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AIR, WATER, AND SOLID RESIDUE PRIORITIZATION MODELS FOR CONVENTIONAL COMBUSTION SOURCES

Industrial Environmental Research Laboratory
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AIR, WATER, AND SOLID RESIDUE PRIORITIZATION MODELS FOR CONVENTIONAL COMBUSTION SOURCES

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PREFACE

The Industrial Environmental Research Laboratory (IERL) of EPA has the responsibility for insuring that pollution control technology is available for stationary sources. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then development of the needed control techniques is conducted. IERL has the responsibility for developing control technology for a large number (>500) of operations in the chemical and related industries. As in any technical program the first step is to identify the unsolved problems.

Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology. Monsanto Research Corporation (MRC) has contracted with EPA (Contract 68-02-1874) to investigate the environmental impact of various industries which represent sources of emissions in accordance with EPA's responsibility. Dr. Robert C. Binning serves as Program Manager in the program entitled, "Source Assessment." MRC has developed a priority listing of the industries in each of four categories (combustion, organic materials, inorganic materials, and open sources) based on the environmental impact of air emissions. This listing serves as one of several guides in the selection of those sources for which detailed source assessments will be performed. Source assessment documents are being produced by MRC and used by EPA to make decisions regarding the need for developing additional control technology for each specific source.

The work described in this report was performed in partial support of the Source Assessment program. Mathematical models were developed to relatively rank the environmental impact of air, water and solid residue emissions. These models were applied to conventional stationary combustion sources and the resulting relative ranking is intended to serve as one of several guides in selecting specific sources for detailed assessment.

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SECTION I

INTRODUCTION

This report includes a general description of air, water, and solid residue prioritization models used for the relative ranking of a selected set of combustion sources. Sensitivity analyses show how the prioritization model responds to changes in input. The models are applied to conventional stationary combustion sources, and the resulting relative prioritizations are presented. Computation of a relative environmental impact factor for each emission source provides the basis for each relative ranking.

No attempt, in any fashion, is made to relate industrial emissions to their effect on public health. Based upon a set of common assumptions, which are clearly identified, the model provides a relative rank ordering (within the framework of these assumptions) of stationary sources of air, water, and solid residue emissions.

It must be understood that the prioritization models are at best a "first-cut" attempt at the rank ordering of numerous source types on the basis of the potential burden they place on their environment. In the water model, for example, the potential burden is expressed as a mass ratio of a discharged material relative to a hazard potential factor which in turn, for this particular case, is based on a drinking water standard.

SECTION II

SUMMARY

Mathematical models were developed to relatively rank the environmental impact of water and solid residue emissions. An air prioritization model, derived in an earlier effort,[1] was utilized in this study. The water model is similar to the air model and is based on mass of emission, hazard potential of the emission, ambient water loading, and population density in the emission region. Solid emissions were divided into an air emission (wind erosion) component and a water emission (leaching) component, and these contributions were incorporated into the air and water prioritization models.

The models were applied to 56 conventional stationary combustion sources as defined by GCA Corporation.[2] The GCA report was the primary source of input data for the models. The resulting relative rankings are presented in Figures 1 and 2.

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[1]Eimutis, E. C. Source Assessment: Prioritization of Stationary Air Pollution Sources--Model Description. Monsanto Research Corporation. Dayton. Report No. MRC-DA-508. U.S. Environmental Protection Agency, EPA-600/2-76-032a. February 1976. 77 p.

[2]Surprenant, N., R. Hall, S. Stater, T. Suza, M. Sussman and C. Young. Preliminary Environmental Assessment of Conventional Stationary Combustion Sources, Vol. I. GCA Corporation. EPA Contract 68-02-1316, Task 11. Bedford. GCA-TR-75-26-G(1) (revised draft of final report). Environmental Protection Agency. September 1975.

RANK	ID CODE	SOURCE TYPE	IMPACT FACTOR
1	4.1.12.0.0	RESIDENTIAL EXT COMB ANTHRACITE	500,000,000
2	4.1.11.0.0	RESIDENTIAL EXT COMB BITUMINOUS	300,000,000
3	4.1.22.0.0	RESIDENTIAL EXT COMB DIST OIL	200,000,000
4	4.1.30.0.0	RESIDENTIAL EXT COMB GAS	100,000,000
5	1.1.11.1.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV DRY BOTM	30,000,000
6	3.1.21.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB RESID OIL OTHER	10,000,000
7	4.1.42.0.0	RESIDENTIAL EXT COMB WOOD	8,000,000
8	3.1.22.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB DIST OIL OTHER	7,000,000
9	2.1.21.0.2	INDUSTRIAL EXT COMB RESID OIL OTHER	7,000,000
10	1.1.11.2.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV WET BOTM	5,000,000
11	1.1.11.3.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS CYCLONE	5,000,000
12	1.3.22.0.0	ELECTRICITY GENERATION INT COMB DIST OIL TURBINE	4,000,000
13	2.1.11.1.0	INDUSTRIAL EXT COMB BITUMINOUS PULV DRY BOTM	3,000,000
14	2.1.30.0.2	INDUSTRIAL EXT COMB GAS OTHER	3,000,000
15	2.4.30.0.0	INDUSTRIAL INT COMB GAS RECIP ENG	3,000,000
16	2.3.30.0.0	INDUSTRIAL INT COMB GAS TURBINE	3,000,000
17	1.4.22.0.0	ELECTRICITY GENERATION INT COMB DIST OIL RECIP ENG	3,000,000
18	2.1.11.4.0	INDUSTRIAL EXT COMB BITUMINOUS STOKER	3,000,000
19	3.2.22.0.0	COMMERCIAL/INSTITUTIONAL INT COMB DIST OIL	2,000,000
20	2.4.22.0.0	INDUSTRIAL INT COMB DIST OIL RECIP ENG	2,000,000
21	3.1.30.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB GAS OTHER	2,000,000
22	2.1.22.0.2	INDUSTRIAL EXT COMB DIST OIL OTHER	1,000,000
23	1.3.30.0.0	ELECTRICITY GENERATION INT COMB GAS TURBINE	1,000,000
24	3.1.12.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB ANTHRACITE STOKER	1,000,000
25	3.1.11.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS STOKER	900,000
26	2.1.21.0.1	INDUSTRIAL EXT COMB RESID OIL TANG FIRE	800,000
27	2.1.30.0.1	INDUSTRIAL EXT COMB GAS TANG FIRE	800,000
28	2.1.11.2.0	INDUSTRIAL EXT COMB BITUMINOUS PULV WET BOTM	700,000
29	2.3.22.0.0	INDUSTRIAL INT COMB DIST OIL TURBINE	400,000
30	1.4.30.0.0	ELECTRICITY GENERATION INT COMB GAS RECIP ENG	400,000
31	1.1.11.4.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS STOKER	400,000
32	3.2.30.0.0	COMMERCIAL/INSTITUTIONAL INT COMB GAS	400,000
33	4.1.13.0.0	RESIDENTIAL EXT COMB LIGNITE	400,000
34	1.1.21.0.2	ELECTRICITY GENERATION EXT COMB RESID OIL OTHER	400,000
35	2.1.40.0.0	INDUSTRIAL EXT COMB REFUSE	400,000
36	3.1.11.1.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV DRY BOTM	300,000
37	2.1.11.3.0	INDUSTRIAL EXT COMB BITUMINOUS CYCLONE	200,000
38	2.1.22.0.1	INDUSTRIAL EXT COMB DIST OIL TANG FIRE	200,000
39	1.1.21.0.1	ELECTRICITY GENERATION EXT COMB RESID OIL TANG FIRE	200,000
40	1.1.12.4.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE STOKER	100,000
41	2.1.12.4.0	INDUSTRIAL EXT COMB ANTHRACITE STOKER	100,000
42	3.1.21.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB RESID OIL TANG FIRE	100,000
43	3.1.30.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB GAS TANG FIRE	90,000
44	1.1.13.1.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV DRY BOTM	90,000
45	3.1.22.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB DIST OIL TANG FIRE	80,000
46	1.1.12.1.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE PULV DRY BOTM	70,000
47	2.1.13.4.0	INDUSTRIAL EXT COMB LIGNITE STOKER	60,000
48	1.1.30.0.2	ELECTRICITY GENERATION EXT COMB GAS OTHER	30,000
49	1.1.13.2.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV WET BOTM	20,000
50	1.1.13.3.0	ELECTRICITY GENERATION EXT COMB LIGNITE CYCLONE	20,000
51	1.1.13.4.0	ELECTRICITY GENERATION EXT COMB LIGNITE STOKER	20,000
52	1.1.30.0.1	ELECTRICITY GENERATION EXT COMB GAS TANG FIRE	20,000
53	3.1.11.2.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV WET BOTM	10,000
54	1.1.22.0.2	ELECTRICITY GENERATION EXT COMB DIST OIL OTHER	3,000
55	1.1.22.0.1	ELECTRICITY GENERATION EXT COMB DIST OIL TANG FIRE	1,000
56	1.1.40.0.0	ELECTRICITY GENERATION EXT COMB REFUSE	80

Figure 1. Air relative prioritization

Rank	ID code	Source type	Impact factor x 10^3
1	1.1.11.1.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV DRY BOTM	1,000,000
2	2.1.30.0.2	INDUSTRIAL EXT COMB GAS OTHER	600,000
3	1.1.21.0.2	ELECTRICITY GENERATION EXT COMB RESID OIL OTHER	600,000
4	1.1.21.0.1	ELECTRICITY GENERATION EXT COMB RESID OIL TANG FIRE	400,000
5	1.1.11.2.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV WET BOTM	400,000
6	1.1.11.3.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS CYCLONE	400,000
7	1.1.30.0.2	ELECTRICITY GENERATION EXT COMB GAS OTHER	300,000
8	2.1.21.0.2	INDUSTRIAL EXT COMB RESID OIL OTHER	90,000
9	2.1.11.1.0	INDUSTRIAL EXT COMB BITUMINOUS PULV DRY BOTM	90,000
10	1.1.30.0.1	ELECTRICITY GENERATION EXT COMB GAS TANG FIRE	80,000
11	2.1.11.4.0	INDUSTRIAL EXT COMB BITUMINOUS STOKER	70,000
12	2.1.30.0.1	INDUSTRIAL EXT COMB GAS TANG FIRE	70,000
13	1.1.11.4.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS STOKER	20,000
14	2.1.21.0.1	INDUSTRIAL EXT COMB RESID OIL TANG FIRE	20,000
15	2.1.11.2.0	INDUSTRIAL EXT COMB BITUMINOUS PULV WET BOTM	20,000
16	2.1.22.0.2	INDUSTRIAL EXT COMB DIST OIL OTHER	10,000
17	1.1.22.0.2	ELECTRICITY GENERATION EXT COMB DIST OIL OTHER	10,000
18	1.1.22.0.1	ELECTRICITY GENERATION EXT COMB DIST OIL TANG FIRE	7,000
19	2.1.40.0.0	INDUSTRIAL EXT COMB REFUSE	6,000
20	2.1.11.3.0	INDUSTRIAL EXT COMB BITUMINOUS CYCLONE	5,000
21	2.1.22.0.1	INDUSTRIAL EXT COMB DIST OIL TANG FIRE	3,000
22	1.1.13.1.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV DRY BOTM	3,000
23	2.1.12.4.0	INDUSTRIAL EXT COMB ANTHRACITE STOKER	2,000
24	4.1.11.0.0	RESIDENTIAL EXT COMB BITUMINOUS	2,000
25	2.1.13.4.0	INDUSTRIAL EXT COMB LIGNITE STOKER	800
26	4.1.12.0.0	RESIDENTIAL EXT COMB ANTHRACITE	800
27	3.1.12.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB ANTHRACITE STOKER	700
28	1.1.13.2.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV WET BOTM	600
29	1.1.13.3.0	ELECTRICITY GENERATION EXT COMB LIGNITE CYCLONE	600
30	1.1.12.4.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE STOKER	500
31	3.1.11.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS STOKER	500
32	1.1.13.4.0	ELECTRICITY GENERATION EXT COMB LIGNITE STOKER	400
33	1.1.12.1.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE PULV DRY BOTM	300
34	3.1.11.1.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV DRY BOTM	100
35	1.1.40.0.0	ELECTRICITY GENERATION EXT COMB REFUSE	5
36	3.1.11.2.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV WET BOTM	3
37	4.1.13.0.0	RESIDENTIAL EXT COMB LIGNITE	1
38	4.1.42.0.0	RESIDENTIAL EXT COMB WOOD	1

