	2711

From table 7 it can be seen that in terms of B.O.D. as related to income, industries based on metals and electronics are fairly clean, whereas those based on textiles, chemicals, food processing, and paper, with wood products the worst offender by far, are the "dirtiest."

Sources of Specific Residuals

Table 8 lists each waste parameter individually with respect to the amounts generated directly and indirectly per one dollar of final demand. For each waste, a maximum of five economic sectors are listed whose activity results in the greatest amounts of that particular waste. Each sector's contribution is depicted as a percentage of the total direct and indirect emissions accompanying a general one dollar expansion in final demand. For any given residual, the percentage value of the sum of the five highest sectors lies between 50 percent and 100 percent. Moreover, for 13 of these effluents, a one dollar expansion in final demand in just one economic sector results in over 50 percent of the total amount that would be generated from an across-the-board, one dollar expansion in sales.

In this respect, most significant are, for example, sector 16 (petroleum refining and related industries) and turbidity—92.90 percent; sector 19 (glass, stone, and clay products) and lead—91.44 percent, and sector 14 (chemicals, drugs, and paints) and acidity —86.20 percent. Interestingly, this table makes evident that many sectors not previously recognized as significant overall dischargers at a per-unit level

Table 8. Percent distribution of direct and indirect waste loadings associated with a general identical increase in final demand, by type of emission.

Biochemical Oxygen Demand$_5$		*Chemical Oxygen Demand$_5$*	
Lumber & wood products	39.26%	Lumber & wood products	53.01%
Paper & allied products	5.81%	Primary iron & steel	11.83%
Food & kindred products	5.45%	Misc. textile goods	5.77%
Chemicals, drugs etc.	4.26%	Chemicals, drugs etc.	5.29%
Misc. textile goods	2.90%	Apparel	3.69%
Ultimate Oxygen Demand		*Total Solids*	
Paper & allied products	67.52%	Paper & allied products	19.02%
Chemicals, drugs etc.	9.93%	Primary iron & steel	12.87%
Petroleum refining & related industries	6.85%	Chemicals, drugs etc.	7.62%
Plastics & synthetics	4.52%	Hotels & personal services	7.14%
Paperboard cartons & boxes	3.05%	Electric, gas, water & sanitary services	5.94%
Suspended Solids		*Dissolved Solids*	
Paper & allied products	24.13%	Primary iron & steel	15.82%
Lumber & wood products	16.92%	Paper & allied products	14.26%
Chemicals, drugs etc.	10.91%	Hotels & personal services	8.64%
Primary iron & steel	5.25%	Electric, gas, water & sanitary services	8.40%
Plastics & synthetics	4.66%	Chemicals, drugs etc.	5.02%
Volatile Solids		*Alkalinity*	
Electric, gas, water & sanitary services	22.35%	Apparel	20.61%
Hotels & personal services	15.44%	Primary iron & steel	14.98%
Primary iron & steel	5.68%	Petroleum refining & related industries	10.57%
Chemicals, drugs etc.	4.01%	Chemicals, drugs etc.	9.13%
Apparel	3.23%	Misc. textile goods	6.06%
Acidity		*Chloride*	
Chemicals, drugs etc.	86.20%	Chemicals, drugs etc.	39.95%
Broad & narrow fabrics	3.18%	Primary iron & steel	25.98%
Other transportation equipment	1.39%	Apparel	9.92%
Paperboard cartons & boxes	1.13%	Stamp, screw & bolt products	2.25%
Motor vehicles & equipment	1.06%	Broad & narrow fabrics	1.72%
Oil & Grease		*Ammonia*	
Misc. textile goods	42.80%	Glass, stone & clay	40.15%
Misc. fabricated textile goods	22.46%	Chemicals, drugs etc.	32.57%
Primary iron & steel	11.24%	Primary iron & steel	5.67%
Petroleum refining & related industries	6.13%	Misc. fabricated textile goods	4.39%
Apparel	5.97%	Apparel	4.35%

Table 8—*Continued*

Kjeldahl Nitrogen	
Apparel	37.75%
Misc. fabricated textile goods	37.42%
Chemicals, drugs etc.	11.29%
Primary iron & steel	8.28%
Stamp, screw & bolt products	0.77%

Phosphorus	
Apparel	31.14%
Misc. fabricated textile goods	30.90%
Chemicals, drugs etc.	13.34%
Hotels & personal services	6.09%
Primary iron & steel	2.42%

Organic Carbon	
Chemicals, drugs etc.	36.43%
Apparel	26.50%
Misc. fabricated textile goods	26.33%
Broad & narrow fabrics	1.35%
Electric lighting & wiring equipment	1.23%

Aluminum	
Chemicals, drugs etc.	67.68%
Other misc. manufacturing	9.39%
Electric, gas, water & sanitary services	3.78%
Broad & narrow fabrics	2.56%
Construction & mining	1.46%

Copper	
Chemicals, drugs etc.	60.45%
Other misc. manufacturing	16.97%
Primary iron & steel	8.40%
Broad & narrow fabrics	2.22%
Office supplies	1.59%

Lead	
Glass, stone & clay	91.44%
Chemicals, drugs etc.	2.31%
Maintenance & repair	1.48%
Construction & mining	0.71%
State & local government enterprises	0.34%

Nickel	
Other misc. manufacturing	61.99%
Chemicals, drugs etc.	15.76%
Office supplies	5.40%
Electric, gas, water & sanitary services	3.05%
Controlling & scientific instruments	1.26%

Sodium	
Chemicals, drugs etc.	37.31%
Apparel	28.08%
Misc. fabricated textile goods	27.91%
Broad & narrow fabrics	1.37%
Other transportation equipment	0.60%

Hardness	
Apparel	45.10%
Misc. fabricated textile goods	44.69%
Stamp, screw & bolt products	4.28%
Heating, plumbing & other metal products	4.15%
General industrial machinery	0.25%

Nitrate	
Primary iron & steel	70.48%
Stamp, screw & bolt products	5.84%
Chemicals, drugs etc.	2.68%
Electric lighting & wiring equipment	2.52%
Other misc. manufacturing	1.83%

Sulfate	
Chemicals, drugs etc.	47.46%
Apparel	15.37%
Misc. fabricated textile goods	15.35%
Primary iron & steel	8.97%
Broad & narrow fabrics	1.75%

Organic Nitrogen	
Apparel	40.66%
Misc. fabricated textile goods	40.31%
Chemicals, drugs etc.	14.33%
Other misc. manufacturing	1.48%
Broad & narrow fabrics	0.53%

Calcium	
Chemicals, drugs etc.	49.53%
Other misc. manufacturing	18.00%
Rubber & misc. plastics	6.96%
Misc. fabricated textile goods	3.93%
Apparel	3.86%

Iron	
Primary iron & steel	51.60%
Chemicals, drugs etc.	29.19%
Stamp, screw & bolt products	4.13%
Glass, stone & clay	3.95%
Machinery except electrical	1.25%

Magnesium	
Apparel	36.42%
Misc. fabricated textile goods	36.11%
Chemicals, drugs etc.	16.88%
Electric machinery	3.67%
Electronic components	3.65%

Potassium	
Chemicals, drugs etc.	75.13%
Misc. fabricated textile goods	6.67%
Apparel	6.54%
Broad & narrow fabrics	2.75%
Other transportation equipment	1.21%

Zinc	
Chemicals, drugs etc.	41.99%
Glass, stone & clay products	37.99%
Misc. fabricated textile goods	4.45%
Apparel	4.39%
General industrial machinery	1.90%

Turbidity	
Petroleum refining & related industries	92.90%
Construction & mining	1.99%
Transportation & warehousing	0.52%
Maintenance & repair	0.28%
Business travel, gifts	0.24%