Figure 2. Water relative prioritization

SECTION III

MODEL DEVELOPMENT AND GENERAL STRUCTURE

A. AIR PRIORITIZATION MODEL

1. Model Description

The mathematical model (Equation 1) used to rank the air impacts of the combustion sources is a modified version of the location sensitive source prioritization model.[1]

$$I_{Ax} = \sum_{j=1}^{K_x} P_j \left[\sum_{i=1}^{N} \left(\frac{\bar{\chi}_{ij}}{F_i} \right)^2 \frac{\chi'_{ij}}{S_i} \right]^{1/2} \qquad (1)$$

where I_{Ax} = impact factor, persons/km^2

K_x = number of sources emitting materials associated with source type x

N = number of materials emitted by each source

P_j = population density in the region associated with the j^{th} source, persons/km^2

$\bar{\chi}_{ij}$ = calculated maximum ground level concentration of the i^{th} material emitted by the j^{th} source, g/m^3

F_i = environmental hazard potential factor of the i^{th} material, g/m^3

χ'_{ij} = ambient concentration of the i^{th} material in the region associated with the j^{th} source

S_i = corresponding standard for the i^{th} material (used only for criteria emissions, otherwise set equal to one)

Changes in the modified program include:

- Reading emission rates directly from raw data in tons/yr. (The original source prioritization data contained emission factors having units of pounds of material emitted per ton of fuel consumed.)

- Adding the solids contribution from raw materials and waste piles.

The solids contribution was treated as another emitted material with an emission height of 10 ft and a representative composite TLV.[a]

2. Location Sensitive Calculation

The fuel consumption data were published on a state basis. State emission rates were calculated by apportioning the total U.S. emission rate by fraction of state fuel consumption.

$$Q_{ij} = K_f (ER_i)(SC_j)/(TC) \qquad (2)$$

where Q_{ij} = emission rate, g/s

K_f = conversion factor, tons/yr to g/s

[a] Section II.C.2.d. Open Sources Calculations in Reference 1.

ER_i = U.S. total emission rate of $i^{\underline{th}}$ material, tons/yr

SC_j = state fuel consumption, tons/yr

TC = U.S. total consumption, tons/yr

The impact factor I_{AX} is then calculated by summing over K_x states.

B. WATER PRIORITIZATION MODEL

As in the air prioritization model, the purpose of the water model is to rank order, i.e., prioritize the source types in terms of the burden that the sources place on the environment. The structure of the water model is similar to that of the air model[1] with one exception: the source severity is a ratio of masses rather than concentrations. In the air prioritization model, it was convenient to treat the severity as a ratio of concentrations because the atmosphere can be considered an infinite volume receiving body. In the water model, the receiving body will often be a stream, river, or lake, of finite volume.

1. Mathematical Structure

The water model may accomodate either or both of two types of contributions: (1) direct discharge or leaching of raw materials into a receiving body; and (2) waste storage piles.

For a given emitted species by a specific point source, an effluent mass load is defined initially for only the water portion, X:

$$X = V_D C_D t \tag{3}$$

where V_D = discharge rate, m^3/s

C_D = discharge concentration, g/m^3

$t = 3.1471 \times 10^7$ s/yr

X = yearly water effluent mass loading/ g/yr

An effluent mass load is then defined for the leachable solid portion, Y:

$$Y = S_G f_1 f_2 \tag{4}$$

where Y = mass loading of leachable solid residuals, g/yr

S_G = solid waste generation rate, g/yr

and f_1 and f_2 are defined as follows:

$$f_1 = \alpha e^{\beta R} \tag{5}$$

where R = annual rainfall, m

α and β = dimensionless constants (intended to maintain total solids under 50 g/l)[a]

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[a]Above 50 g/l, the resulting solution would not flow readily.[3] Assuming a maximum annual rainfall of 1.7 m, $\alpha = 1.723 \times 10^{-4}$, $\beta = 1.48$.

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[3]Personal communication. G. Nelson. U.S. Environmental Protection Agency, IERL-Cincinnati.

$$f_2 = [1 - (H_2O)_F][i_F] \tag{6}$$

where $(H_2O)_F$ = fraction of water in solid wastes

i_F = fraction of constituent on a dry basis

A potentially hazardous mass load in a given river is then defined as

$$Z = V_R Dt \tag{7}$$

where Z = potentially hazardous mass loading, g/yr

D = drinking water standard, g/m^3

V_R = river flow rate, m^3/s

t = time of duration (3.1471×10^7 s/yr)

A total relative effluent mass loading factor, A, is then defined as

$$A = \frac{X + Y}{Z} \tag{8}$$

where X, Y, and Z are defined by Equations 3, 4, and 7, respectively

The weighting factor, W, can be defined as

$$W = \frac{W_1}{Z} \tag{9}$$

where $W_1 = V_R C_A t$

and C_A = an ambient concentration, g/m^3

The weighting factor is the ratio of ambient mass relative to a potentially hazardous mass. If we use the same reference time period (e.g., 1 yr), then:

$$W = \frac{C_A}{D} \tag{10}$$

The following restriction is imposed on the weighting factor, W:

$$W = \begin{cases} \frac{C_A}{D} \text{ if } C_A > D \\ 1.0 \text{ if } C_A \leq D \end{cases} \tag{11}$$

The two factors A and W are combined into the quantity designated M as follows:[a]

$$M = A^2W \tag{12}$$

By summing over i = 1,2, . . . N emissions and j = 1,2, . . . , K_x point sources, the impact factor, I_{WX}, is defined for water as follows:

$$I_{WX} = \sum_{j=1}^{K_x} P_j \left[\sum_{i=1}^{N} M_{ij} \right]^{1/2} \tag{13}$$

The full detailed form of the impact factor model for source type X emitting species i = 1,2, . . ., N by point sources j = 1,2, . . ., K_X is:

[a]See Reference 1 for mathematical rationale.

$$I_{WX} = \sum_{j=1}^{K_X} P_j \left[\sum_{i=1}^{N} \left(\frac{V_{D_{ij}} C_{D_{ij}} t + S_{G_j} f_{1_j} f_{2_{ij}}}{V_{R_j} D_i t} \right)^2 \left(\frac{C_{A_{ij}}}{D_i} \right) \right]^{1/2} \qquad (14)$$

where I_{WX} = total water impact factor for source type X, persons/km^2

K_X = number of sources emitting materials associated with source type X

P_j = population density in the region associated with the $j^{\underline{th}}$ source, persons/km^2

N = number of materials emitted by source type X

$V_{D_{ij}}$ = discharge flow rate of $i^{\underline{th}}$ species by the $j^{\underline{th}}$ source, m^3/s

$C_{D_{ij}}$ = discharge concentration of the $i^{\underline{th}}$ species by the $j^{\underline{th}}$ point source, g/m^3

t = 3.1471×10^7 s/yr

S_{G_j} = leachable solid waste generation by the $j^{\underline{th}}$ point source, g/yr

f_{1_j} = fraction of solid waste to water by the $j^{\underline{th}}$ point source

$f_{2_{ij}}$ = fraction of the $i^{\underline{th}}$ material in the $j^{\underline{th}}$ source

V_{R_j} = river flow rate at the $j^{\underline{th}}$ source, m^3/s

D_i = drinking water standard for the $i^{\underline{th}}$ emission, g/m^3

$C_{A_{ij}}$ = ambient level of the $i^{\underline{th}}$ emission at the $j^{\underline{th}}$ point source, g/m^3

2. Assumptions and Limitations

The structure of the water model produced impact factors with a range of several orders of magnitude. This has proved useful in meeting the initial objective - the generation of a relative rank ordering of combustion source types on the basis of potential water pollution severity.

The extent to which this rank ordered (i.e., prioritized) list of source types can be used is limited by two factors: the structural validity (appropriateness) of the model, and the accuracy of the input data. Addressing the latter point, the input data were provided by another contractor (GCA) and thus the estimation of accuracy beyond that discussed in Section IV.D, Data Quality, with the exception of certain obvious discrepancies noted by the researchers, was outside the scope of this project. Concerning the validity or appropriateness of the water prioritization model, objections to the structure of the model can be answered by one of three observations.

In some cases, gathering information of a more detailed nature would not affect the ranking sufficiently to warrant the time and expense. Examples of this include gathering detailed rainfall statistics for various regions, detailed river flow rates, or river ambient concentrations for various species. All of these parameters affect the ranking very little. Sensitivity analyses are informative in this respect.

The second observation regarding the structure of the water prioritization model is that many effects were not considered because of the three-month time constraint on this project. Included in this category are synergism, BOD, COD, receptor mix (i.e., types of aquatic or marine life affected), conservative vs. nonconservative substances (i.e., decay rates), water hardness, sedimentation rates, river bottom exchange kinetics, ion exchange, gas exchange, and chemical reactivity. Also in this category are various possible configurations: presence or absence of a diffuser, discharge configurations (i.e., single or multiple-point discharges).

The third observation regarding the structure of the water prioritization model is concerned with those effects which are not well understood. The selection of an appropriate standard, drinking water standards or LC_{50} for fish, is an example. Discharges or solid residuals containing biological activity and leaching dynamics are additional examples.

Thus, it must be understood that the prioritization model is at best a "first-cut" attempt at the rank ordering of numerous source types on the basis of the potential burden they place on their environment. In this model, the potential burden is expressed as a mass ratio of a discharged material relative to a hazard potential factor which in turn is based on a drinking water standard.

3. Sensitivity Analysis

The prioritization model was computerized on the APL/370 time-sharing system. A sample source type was defined to emit three materials in 50 states:

Emitted material	Drinking water standards[8]
Arsenic	1×10^{-4} g/l
Cadmium	1×10^{-5} g/l
Chromium	5×10^{-5} g/l

A simulated data set for discharge concentrations (C_D), ambient concentrations (C_A), discharge flow rates (V_D), and river flow rates (V_R), is given in Table 1. Discharge and ambient concentrations are listed for arsenic (As), cadmium (Cd), and chromium (Cr). The sensitivity analyses are presented in Figures 3 - 6.

The sensitivity analyses were conducted by first sampling a baseline value (value of 1.0 on the abscissa). Then the variable of interest was increased or decreased by succeeding orders of magnitude. Thus an impact factor computed for a given model with C_D set at 0.1 means that every C_D (3 x 50) in the simulated data set was reduced by 0.1, etc.

C. SOLIDS PRIORITIZATION MODEL

As described in the previous sections, the environmental impact of solid emissions was separated into air and water contributions and incorporated into the air and water models. The air contribution from raw materials and waste piles was treated as another air emission having a representative composite TLV with a stack height of 10 feet. The water contribution was determined using annual rainfall data and dry composition of the solid.