Table 8—*Continued*

Sulfide	
Other misc. manufacturing	53.59%
Glass, stone & clay products	33.23%
Office supplies	4.67%
Controlling & scientific instruments	1.09%
Jewelry	0.89%
Fluoride	
Stamp, screw & bolt products	45.13%
Heating, plumbing & other metal products	43.82%
General industrial machinery	2.50%
Lumber & wood products	1.84%
Other transportation equipment	0.79%
Phosphorus Ortho	
Electric machinery	38.06%
Electric lighting & wiring equipment	38.06%
Jewelry	23.88%
Chromium	
Glass, stone & clay products	84.75%
Controlling & scientific instruments	3.40%
Optical & photographic equipment	3.32%
Electric lighting & wiring equipment	1.74%
Electric machinery	1.66%
Arsenic	
Stamp, screw & bolt products	47.62%
Heating, plumbing & other metal products	47.62%
General industrial machinery	4.76%

do, in actuality, contribute sizable per-unit percentages for specific residuals. For example, table 5, sector 37 (jewelry manufacturing) shows the second lowest composite direct and indirect loadings per 1,000 dollars of output. However, given the same expansion in output, table 8 shows it to be a major contributor of phosphorus ortho. Similarly, sector 22 (heating, plumbing, and other metal products) is ranked 28th among the 40 sectors reported in table 5 for total direct and indirect loadings per 1,000 dollars of output; nevertheless, its activity results in over 40 percent of the fluoride and arsenic that would accrue from a general increase in final demand.

Conclusions

The results of this study suggest that if a particular residual poses a severe threat to water quality in the Bay, then highly discriminatory measures can be very beneficial in reducing its outflow. In fact, table 8 indicates that for any one of 13 residuals specified in this analysis, a single economic sector would be responsible for over 50 percent of the waste from a general increase in output.

Output restrictions are a possible short-run approach to residual abatement. They are not a viable solution, however, if people still demand the products or services formerly produced. A more likely solution is the increased use of various waste reduction programs. Presently, action in this area is being stimulated by the establishment of standards and guidelines under the federal government's National Pollutant Discharge Elimination System. These guidelines typically limit discharges by activity to a standard number of pounds per day or to some concentration value. In some instances, the guidelines require that 80 percent of the wastes be removed prior to entering the water. Obviously, such a thorough system of controls should effectively check residual flows. However, from the point of view of efficiency one must question the desirability of such a program. If a given level of abatement control is deemed desirable, one should seek out the approach that will achieve it at a minimum cost or at the minimum use of resources. The results of the present analysis indicate that most of the direct loadings are attributable to only a few sectors. For example, in table 4 the first five sectors listed generate almost 75 percent of all the waterborne wastes in the Narragansett Bay region. Thus, select controls on these relatively few sectors would go a long way in curbing the outflow of residuals. Also, to the extent that environmental effects of given residuals are rather specific, it would appear that improving water quality can be done most rapidly and probably most cheaply with selective rather than broad controls.

A further advantage is that regulatory agencies should find it less expensive to monitor a selective system than a broad, comprehensive one because only a fraction of the total number of firms would be involved.

It is not possible to be more specific about which solutions would cost least without having good cost data on various means for removing specific residuals from waste water. In some cases, treatment through a municipal system may be most efficient; in other cases, notably those involving residuals not easily removed by primary or secondary treatment or those interfering with bacterial action, the standard could apply to the water entering the treatment plant. This would force the industry itself to "pre-clean" its wastes and make them suitable for standard municipal treatment.

The selectivity of controls takes on additional importance when one considers pollution effects of economic growth. When considering a new industry or firm, or an expansion of existing firms in a given area, an examination of the types of economic-ecological linkages developed in this analysis will often prove useful. The tendency is to look at the given firm, its location, its employment, its water supply and sewage systems and to neglect interdependent enterprises with induced growth. These supportive firms may be located in other communities, and may be unaware that they will be affected by the original industry growth.

In summary, this study cannot provide solutions to problems of determining optimum economic growth and waste treatment systems. For this, additional data are needed such as treatment cost and effectiveness of various systems, and an economic-ecological model which is dynamic and which incorporates treatment systems. However, in addition to providing a first step in that process for a specific watershed, this study directs attention to the concept of "waste multipliers" that follow inexorably on the heels of income multipliers.