Table 1. BASELINE INPUT DATA USED IN THE SENSITIVTY ANALYSES

C_D, g/l			C_A, g/l			V_D,	V_R,
As	Cd	Cr	As	Cd	Cr	ft^3/sec	ft^3/sec
4.690E¯2	2.880E¯2	1.800E¯2	1.100E¯5	7.760E¯4	7.310E¯4	1.284E4	2.919E5
1.550E¯2	5.730E¯2	8.030E¯2	3.260E¯4	4.240E¯4	6.860E¯4	6.901E4	1.503E5
3.500E¯3	5.350E¯2	4.990E¯2	6.840E¯4	2.140E¯4	8.390E¯4	4.228E4	1.722E5
9.560E¯2	7.490E¯2	5.560E¯2	7.120E¯4	8.310E¯4	1.040E¯4	4.895E4	2.220E5
8.910E¯2	6.260E¯2	8.430E¯2	9.100E¯5	7.670E¯4	6.340E¯4	2.071E4	1.082E5
1.610E¯2	2.140E¯2	7.150E¯2	2.220E¯4	2.220E¯4	9.100E¯5	5.235E3	2.970E5
1.320E¯2	9.200E¯3	2.760E¯2	3.950E¯4	9.530E¯4	9.490E¯4	6.210E4	5.396E5
4.000E¯4	4.150E¯2	2.800E¯3	3.960E¯4	2.770E¯4	6.960E¯4	6.214E4	5.464E5
7.110E¯2	9.380E¯2	2.410E¯2	2.920E¯4	7.800E¯4	7.870E¯4	8.512E4	4.573E4
1.820E¯2	3.190E¯2	8.880E¯2	4.290E¯4	2.900E¯4	2.030E¯4	3.552E4	5.437E5
6.530E¯2	1.520E¯2	6.820E¯2	2.200E¯5	2.000E¯4	9.840E¯4	4.775E4	3.077E5
3.870E¯2	3.890E¯2	5.010E¯2	2.520E¯4	8.220E¯4	1.460E¯4	7.579E4	3.146E5
1.490E¯2	5.880E¯2	8.460E¯2	4.050E¯4	6.060E¯4	1.860E¯4	4.112E3	1.982E5
5.910E¯2	9.560E¯2	5.570E¯2	8.310E¯4	1.670E¯4	9.890E¯4	5.812E3	5.921E5
1.500E¯2	9.840E¯2	4.100E¯2	2.650E¯4	2.420E¯4	1.110E¯4	4.867E4	3.014E5
1.430E¯2	5.660E¯2	2.530E¯2	2.280E¯4	6.390E¯4	7.000E¯4	6.140E4	1.670E5
4.900E¯2	4.650E¯2	9.620E¯2	7.970E¯4	7.000E¯4	7.560E¯4	1.693E3	6.353E4
1.270E¯2	2.010E¯2	3.200E¯2	6.730E¯4	6.380E¯4	6.600E¯5	3.551E4	5.692E5
6.300E¯2	1.280E¯2	6.520E¯2	6.030E¯4	2.350E¯4	3.260E¯4	7.016E3	5.351E4
6.230E¯2	8.040E¯2	2.490E¯2	7.030E¯4	1.270E¯4	7.650E¯4	3.857E4	3.054E5
4.770E¯2	3.900E¯2	2.050E¯2	5.310E¯4	5.590E¯4	5.930E¯4	6.281E4	2.366E5
3.000E¯3	9.020E¯2	4.280E¯2	3.370E¯4	7.060E¯4	1.520E¯4	5.401E4	1.735E5
1.430E¯2	9.480E¯2	4.110E¯2	1.710E¯4	4.910E¯4	8.620E¯4	8.474E4	5.492E5
1.330E¯2	8.860E¯2	9.400E¯3	8.160E¯4	5.620E¯4	7.420E¯4	7.716E4	3.226E5
1.640E¯2	7.200E¯3	3.660E¯2	3.230E¯4	1.440E¯4	5.340E¯4	4.842E4	2.840E5
2.540E¯2	1.360E¯2	P.840E¯2	3.180E¯4	5.930E¯4	5.230E¯4	9.277E3	5.652E5
4.560E¯2	3.510E¯2	4.530E¯2	4.370E¯4	2.670E¯4	3.770E¯4	5.985E4	3.955E4
8.100E¯2	9.320E¯2	6.520E¯2	4.000E¯4	4.530E¯4	4.820E¯4	3.844E4	4.593E5
2.170E¯2	6.800E¯2	9.100E¯2	3.940E¯4	2.870E¯4	8.800E¯5	6.411E4	4.644E5
2.510E¯2	8.610E¯2	4.720E¯2	3.770E¯4	2.620E¯4	6.760E¯4	8.293E4	4.984E5
5.070E¯2	6.010E¯2	8.180E¯2	6.800E¯4	5.190E¯4	7.320E¯4	6.960E4	8.397E4
7.570E¯2	4.630E¯2	9.520E¯2	7.240E¯4	9.460E¯4	4.670E¯4	2.462E4	1.936E4
6.340E¯2	4.400E¯2	8.250E¯2	9.410E¯4	3.290E¯4	4.660E¯4	5.272E3	4.162E5
6.900E¯2	7.030E¯2	9.880E¯2	5.220E¯4	6.650E¯4	4.080E¯4	6.725E4	5.223E5
9.550E¯2	8.520E¯2	2.910E¯2	6.100E¯4	9.870E¯4	1.590E¯4	3.054E4	3.814E5
5.380E¯2	5.150E¯2	1.050E¯2	6.740E¯4	3.510E¯4	5.470E¯4	5.794E4	4.444E5
4.150E¯2	5.780E¯2	8.770E¯2	5.280E¯4	8.310E¯4	2.500E¯5	6.908E4	4.380E5
4.410E¯2	7.310E¯2	8.700E¯2	2.820E¯4	6.470E¯4	5.510E¯4	9.019E4	5.997E5
7.160E¯2	8.010E¯2	7.070E¯2	9.190E¯4	2.740E¯4	9.710E¯4	3.388E4	5.343E5
7.420E¯2	2.100E¯3	8.870E¯2	2.550E¯4	8.460E¯4	6.980E¯4	2.323E4	1.476E5
5.260E¯2	4.640E¯2	6.700E¯3	4.620E¯4	8.190E¯4	3.200E¯5	8.943E4	1.907E5
7.140E¯2	4.900E¯2	6.690E¯2	1.700E¯4	7.100E¯4	7.110E¯4	6.604E4	2.171E5
6.830E¯2	2.010E¯2	9.170E¯2	4.430E¯4	5.870E¯4	7.550E¯4	6.880E4	3.128E5
8.670E¯2	8.910E¯2	5.450E¯2	9.920E¯4	6.990E¯4	2.870E¯4	5.964E4	3.588E5
1.410E¯2	4.510E¯2	9.900E¯2	7.570E¯4	1.800E¯4	1.500E¯5	7.542E3	5.091E5
2.170E¯2	4.470E¯2	3.170E¯2	5.010E¯4	9.000E¯5	1.720E¯4	5.785E4	2.531E5
5.160E¯2	8.820E¯2	4.410E¯2	9.050E¯4	7.860E¯4	7.500E¯4	8.062E4	5.065E5
4.690E¯2	8.070E¯2	3.660E¯2	4.430E¯4	1.700E¯5	5.890E¯4	2.554E4	1.689E5
2.130E¯2	1.000E¯1	1.550E¯2	5.240E¯4	7.700E¯5	5.490E¯4	4.028E4	2.551E5
6.310E¯2	6.170E¯2	2.000E¯4	3.960E¯4	2.240E¯4	3.920E¯4	6.999E4	3.270E5

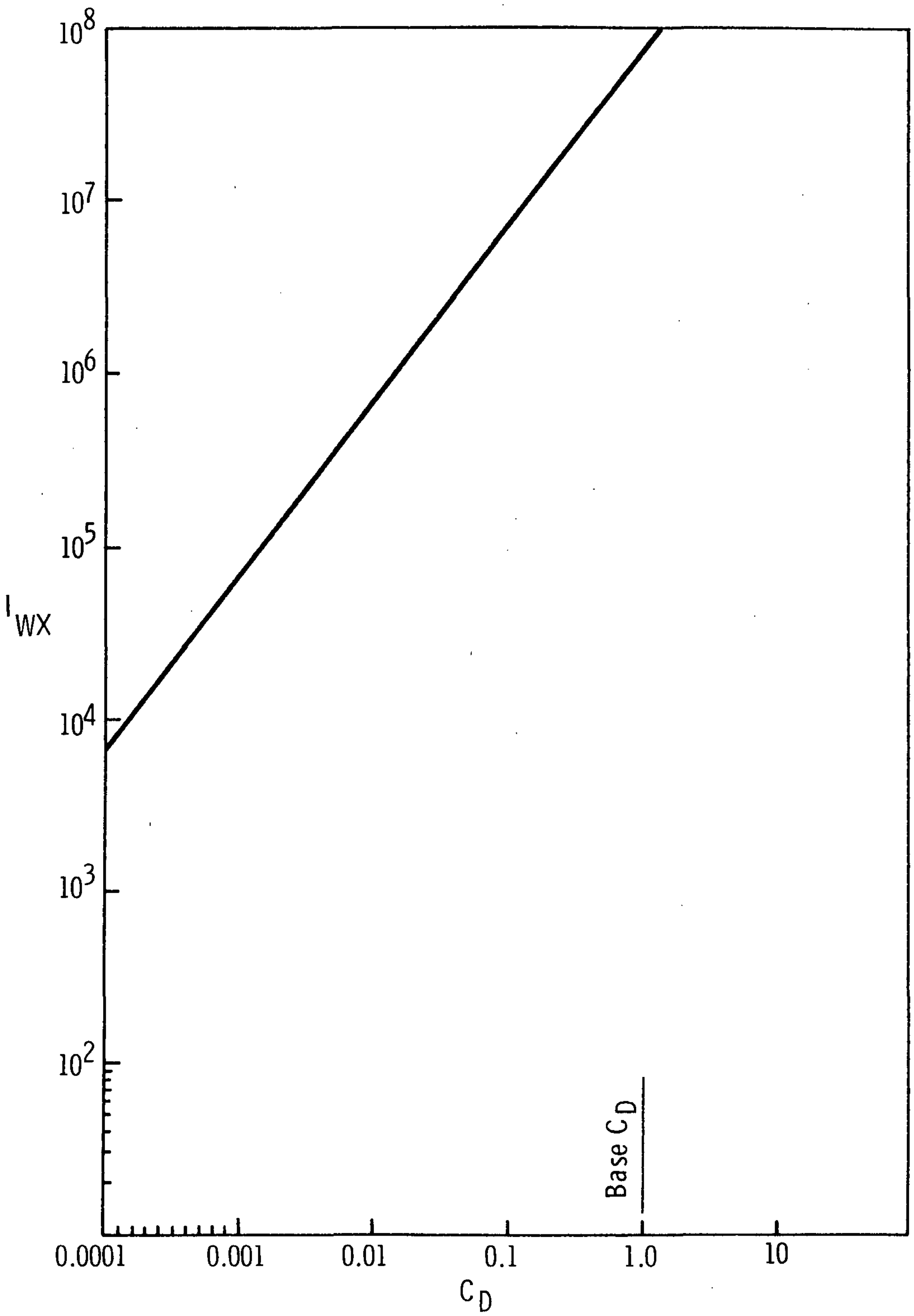

Figure 3. Sensitivity analysis - discharge concentration

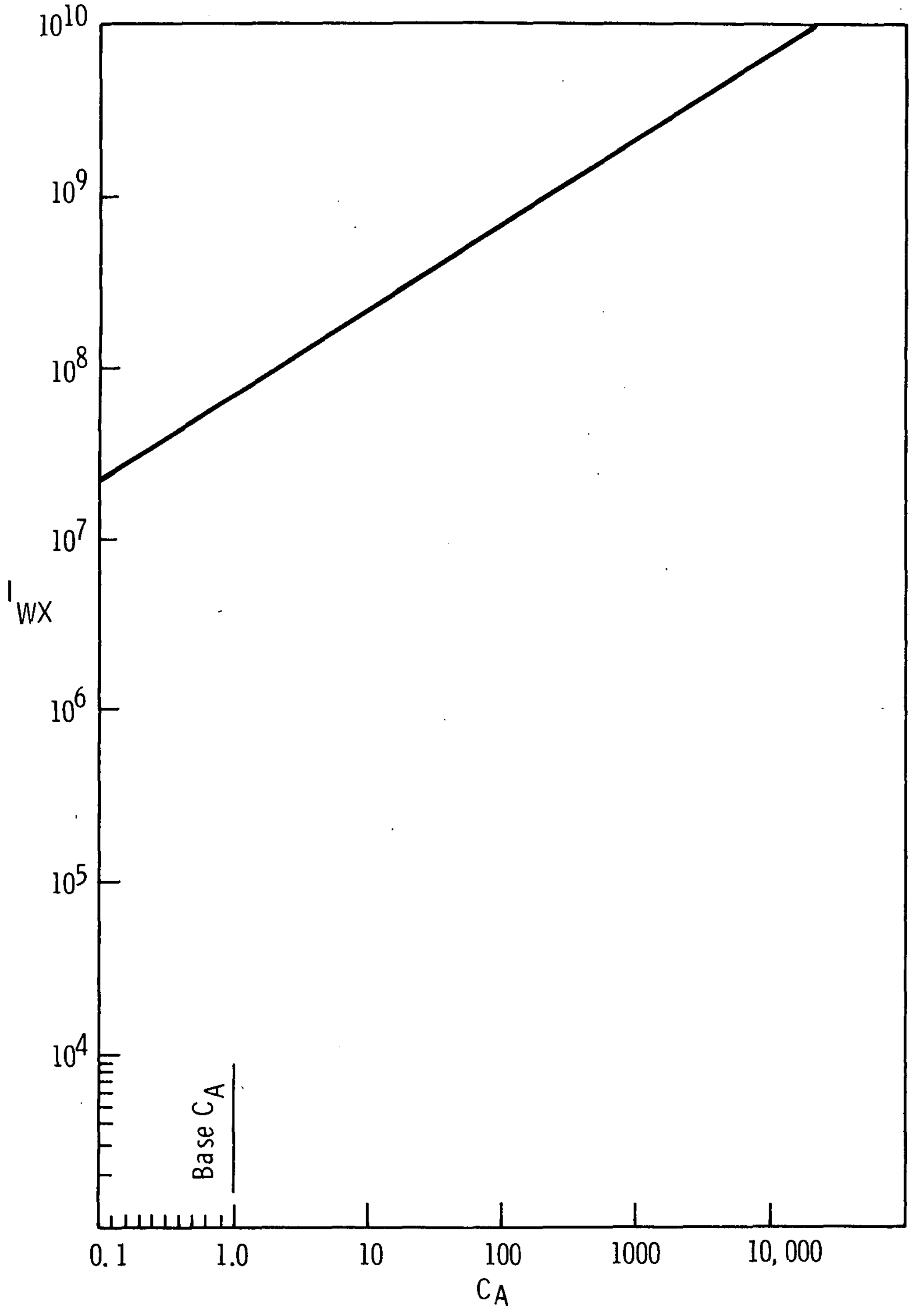

Figure 4. Sensitivity analysis - ambient concentration

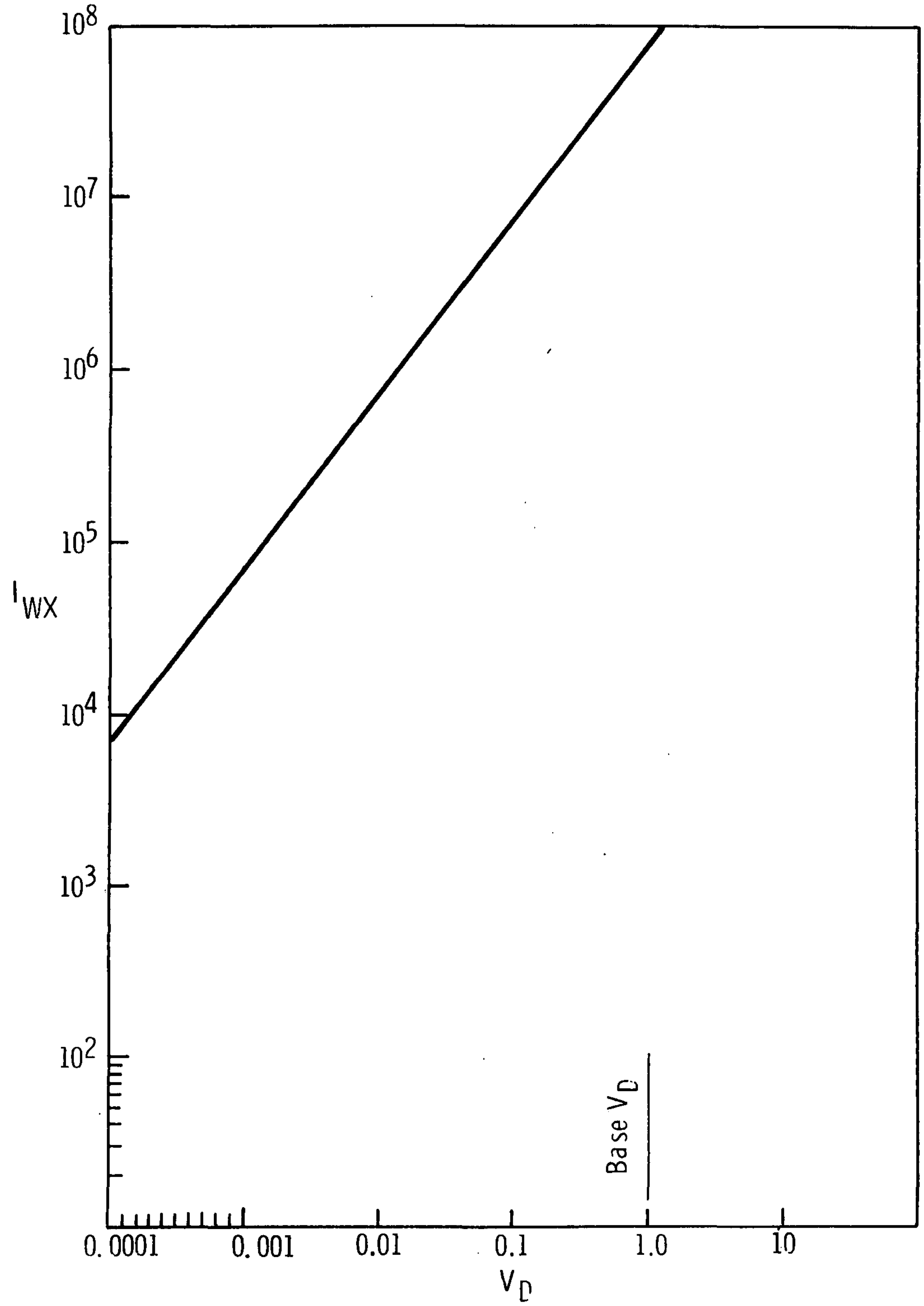

Figure 5. Sensitivity analysis - discharge flow rate

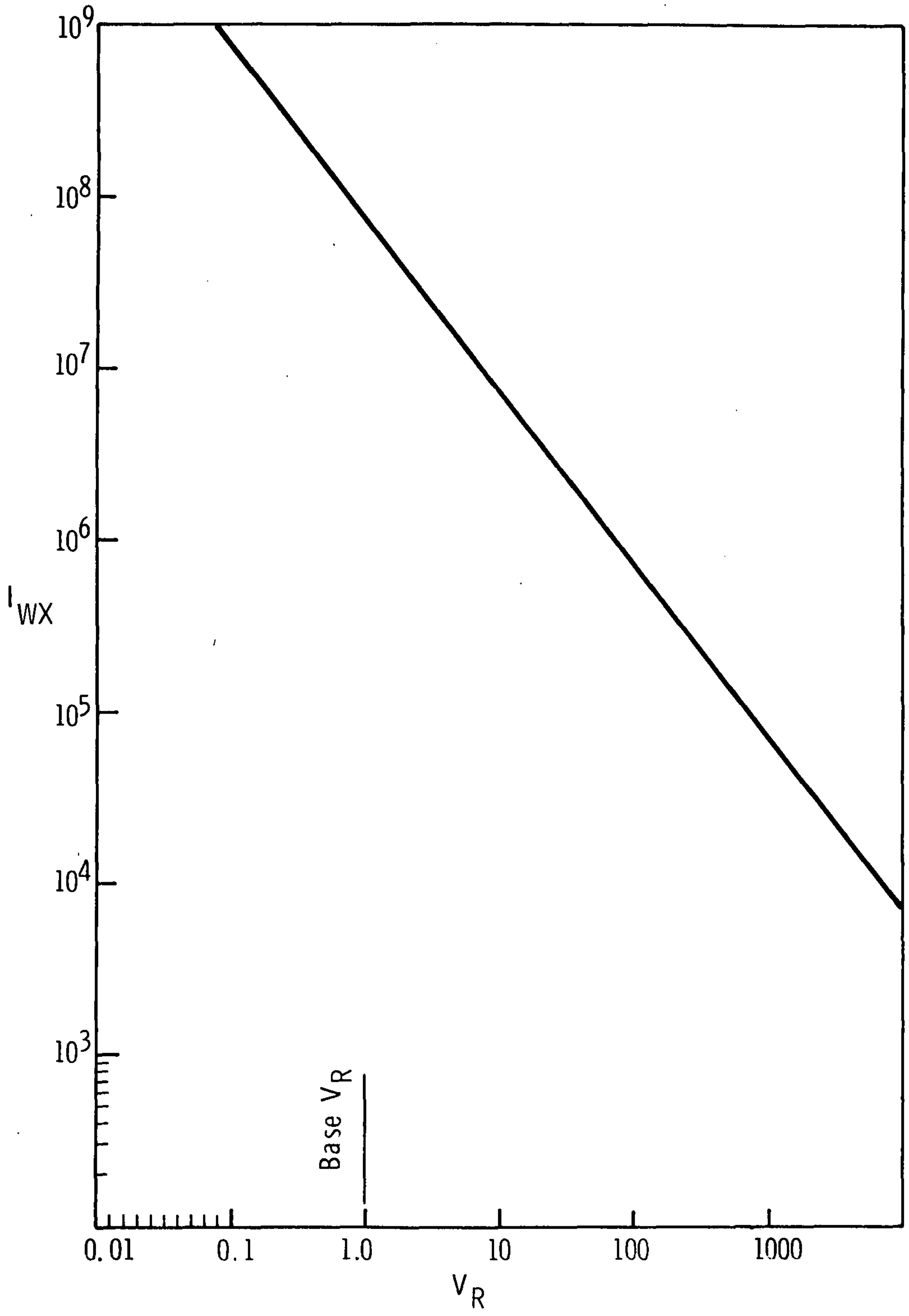

Figure 6. Sensitivity analysis - river flow rate

SECTION IV

PRIORITIZATION OF COMBUSTION SOURCES

A relative ranking of the environmental impact of conventional stationary combustion sources was generated on a multi-media basis. Air, water, and solid residue emissions from 56 sources were used to establish two prioritization lists, one based on air emissions and one based on water emissions with the solid residue impact divided into air and water components.