Appendix

Appendix table 1. Sources of data for the direct environmental coefficients.

Sector No.	No. of Param-eters	Source	Sector No.	No. of Param-eters	Source	Sector No.	No. of Param-eters	Source	Sector No.	No. of Param-eters	Source
1	4	e	16	11	a,b	31	18	d	46	4	e
2	16	d	17	15	a,b,d	32	4	c	47	4	e
3	4	e	18	6	a,d	33	3	c,f	48	4	e
4	9	a,b	19	20	a,b,d	34	3	d,f	49	4	e
5	10	a,c	20	17	a,d	35	10	a,d	50	4	e
6	9	a	21	15	d	36	10	f	51	4	e
7	22	d	22	16	a,d	37	14	d	52	4	e
8	21	f	23	16	f	38	21	d	53	N/A	
9	4	a,b	24	13	c,d,e,f	39	4	e	54	N/A	
10	5	a,e	25	12	d,f	40	4	e	55	N/A	
11	13	a,d	26	11	d	41	4	e	56	4	e
12	6	a,e	27	9	d	42	17	d	57	0	
13	6	a,e	28	12	f	43	4	e	58	4	e
14	30	a,b,d	29	23	f	44	4	e	59	4	e
15	9	a,c	30	23	d	45	8	d			

Sources: a—(1), b—(2), c—(3), d—(4) permits, e—per-capita waste loadings, f—extrapolation based on similarity of sectors.

Appendix table 2. Dollars of local personal income generated by a one dollar increase in output, by sector (interdependency coefficients, row 59).

1	Agriculture	.735487	31	Electronic components	.564882
2	Construction & mining	.755326	32	Motor vehicles & equipment	.472165
3	Maintenance & repair	.747222	33	Aircraft & parts	.775685
4	Food & kindred products	.414298	34	Other transportation (boats)	.327223
5	Broad & narrow fabrics	.456410	35	Controlling & scientific instruments	.633555
6	Miscellaneous textile goods	.502560	36	Optical & photographic equipment	.631300
7	Apparel	.451479	37	Jewelry	.498130
8	Misc. fabricated textile goods	.421672	38	Other misc. manufacturing	.529483
9	Lumber & wood	.603899	39	Transportation & warehousing	1.011218
10	Furniture & fixtures	.586302	40	Communications less radio & TV	.984629
11	Paper & allied products	.436290	41	Radio and TV broadcasting	.624351
12	Paperboard boxes & containers	.582272	42	Electric, gas, water & sanitary services	.737286
13	Printing & publishing	.669705	43	Wholesale & retail trade	.955860
14	Chemicals, drugs & paints	.395551	44	Finance, insurance & real estate	.402440
15	Plastics & synthetics	.448720	45	Hotels: personal services	.581364
16	Petroleum refining & related industries	.345356	46	Business services	.636471
17	Rubber & miscellaneous plastics	.449729	47	Research & development	.485877
18	Leather	.452901	48	Automobile repair & services	.500775
19	Glass, stone & clay products	.607729	49	Amusements	.419299
20	Primary iron & steel	.560154	50	Medical, education & non-profit organizations	.842777
21	Primary nonferrous metals	.307509	51	Federal government enterprises	.841951
22	Heating, plumbing & other metal products	.628737	52	State & local government enterprises	.941230
23	Stamp, screw & bolt products	.650680	53	Imports	0
24	Equipment & machines	.621363	54	Business travel, gifts & entertainment	.567566
25	Metalworking machinery & equipment	.730204	55	Office supplies	.164017
26	Special industrial machinery	.568702	56	Government industry	1.362813
27	General industrial machinery	.570463	57	Household industry	1.362813
28	Machine shop products	.745239	58	U.S. Navy	1.282042
29	Electric machinery	.430627	59	Personal consumption	1.362813
30	Electric lighting & wiring equipment	.383464			

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