A. SOURCE DEFINITION

The 56 source definitions were extracted from a GCA Corporation report.[2] This document also served as the primary source of emission data. GCA's classification system is presented in Table 2 and the resulting sources are defined in Table 3.

B. EMISSION POINTS AND INPUT FORMAT

Air prioritization was based on stack emission estimates and and fugitive emission estimates from fuel storage and handling, and from ash disposal. Emission estimates were extracted from GCA's report for some or all of 36 emission

Table 2. COMBUSTION SYSTEM CLASSIFICATION TABLE[2]

	Column 1	Column 2	Column 3	Column 4	Column 5
Row	Function	Combustion	Fuel (2-digit designation)	Furnace type	Firing
0	All	All	00 All	All	All
1	Electric generations: utilities	External	10 Coal: total	Pulverized: dry bottom	Tangential
2	Industrial	Internal: all	11 Coal: bituminous	Pulverized: wet bottom	All other than tangential
3	Commercial	Internal gas turbine	12 Coal: anthracite	Cyclone	Front or back
4	Residential	Internal recipro.	13 Coal: lignite	Stoker: all	Opposed
5	Mixed function		20 Petroleum: total	Stoker: overfeed	Vertical
6			21 Oil: residual	Stoker: spreader	
7			22 Oil: distillate	Stoker: underfeed	
			23 Oil: crude		
			24 kerosene		
			25 diesel		
			26 gasoline		
			30 Gas: total		
			31 natural		
			32 process		
			33 LPG		
			40 Refuse: All		
			41 bagasse		
			42 wood/bark		
			43 other		

Table 3. SELECTED COMBUSTION SYSTEMS[2]

System No.	Classification code	Combustion system
	1.0.00.0.0	Electric generation
	1.1.00.0.0	External combustion
	1.1.10.0.0	Coal
	1.1.11.0.0	Bituminous
1	1.1.11.1.0	Pulverized dry
2	1.1.11.2.0	Pulverized wet
3	1.1.11.3.0	Cyclone
4	1.1.11.4.0	All stokers
	1.1.12.0.0	Anthracite
5	1.1.12.1.0	Pulverized dry
6	1.1.12.4.0	All stokers
	1.1.13.0.0	Lignite
7	1.1.13.1.0	Pulverized dry
8	1.1.13.2.0	Pulverized wet
9	1.1.13.3.0	Cyclone
10	1.1.13.4.0	All stokers
	1.1.20.0.0	Petroleum
	1.1.21.0.0	Residual oil
11	1.1.21.0.1	Tangential firing
12	1.1.21.0.2	All other
	1.1.22.0.0	Distillate oil
13	1.1.22.0.1	Tangential firing
14	1.1.22.0.2	All other
	1.1.30.0.0	Gas
15	1.1.30.0.1	Tangential firing
16	1.1.30.0.2	All other
17	1.1.40.0.0	Refuse

Table 3 (continued). SELECTED COMBUSTION SYSTEMS[2]

System No.	Classification code	Combustion system
	1.2.00.0.0	Internal combustion
	1.2.20.0.0	Petroleum
	1.2.30.0.0	Gas
	1.3.00.0.0	Internal combustion/gas turbine
	1.3.20.0.0	Petroleum
	1.3.21.0.0	Residual oil
18	1.3.22.0.0	Distillate oil
19	1.3.30.0.0	Gas
	1.4.00.0.0	Internal combustion/reciprocating engine
	1.4.20.0.0	Petroleum
20	1.4.22.0.0	Distillate oil
21	1.4.30.0.0	Gas
	2.0.00.0.0	Industrial
	2.1.00.0.0	External combustion
	2.1.10.0.0	Coal
	2.1.11.0.0	Bituminous
22	2.1.11.1.0	Pulverized dry
23	2.1.11.2.0	Pulverized wet
24	2.1.11.3.0	Cyclone
25	2.1.11.4.0	All stokers
	2.1.12.0.0	Anthracite
26	2.1.12.4.0	All stokers
	2.1.13.0.0	Lignite
27	2.1.13.6.0	Spreader stokers
	2.1.20.0.0	Petroleum
	2.1.21.0.0	Residual oil
28	2.1.21.0.1	Tangential firing
29	2.1.21.0.2	All other

Table 3 (continued). SELECTED COMBUSTION SYSTEMS[2]

System No.	Classification code	Combustion system
	2.1.22.0.0	Distillate oil
30	2.1.22.0.1	Tangential firing
31	2.1.22.0.2	All other
	2.1.30.0.0	Gas
32	2.1.30.0.1	Tangential firing
33	2.1.30.0.2	All other
34	2.1.40.0.0	Waste
	2.2.00.0.0	Internal combustion
	2.2.20.0.0	Petroleum
	2.2.30.0.0	Gas
	2.3.00.0.0	Internal combustion gas turbine
	2.3.20.0.0	Petroleum
	2.3.21.0.0	Residual oil
35	2.3.22.0.0	Distillate oil
36	2.3.30.0.0	Gas
	2.4.00.0.0	Internal combustion/reciprocating engine
	2.4.20.0.0	Petroleum
37	2.4.22.0.0	Distillate oil
38	2.4.30.0.0	Gas
	3.0.00.0.0	Commercial generation
	3.1.00.0.0	External combustion
	3.1.10.0.0	Coal
	3.1.11.0.0	Bituminous
39	3.1.11.1.0	Pulverized dry
40	3.1.11.2.0	Pulverized wet
41	3.1.11.4.0	All stokers
	3.1.12.0.0	Anthracite

Table 3 (continued). SELECTED COMBUSTION SYSTEMS[2]

System No.	Classification code	Combustion system
42	3.1.12.4.0	All stokers
	3.1.13.0.0	Lignite
	3.1.13.4.0	All stokers
	3.1.20.0.0	Petroleum
	3.1.21.0.0	Residual oil
43	3.1.31.0.1	Tangential firing
44	3.1.21.0.2	All other
	3.1.22.0.0	Distillate oil
45	3.1.22.0.1	Tangential firing
46	3.1.22.0.2	All other
	3.1.30.0.0	Gas
47	3.1.30.0.1	Tangential firing
48	3.1.30.0.2	All other
	3.1.40.0.0	Refuse
	3.2.00.0.0	Internal combustion
49	3.2.20.0.0	Petroleum
50	3.2.30.0.0	Gas
	4.0.00.0.0	Residential
	4.1.00.0.0	External combustion
	4.1.10.0.0	Coal
51	4.1.11.0.0	Bituminous
52	4.1.12.0.0	Anthracite
53	4.1.13.0.0	Lignite
	4.1.20.0.0	Petroleum
54	4.1.22.0.0	Distillate oil
55	4.1.30.0.0	Gas
56	4.1.42.0.0	Wood

species depending on the quality of emission characterization for each source type. The 36 species are identified in Figure 7, which is a sample copy of the air prioritization input data sheets. The air input data forms, designed for an earlier prioritization effort, were adapted for application to this task. Required input to the air prioritization model includes: fuel consumption plus appropriate emission factors or emission rates, frequency of operation, threshold limit values (TLV) for each species, average emission height, and statewise geographical distribution of sources. Other information on the input sheets relate to source identification or generalization in order that the forms may be used later for source types other than combustion.

Points of water emissions from stationary combustion sources are, in general, more numerous than those for air. Water emission sources include cooling system wastewater, equipment cleaning wastewater, boiler blowdown, boiler feedwater treatment waste, ash pond overflow, runoff from landfilled ash, and runoff from coal storage piles. Characterization of water emissions is not as thorough as air characterization with only a maximum of 13 species being quantified for each source. Selection of species to be used for prioritization purposes was based on three criteria. The following parameters were required for each species: an emission factor and discharge rate or emission rate, ambient water quality data, and a drinking water quality standard. Thirteen species meet this criteria and are listed in Figure 8.

Figures 8 and 9 are samples of the water prioritization input data sheets. Separate forms are required for direct water emissions (Figure 8) and for water emissions from solid residue (Figure 9) due to the input requirements of the water

LOCATION SENSITIVE PRIORITIZATION DATA

CATEGORY ____________________

SOURCE DESCRIPTION ____________________

SCC ____________________

TOTAL PRODUCTION ____________________ (TONS/YEAR)

FREQUENCY OF OPERATION ____________________ (% OF YEAR)

NUMBER OF PLANTS/SITES ____________________

NUMBER OF MATERIALS EMITTED ____________________

MATERIAL EMITTED	TLV (gm/m^3)	EMISSION RATE (tons/yr)	AVG EMISSION HEIGHT (ft)	REFERENCE
Particulate				
SOX				
NOX				
HC				
CO				
BSO	2.0×10^{-3}			
PPOM	2.0×10^{-3}			
BaP	1.0×10^{-6}			
Sb	0.5×10^{-3}			
As	0.5×10^{-3}			
Ba	0.5×10^{-3}			
Be	0.002×10^{-3}			
Bi	10.0×10^{-3}			
B	10.0×10^{-3}			
Br	0.7×10^{-3}			
Cd	0.05×10^{-3}			
Cl	3.0×10^{-3}			
Cr	0.1×10^{-3}			
Co	0.1×10^{-3}			
Cu	0.2×10^{-3}			
F	2.0×10^{-3}			
Fe	1.0×10^{-3}			
Pb	0.15×10^{-3}			
Mn	5.0×10^{-3}			
Hg	0.01×10^{-3}			
Mo	5.0×10^{-3}			

Figure 7. Sample air prioritization input data sheet

LOCATION SENSITIVE PRIORITIZATION DATA

CATEGORY __________

SOURCE DESCRIPTION __________

SCC __________

TOTAL PRODUCTION __________ (TONS/YEAR)

FREQUENCY OF OPERATION __________ (% OF YEAR)

NUMBER OF PLANTS/SITES __________

NUMBER OF MATERIALS EMITTED __________

MATERIAL EMITTED	TLV (gm/m^3)	EMISSION RATE (tons/yr)	AVG EMISSION HEIGHT (ft)	REFERENCE
Ni	1.0×10^{-3}			
Se	0.2×10^{-3}			
Te	0.1×10^{-3}			
Tl	0.1×10^{-3}			
Sn	0.1×10^{-3}			
Ti	10.0×10^{-3}			
U	0.2×10^{-3}			
V	0.5×10^{-3}			
Zn	5.0×10^{-3}			
Zr	5.0×10^{-3}			

Figure 7 (Continued). Sample air prioritization input data sheet

SOURCE DESCRIPTION ________________________________

AVERAGE PLANT SIZE ________________________ (TONS/YR)

NUMBER OF STATES ________________________

STATE CODE (XX)	STATE PRODUCTION (tons/year)	NUMBER OF PLANTS	REFERENCE

Figure 7 (Continued). Sample air prioritization input data sheet

WATER PRIORITIZATION DATA
WATER EMISSIONS CONTRIBUTION

Category____________________

Source Description____________________

SCC____________________

Total Production (Fuel Consumption)__________(Units/Year)

Frequency__________ Number of Plants/Sites______

Number of Emitted Species__________

Material	C_D (mg/l)	V_D (l/min)	D (mg/l)	Remarks
Total Dissolved Solids			500	
As			0.05	
Cd			0.01	
Cl			250	
Cu			1.0	
Cr			0.05	
F			1.4-2.4	Use 2.0
Fe			0.3	
Hg			0.002	
Mn			0.05	
NO_3			10	
Pb			0.05	
SO_4			250	

Figure 8. Sample water prioritization input data sheet - direct emissions

SOLID EMISSIONS TO WATER

Source Description____

Area of Pile____

Waste Generation Rate___________________________(Units/Year)

Fraction of Water in Waste________________________________

Material	Fraction on Dry Basis	D (mg/l)	Remarks

Figure 9. Sample water prioritization input data sheet - solid emissions to water

prioritization model. For direct water emissions, the required input information includes discharge concentration and discharge rate or emission rate, ambient water quality data, drinking water quality standard, and statewise distribution of sources. For water emissions from solid waste sources, the waste generation rate, water content of the waste, waste composition on a dry basis, ambient water quality data, drinking water quality standard, and statewise distribution of sources are required. For both types of water emissions, ambient water quality statistics on a statewise basis have been programmed into the model. The distribution of sources by state that was used for air prioritization was also applied to water prioritization.

Direct water emissions were divided into two categories due to a difference in effluent characterization. In our data sources, the composition of ash pond overflow was presented as the difference between discharge concentration and ambient concentration while the other direct emission points were characterized by effluent concentrations including ambient contribution. For consistency, ambient concentrations were added to the ash pond overflow yielding a prioritization that includes an impact contribution due to ambient discharge concentrations.

C. DATA ACQUISITION

GCA's report[2] was the primary source of input data for the prioritization models. Required information was either extracted directly from the report or the information from the report was manipulated into a useable format. For example, statewise distributions for individual sources were obtained by deaggregating state fuel consumptions assuming that the source's fraction of national fuel consumption applied to each state.

Air emission species, rates of emission, frequency of emission, and statewise distribution of emissions were extracted from GCA's report. Average heights of emission were estimated using Federal Power Commission (FPC) and National Emissions Data System (NEDS) data bases. Input for the water model was extracted from GCA's report except for ambient water quality data. Sampling data from the U.S. Geological Survey was utilized for ambient water characterization.

Extensive deaggregation of GCA data was required to obtain input for the specific sources as defined by GCA. Deaggregation was generally accomplished by using fuel consumption data. Where available, more appropriate deaggregation data was utilized, e.g., solid waste generation rate or water effluent rate.

In cases of uncertainty concerning required input from the report, original data sources, alternative information sources if available, and finally GCA were consulted to resolve recognized inconsistencies.

D. DATA QUALITY

Data quality parameters were presented in the GCA report to characterize the data. Since these data were used as input to the prioritization models, as a best case the same reservations concerning quality must apply to the prioritization lists. Definitions of data quality are presented in Table 4 with the resulting data characterization in Table 5. It should be noted that less than 15% of the data quality entries have an error $<10\%$, while 45% have an error $\geq 100\%$. In addition to having a minimum of 100% error, the validity of these data are described as questionable.

Table 4. DATA QUALITY DEFINITIONS[2]

Data quality factor	Definition
A	Very good - highest confidence. Error probably ≤ 10%. Data well accepted and verified.
B	Good - reputable and accepted. Error probably ≤25%.
C	Fair - error probably ≤50%. Validity may be uncertain due to method of combining or applying data.
D	Poor - low confidence in data. Error probably 100%. Validity questionable.
E	Very poor - validity of data unknown. Error probably within or around an order of magnitude.
NA	Not applicable.

E. RELATIVE PRIORITIZATION LISTINGS FOR COMBUSTION SOURCES

Relative rankings of 56 combustion sources having air emissions and 38 sources having water emissions were presented earlier in Figures 1 and 2, and are repeated on pages 39 and 40 for reader convenience.

Table 5. DATA QUALITY[2]

	Utilities	Industrial	Commercial/ institutional	Residential
Fuel and boiler data				
Fuel consumption	A	B	B	B
Combustion unit population	A	D	D	D
Combustion unit characteristics	A	B	B	B
Control devices	A	C	NA	NA
Emissions data				
Stack emissions				
Particulates	B	C	D	C
Fine particulates	D	D	D	C
SO_x	A	A	A	A
NO_x	B	B	C	C
HC	D	D	D	D
CO	B	C	C	C
PPOM	E	E	E	E
Trace elements	E	E	E	E
Ash handling				
Air emissions	E	E	NA	NA
Pond discharge	C	D	NA	NA
Amount composition	E	E	NA	NA
Solid waste				
Amount	A	B	B	B
Composition, major elements	A	A	B	B
Composition, trace elements	E	E	E	E
Cooling systems				
Water discharge				
Volume	A	E	NA	NA
Composition	C	C	NA	NA
Thermal	A	E	NA	NA
Air emissions	C	NA	NA	NA
Other waste water sources				
Boiler water treament				
Volume	D	E	NA	NA
Composition	C	D	NA	NA
Boiler blowdown				
Volume	E	E	NA	NA
Composition	D	E	NA	NA
Equipment cleaning				
Volume	D	D	NA	NA
Composition	C	C	NA	NA
Fuel handling				
Air emissions	E	E	E	NA
Coal pile drainage				
Volume	C	C	C	NA
Composition	C	C	C	NA

RANK	ID CODE	SOURCE TYPE	IMPACT FACTOR
1	4.1.12.0.0	RESIDENTIAL EXT COMB ANTHRACITE	500,000,000
2	4.1.11.0.0	RESIDENTIAL EXT COMB BITUMINOUS	300,000,000
3	4.1.22.0.0	RESIDENTIAL EXT COMB DIST OIL	200,000,000
4	4.1.30.0.0	RESIDENTIAL EXT COMB GAS	100,000,000
5	1.1.11.1.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV DRY BOTM	30,000,000
6	3.1.21.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB RESID OIL OTHER	10,000,000
7	4.1.42.0.0	RESIDENTIAL EXT COMB WOOD	8,000,000
8	3.1.22.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB DIST OIL OTHER	7,000,000
9	2.1.21.0.2	INDUSTRIAL EXT COMB RESID OIL OTHER	7,000,000
10	1.1.11.2.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV WET BOTM	5,000,000
11	1.1.11.3.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS CYCLONE	5,000,000
12	1.3.22.0.0	ELECTRICITY GENERATION INT COMB DIST OIL TURBINE	4,000,000
13	2.1.11.1.0	INDUSTRIAL EXT COMB BITUMINOUS PULV DRY BOTM	3,000,000
14	2.1.30.0.2	INDUSTRIAL EXT COMB GAS OTHER	3,000,000
15	2.4.30.0.0	INDUSTRIAL INT COMB GAS RECIP ENG	3,000,000
16	2.3.30.0.0	INDUSTRIAL INT COMB GAS TURBINE	3,000,000
17	1.4.22.0.0	ELECTRICITY GENERATION INT COMB DIST OIL RECIP ENG	3,000,000
18	2.1.11.4.0	INDUSTRIAL EXT COMB BITUMINOUS STOKER	3,000,000
19	3.2.22.0.0	COMMERCIAL/INSTITUTIONAL INT COMB DIST OIL	2,000,000
20	2.4.22.0.0	INDUSTRIAL INT COMB DIST OIL RECIP ENG	2,000,000
21	3.1.30.0.2	COMMERCIAL/INSTITUTIONAL EXT COMB GAS OTHER	2,000,000
22	2.1.22.0.2	INDUSTRIAL EXT COMB DIST OIL OTHER	1,000,000
23	1.3.30.0.0	ELECTRICITY GENERATION INT COMB GAS TURBINE	1,000,000
24	3.1.12.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB ANTHRACITE STOKER	1,000,000
25	3.1.11.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS STOKER	900,000
26	2.1.21.0.1	INDUSTRIAL EXT COMB RESID OIL TANG FIRE	800,000
27	2.1.30.0.1	INDUSTRIAL EXT COMB GAS TANG FIRE	800,000
28	2.1.11.2.0	INDUSTRIAL EXT COMB BITUMINOUS PULV WET BOTM	700,000
29	2.3.22.0.0	INDUSTRIAL INT COMB DIST OIL TURBINE	400,000
30	1.4.30.0.0	ELECTRICITY GENERATION INT COMB GAS RECIP ENG	400,000
31	1.1.11.4.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS STOKER	400,000
32	3.2.30.0.0	COMMERCIAL/INSTITUTIONAL INT COMB GAS	400,000
33	4.1.13.0.0	RESIDENTIAL EXT COMB LIGNITE	400,000
34	1.1.21.0.2	ELECTRICITY GENERATION EXT COMB RESID OIL OTHER	400,000
35	2.1.40.0.0	INDUSTRIAL EXT COMB REFUSE	400,000
36	3.1.11.1.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV DRY BOTM	300,000
37	2.1.11.3.0	INDUSTRIAL EXT COMB BITUMINOUS CYCLONE	200,000
38	2.1.22.0.1	INDUSTRIAL EXT COMB DIST OIL TANG FIRE	200,000
39	1.1.21.0.1	ELECTRICITY GENERATION EXT COMB RESID OIL TANG FIRE	200,000
40	1.1.12.4.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE STOKER	100,000
41	2.1.12.4.0	INDUSTRIAL EXT COMB ANTHRACITE STOKER	100,000
42	3.1.21.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB RESID OIL TANG FIRE	100,000
43	3.1.30.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB GAS TANG FIRE	90,000
44	1.1.13.1.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV DRY BOTM	90,000
45	3.1.22.0.1	COMMERCIAL/INSTITUTIONAL EXT COMB DIST OIL TANG FIRE	80,000
46	1.1.12.1.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE PULV DRY BOTM	70,000
47	2.1.13.4.0	INDUSTRIAL EXT COMB LIGNITE STOKER	60,000
48	1.1.30.0.2	ELECTRICITY GENERATION EXT COMB GAS OTHER	30,000
49	1.1.13.2.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV WET BOTM	20,000
50	1.1.13.3.0	ELECTRICITY GENERATION EXT COMB LIGNITE CYCLONE	20,000
51	1.1.13.4.0	ELECTRICITY GENERATION EXT COMB LIGNITE STOKER	20,000
52	1.1.30.0.1	ELECTRICITY GENERATION EXT COMB GAS TANG FIRE	20,000
53	3.1.11.2.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV WET BOTM	10,000
54	1.1.22.0.2	ELECTRICITY GENERATION EXT COMB DIST OIL OTHER	3,000
55	1.1.22.0.1	ELECTRICITY GENERATION EXT COMB DIST OIL TANG FIRE	1,000
56	1.1.40.0.0	ELECTRICITY GENERATION EXT COMB REFUSE	80

Figure 1. Air relative prioritization

Rank	ID code	Source type	Impact factor x 10^3
1	1.1.11.1.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV DRY BOTM	1,000,000
2	2.1.30.0.2	INDUSTRIAL EXT COMB GAS OTHER	600,000
3	1.1.21.0.2	ELECTRICITY GENERATION EXT COMB RESID OIL OTHER	600,000
4	1.1.21.0.1	ELECTRICITY GENERATION EXT COMB RESID OIL TANG FIRE	400,000
5	1.1.11.2.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV WET BOTM	400,000
6	1.1.11.3.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS CYCLONE	400,000
7	1.1.30.0.2	ELECTRICITY GENERATION EXT COMB GAS OTHER	300,000
8	2.1.21.0.2	INDUSTRIAL EXT COMB RESID OIL OTHER	90,000
9	2.1.11.1.0	INDUSTRIAL EXT COMB BITUMINOUS PULV DRY BOTM	90,000
10	1.1.30.0.1	ELECTRICITY GENERATION EXT COMB GAS TANG FIRE	80,000
11	2.1.11.4.0	INDUSTRIAL EXT COMB BITUMINOUS STOKER	70,000
12	2.1.30.0.1	INDUSTRIAL EXT COMB GAS TANG FIRE	70,000
13	1.1.11.4.0	ELECTRICITY GENERATION EXT COMB BITUMINOUS STOKER	20,000
14	2.1.21.0.1	INDUSTRIAL EXT COMB RESID OIL TANG FIRE	20,000
15	2.1.11.2.0	INDUSTRIAL EXT COMB BITUMINOUS PULV WET BOTM	20,000
16	2.1.22.0.2	INDUSTRIAL EXT COMB DIST OIL OTHER	10,000
17	1.1.22.0.2	ELECTRICITY GENERATION EXT COMB DIST OIL OTHER	10,000
18	1.1.22.0.1	ELECTRICITY GENERATION EXT COMB DIST OIL TANG FIRE	7,000
19	2.1.40.0.0	INDUSTRIAL EXT COMB REFUSE	6,000
20	2.1.11.3.0	INDUSTRIAL EXT COMB BITUMINOUS CYCLONE	5,000
21	2.1.22.0.1	INDUSTRIAL EXT COMB DIST OIL TANG FIRE	3,000
22	1.1.13.1.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV DRY BOTM	3,000
23	2.1.12.4.0	INDUSTRIAL EXT COMB ANTHRACITE STOKER	2,000
24	4.1.11.0.0	RESIDENTIAL EXT COMB BITUMINOUS	2,000
25	2.1.13.4.0	INDUSTRIAL EXT COMB LIGNITE STOKER	800
26	4.1.12.0.0	RESIDENTIAL EXT COMB ANTHRACITE	800
27	3.1.12.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB ANTHRACITE STOKER	700
28	1.1.13.2.0	ELECTRICITY GENERATION EXT COMB LIGNITE PULV WET BOTM	600
29	1.1.13.3.0	ELECTRICITY GENERATION EXT COMB LIGNITE CYCLONE	600
30	1.1.12.4.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE STOKER	500
31	3.1.11.4.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS STOKER	500
32	1.1.13.4.0	ELECTRICITY GENERATION EXT COMB LIGNITE STOKER	400
33	1.1.12.1.0	ELECTRICITY GENERATION EXT COMB ANTHRACITE PULV DRY BOTM	300
34	3.1.11.1.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV DRY BOTM	100
35	1.1.40.0.0	ELECTRICITY GENERATION EXT COMB REFUSE	5
36	3.1.11.2.0	COMMERCIAL/INSTITUTIONAL EXT COMB BITUMINOUS PULV WET BOTM	3
37	4.1.13.0.0	RESIDENTIAL EXT COMB LIGNITE	1
38	4.1.42.0.0	RESIDENTIAL EXT COMB WOOD	1

Figure 2. Water relative prioritization

SECTION V

APPENDIX A

SAMPLE CALCULATIONS

Table A-1 lists the data that had been compiled for electricity generation, external combustion, bituminous coal, pulverized dry bottom. The mass of each effluent material shown is the total amount for the U.S. However, coal consumption data are available on a state-by-state basis as shown in Table A-2. Hence, the effluent mass can be apportioned over the states based on a fraction of the coal consumed. Table A-3 is a summary of annual average ambient concentrations of selected species, turbidity, river flow rates and rainfall.[4]

1. TOTAL DISSOLVED SOLIDS

For total dissolved solids, TDS, a direct water discharge and an overflow from the ash pond exist. The amount of TDS in the total effluent discharge in the U.S. is 0.2168×10^6 tons/yr as shown in Table A-1. The ash pond discharge, however, takes into account only the contribution from the ash pond, i.e., the ambient TDS mass has been subtracted. Since the model described is this report treats total effluent mass, a correction is made for the ambient TDS. From Table A-3, the ambient TDS in Alabama (state 1) is

[4]Personal communication. J. F. Ficke, U.S. Geological Survey.

Table A-1. SAMPLE INPUT DATA

ELECTRICITY GENERATION EXT COMB BITUMINOUS PULV DRY BOTM 1

IDC 1.1.11.1.0 DATA QUALITY TYPE OF CALC 2 CATEGORY 1

TOTAL CONSUMPTION (T/YR)	0.2755181E+09
NO OF POLLUTANTS	13
FRACTION OF WATER IN WASTE	0.0000
WASTE GEN RATE (T/YR)	0.2878420E+09
WATER DISCHG 10**6 GAL/YR	0.1274200E+05
ASH PD DISCG 10**6 GAL/TR	0.2184000E+06

MATERIAL		EFFLUENT DISCHG (T/YR)	ASH POND DISCHG (T/YR)	FRACT DRY BASIS
1	TDS	0.2168000E+06	0.5827180E+06	0.0000000E+00
2	AS	0.0000000E+00	0.0000000E+00	0.2623000E-03
3	CD	0.0000000E+00	0.0000000E+00	0.2164000E-05
4	CL	0.7470000E+05	0.5007700E+05	0.0000000E+00
5	CU	0.1450000E+04	0.1820000E+03	0.7649999E-04
6	CR	0.9700000E+03	0.9100000E+02	0.8742999E-04
7	F	0.2500000E+04	0.0000000E+00	0.0000000E+00
8	FE	0.7700000E+04	0.2730000E+03	0.2623000E-01
9	HG	0.0000000E+00	0.0000000E+00	0.1093000E-06
10	MN	0.4400000E+02	0.0000000E+00	0.2842000E-03
11	NO3	0.3400000E+02	0.1184000E+04	0.0000000E+00
12	PB	0.0000000E+00	0.0000000E+00	0.4809000E-04
13	SO4	0.8540000E+05	0.1820990E+06	0.0000000E+00

Table A-2. STATE COAL CONSUMPTION DATA

State code	State name	State consumption, T/yr
1	Alabama	0.1338500E+08
2	Alaska	0.3210000E+06
3	Arizona	0.3350000E+06
6	Colorado	0.3124000E+07
7	Connecticut	0.2100000E+05
8	Delaware	0.6710000E+06
9	Florida	0.4738000E+07
10	Georgia	0.7743000E+07
13	Illinois	0.2332000E+08
14	Indiana	0.1930400E+08
15	Iowa	0.2057000E+07
16	Kansas	0.7450000E+06
17	Kentucky	0.1593300E+08
20	Maryland	0.2794000E+07
21	Massachusetts	0.9000000E+04
22	Michigan	0.1418100E+08
23	Minnesota	0.4987000E+07
24	Mississippi	0.8540000E+06
25	Missouri	0.1110400E+08
26	Montana	0.4230000E+06
27	Nebraska	0.9610000E+06
28	Nevada	0.2756000E+07
29	New Hampshire	0.7450000E+06
30	New Jersey	0.1698000E+07
31	New Mexico	0.5361000E+07
32	New York	0.4133000E+07
33	North Carolina	0.1419700E+08
35	Ohio	0.3112400E+08
36	Oklahoma	0.1000000E+04
38	Pennsylvania	0.2687500E+08
40	South Carolina	0.3937000E+07
41	South Dakota	0.2570000E+06
42	Tennessee	0.1493400E+08
43	Texas	0.1948000E+07
44	Utah	0.7020000E+07
45	Vermont	0.2500000E+05
46	Virginia	0.3567000E+07
47	Washington	0.2224000E+07
48	West Virginia	0.1655600E+07
49	Wisconsin	0.7210000E+07
50	Wyoming	0.3940000E+07

Table A-3. STATE AMBIENT CONCENTRATIONS

State	TDS, g/m^3	As, $\mu g/m^3$	Cd, $\mu g/m^3$	Cl, mg/m^3	Cu, $\mu g/m^3$	Cr, mg/m3	F, mg/m^3	Fe, $\mu g/m^3$	Hg, $\mu g/m^3$	Mn, $\mu g/m^3$	NO3, mg/m^3	Pb, $\mu g/m^3$	SO_4, mg/m^3	Flow rate, m^3/s	Tur-bidity	Rain-fall, m
1	73.0	0.0005	0.0010	4.8	0.0070	0.0000	0.2000	0.1050	0.0002	0.0085	0.4100	0.0065	6.8	957.11	38.0	1.495
2	183.0	0.0005	0.0215	2.3	0.0065	0.0000	0.2000	0.2100	0.0001	0.7250	6.4000	0.0115	2.0	46.44	33.0	1.389
3	1324.0	0.0089	0.0005	401.5	0.0075	0.0000	0.9100	0.2875	0.0000	0.0450	2.7000	0.0022	319.0	156.08	15.0	0.179
4	159.5	0.0012	0.0010	5.4	0.0135	0.0000	0.3000	0.4175	0.0000	0.0150	0.3900	0.0030	14.5	138.12	97.5	1.232
5	1055.7	0.0047	0.0007	321.9	0.0101	0.0042	0.4200	0.2508	0.0001	0.0502	0.5200	0.0052	239.9	291.78	33.8	0.426
6	838.0	0.0025	0.0007	46.0	0.0060	0.0000	0.5700	0.2450	0.0000	0.0213	0.9800	0.0022	385.0	45.48	23.0	0.394
7	70.0	0.0010	0.0020	9.2	0.0050	0.0000	0.2000	0.2550	0.0005	0.0800	0.4000	0.0015	11.0	552.18	2.4	1.169
8	0.0	0.0000	0.0000	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	8.95	0.0	1.022
9	180.0	0.0020	0.0015	44.7	0.0041	0.0006	0.5300	0.1950	0.0001	0.0105	0.3600	0.0030	36.7	196.63	7.8	1.306
10	62.0	0.0030	0.0025	5.0	0.0055	0.0005	0.1000	0.1450	0.0000	0.0085	0.3400	0.0025	5.0	351.13	15.0	1.228
11	223.0	0.0005	0.0005	55.0	0.0060	0.0000	0.2000	0.0550	0.0000	0.0900	0.9400	0.0025	3.2	8.95	35.0	0.582
12	154.0	0.0045	0.0015	7.4	0.0100	0.0000	0.4500	0.0600	0.0002	0.2080	0.7000	0.0085	25.0	363.59	9.1	0.292
13	248.0	0.0010	0.0020	16.0	0.0080	0.0002	0.2700	0.3950	0.0001	0.0788	1.8500	0.0038	56.0	3989.87	76.0	0.875
14	330.0	0.0030	0.0000	20.0	0.0050	0.0000	0.3000	0.0000	0.0000	0.0330	1.5000	0.0130	56.0	413.43	69.0	0.984
15	491.0	0.0075	0.0030	10.0	0.0060	0.0015	0.5000	0.0300	0.0006	0.2500	0.0900	0.0100	207.0	836.31	15.0	0.845
16	748.0	0.0045	0.0020	181.0	0.0072	0.0075	0.5300	0.0600	0.0005	0.0300	0.9500	0.0072	146.0	77.19	70.0	0.722
17	116.0	0.0015	0.0020	6.0	0.0108	0.0005	0.2100	0.0517	0.0002	0.0110	0.4700	0.0030	19.3	1503.63	40.0	1.095
18	141.0	0.0025	0.0016	20.1	0.0070	0.0005	0.2600	0.1090	0.0001	0.0443	0.3800	0.0049	23.4	252.02	75.0	1.442
19	40.0	0.0005	0.0000	2.6	0.0050	0.0000	0.3000	0.1200	0.0005	0.0350	0.0400	0.0085	8.4	566.34	30.0	1.036
20	165.0	0.0005	0.0000	12.5	0.0000	0.0000	0.2000	0.0550	0.0005	0.0050	0.8500	0.0040	41.0	224.98	24.0	1.028
21	61.0	0.0010	0.0010	13.0	0.0150	0.0050	0.3000	0.1600	0.0006	0.0600	0.3800	0.0035	8.3	272.98	3.0	1.080
22	187.4	0.0032	0.0009	14.0	0.0036	0.0002	0.3000	0.0325	0.0003	0.0188	0.2900	0.0056	20.0	1793.60	5.7	0.796
23	319.0	0.0022	0.0007	12.0	0.0108	0.0100	0.2700	0.1180	0.0000	0.0220	0.3800	0.0050	53.0	147.53	39.0	0.659
24	140.0	0.0038	0.0023	14.0	0.0045	0.0018	0.2300	0.4520	0.0001	0.0440	0.7000	0.0152	25.0	13520.52	63.5	1.257
25	308.0	0.0018	0.0008	13.8	0.0055	0.0033	0.3300	1.0570	0.0002	0.0750	2.1200	0.0042	65.0	1198.66	144.0	0.912
26	342.0	0.0102	0.0015	10.5	0.0065	0.0000	0.7200	0.0475	0.0001	0.0275	0.1700	0.0028	121.0	113.66	125.0	0.289
27	0.0	0.0035	0.0005	19.0	0.0210	0.0000	0.4700	0.0400	0.0000	0.0065	1.6000	0.0040	185.0	70.79	43.0	0.767
28	146.0	0.0090	0.0015	19.0	0.0035	0.0000	0.1800	0.2450	0.0001	0.0150	0.0000	0.0040	21.0	34.58	10.0	0.219
29	0.0	0.0000	0.0000	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	8.95	0.0	0.919
30	99.0	0.0010	0.0005	8.9	0.0100	0.0050	0.2000	0.0750	0.0005	0.0200	0.9200	0.0025	23.0	951.45	3.9	1.076
31	264.0	0.0020	0.0002	6.7	0.0032	0.0150	0.5100	0.0750	0.0000	0.0258	0.1600	0.0005	79.0	29.48	68.0	0.246
32	241.0	0.0012	0.0056	27.8	0.0050	0.0025	0.5600	0.1000	0.0005	0.0412	0.4500	0.0020	33.2	3173.77	21.9	0.952
33	73.0	0.0035	0.0020	8.8	0.0050	0.0010	0.2000	0.4050	0.0001	0.2020	0.5200	0.0080	9.9	137.05	17.5	1.091
34	780.0	0.0035	0.0018	42.3	0.0125	0.0025	0.3900	0.0725	0.0001	0.0150	0.4400	0.0020	346.0	20.22	1150.0	0.410
35	540.0	0.0025	0.0007	82.3	0.0162	0.0107	0.4700	0.0383	0.0003	0.2680	2.8000	0.0033	100.0	215.21	51.0	0.953
36	906.0	0.0026	0.0010	275.0	0.0062	0.0000	0.5500	0.0600	0.0000	0.0185	0.3400	0.0042	196.0	233.90	40.0	0.797
37	48.0	0.0025	0.0010	3.6	0.0088	0.0075	0.2000	0.1650	0.0000	0.0325	0.1400	0.0055	7.9	1815.12	6.6	0.955
38	172.0	0.0010	0.0042	38.2	0.0050	0.0025	0.1700	0.1880	0.0005	0.4750	0.9600	0.0012	346.0	1257.27	18.7	0.985
39	0.0	0.0000	0.0000	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	8.95	0.0	1.027
40	64.0	0.0025	0.0020	6.9	0.0042	0.0002	0.1500	0.0625	0.0000	0.0168	0.1200	0.0072	8.0	227.39	7.7	1.324
41	391.0	0.0145	0.0000	7.4	0.0150	0.0000	0.7300	0.0800	0.0000	0.0100	1.0000	0.0025	103.0	11.30	6483.0	0.464
42	209.0	0.0050	0.0005	12.0	0.0125	0.0000	0.4700	0.9650	0.0000	0.0140	1.4000	0.0035	49.0	23361.52	117.0	1.168
43	373.0	0.0030	0.0003	63.0	0.0052	0.0050	0.2400	0.0830	0.0001	0.0700	0.4700	0.0017	69.0	181.14	52.0	0.932
44	699.0	0.0058	0.0018	131.0	0.0128	0.0017	0.4000	0.0650	0.0001	0.0250	0.9700	0.0065	187.0	96.50	75.0	0.385
45	0.0	0.0000	0.0000	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	8.95	0.0	0.827
46	92.0	0.0000	0.0035	7.6	0.0030	0.0010	0.1000	0.1050	0.0011	0.0035	0.2200	0.0050	12.0	203.03	18.0	1.135
47	85.8	0.0016	0.0014	3.0	0.0096	0.0000	0.2000	0.0460	0.0000	0.0120	0.2800	0.0049	11.0	8495.10	19.0	0.714
48	145.0	0.0010	0.0035	17.0	0.0200	0.0000	0.1800	0.0650	0.0005	0.0650	0.6700	0.0050	38.0	441.75	21.0	0.976
49	421.0	0.0065	0.0045	43.0	0.0050	0.0015	0.4000	0.0300	0.0005	0.0235	1.2000	0.0110	43.0	29.73	20.0	0.752
50	204.0	0.0040	0.0005	5.4	0.0025	0.0000	0.5000	0.0450	0.0000	0.0100	0.0200	0.0085	40.0	244.36	11.0	0.383

noted to be 73 g/m^3. The total U.S. ash pond discharge volume is 0.2184×10^{12} gal/yr from Table A-1. Conversion of ambient TDS into tons/yr is determined from:

$$\frac{0.2184 \times 10^{12} \text{ gal}}{\text{yr}} \times \frac{m^3}{264.2 \text{ gal}} \times \frac{73 \text{ g}}{m^3} \times \frac{\text{lb}}{453.6 \text{ g}} \times \frac{\text{ton}}{2000 \text{ lb}}$$

$$= \frac{6.652 \times 10^4 \text{ tons}}{\text{yr}} \qquad \text{(A-1)}$$

This ambient TDS value is then added to the TDS mass of the ash pond discharge, 0.5827×10^6 tons/year, shown in Table A-1, to obtain the total TDS ash pond discharge mass:

$$\text{Total TDS ash pond discharge mass} = (6.652 \times 10^4) + (0.5827 \times 10^6)$$

$$= \frac{6.49 \times 10^5 \text{ tons}}{\text{yr}} \qquad \text{(A-2)}$$

From Table A-2, the coal consumption for Alabama is shown to be 0.13385×10^8 tons/year. From Table A-1, the total annual coal consumption for the U.S. is 0.276×10^9 tons/yr. Hence, the fraction of total coal consumed for Alabama is:

$$\text{Fraction of coal consumed for Alabama} = \frac{0.1339 \times 10^8}{0.2761 \times 10^9} \qquad \text{(A-3)}$$

$$= 0.0485$$

An effluent mass loading, X, for only the water portion due to TDS is calculated as:

$$X = 0.0485\ (0.2168 \times 10^6 + 6.49 \times 10^5) \text{ tons/yr}$$

$$= 4.2 \times 10^4 \text{ tons/yr or } 0.121 \times 10^4 \text{ g/s} \qquad \text{(A-4)}$$

TDS does not enter into the solid waste calculation. Hazard potential, Z, is then calculated for this material from:

$$Z = V_R D \qquad \text{(A-5)}$$

where Z = hazard potential
V_R = river discharge rate, m^3/s
D = drinking water standard for TDS, g/m^3

From Table A-3, the average river flow rate, V_R, for Alabama is 957.11 m^3/s. The drinking water standard for TDS is 500 g/m^3. Hence, substitution into Equation A-5 yields:

$$Z = 957.11 \frac{m^3}{s} \times 500 \frac{g}{m^3} = 4.79 \times 10^5 \text{ g/s}$$

A relative mass loading factor, A, is defined as:

$$A = \frac{X}{Z} = \frac{0.121 \times 10^4}{4.79 \times 10^5} = 2.53 \times 10^{-3} \qquad \text{(A-6)}$$

As in the air model, weighting factor is defined as the ratio of an ambient concentration relative to the standard:

$$W = \frac{C_A}{D} \qquad \text{(A-7)}$$

where W = ambient weighting factor
C_A = ambient concentration for TDS in Alabama, g/m^3
D = drinking water standard, g/m^3

From Table A-3, for Alabama the average TDS is 73 g/m^3; thus, substitution into Equation A-7 yields:

$$W = \frac{C_A}{D} = \frac{73 \text{ g/m}^3}{500 \text{ g/m}^3} = 0.146$$

As in the air model, weighting factors less than one will not be used. Hence, W is set equal to one for such values.

This condition is stated mathematically as follows:

$$W = \begin{cases} \frac{C_A}{D} \text{ if } \frac{C_A}{D} \geq 1.0 \\ 1.0 \text{ if } \frac{C_A}{D} \leq 1.0 \end{cases} \quad \text{(A-8)}$$

The first term, T_{11}, (for TDS in Alabama) is defined as follows:

$$T_{11} = A^2W = (2.53 \times 10^{-3})^2(1.0) = 6.4 \times 10^{-6} \quad \text{(A-9)}$$

2. ARSENIC

The procedure for calculating the term due to arsenic (As) in Alabama consists of first defining the relative mass loading term A as:

$$A = \frac{X + Y}{Z} \quad \text{(A-10)}$$

where X = effluent mass loading for only the direct water discharge

Y = effluent mass loading due to solid residual leaching

and Z = hazard potential mass

Even though in Table A-3 the ash pond discharge for arsenic is zero, the ambient level average for Alabama is included as follows:

$$\text{Alabama ash pond discharge} = (0.2184 \times 10^{12})(0.0485) = 1.059 \times 10^{10} \text{ gal/yr} \quad \text{(A-11)}$$

C_A, the ambient arsenic concentration in Alabama, is 5×10^{-4} g/m^3 from Table A-3. Hence, the effluent mass loading for only the direct water discharge, X, is determined from:

$$X = \frac{1.059 \times 10^{10}\ \text{gal}}{\text{yr}} \times \frac{\text{m}^3}{264.2\ \text{gal}} \times \frac{5 \times 10^{-4}\ \text{g}}{\text{m}^3} \times \frac{\text{lb}}{453.6\ \text{g}} \times \frac{\text{ton}}{2000\ \text{lb}}$$

$$= \frac{0.022\ \text{tons}}{\text{yr}} \text{ or } 6.35 \times 10^{-4}\ \text{g/s} \qquad \text{(A-12)}$$

The effluent mass loading due to solid residual leaching, Y, is defined as:

$$Y = S_G f_1 f_2 \qquad \text{(A-13)}$$

where S_G = solid waste generation rate, tons/yr

$f_2 = [1 - (H_2O)_f][i_f]$ (A-14)

$(H_2O)_f$ = fraction of water in solid residual

i_f = fraction of constituent on a dry basis

$f_1 = \alpha e^{\beta R}$ (A-15)

f_1 = fraction of solid residual leached by rainfall

R = annual rainfall, m

α and β = dimensionless constants that keep total solids under 50 g/l

$\alpha = 1.723 \times 10^{-4}$

$\beta = 1.48$

From Table A-1, the solid waste generation rate, the fraction of arsenic on a dry basis, and the fraction of water in the solid residual are respectively:

$$S_G \text{ (total U.S.)} = 0.288 \times 10^9 \text{ tons/yr}$$
$$i_f = 0.262 \times 10^{-3}$$
$$(H_2O)_f = 0.0$$

From Table A-3, for state 1 (Alabama), the rainfall is 1.495 m. As before, the solid residual generation rate in Alabama is computed by applying the coal consumption for that state to the total U.S. solid waste generation rate:

$$S_G \text{ (Alabama)} = S_G \text{ (total U.S.)} \cdot 0.0485 \qquad \text{(A-16)}$$
$$= 1.4 \times 10^7 \text{ tons/yr}$$

As shown earlier,

$$f_2 = [1 - (H_2O)_f][i_f] \qquad \text{(A-14)}$$

Substitution yields:

$$f_2 = (1 - 0.0)(0.262 \times 10^{-3}) = 0.262 \times 10^{-3}$$

The fraction of solid residual leached by rainfall, f_1, is computed from $f_1 = \alpha e^{\beta R}$, which is Equation A-15, shown earlier. Using the rainfall (R) as 1.495 m from Table A-3 and values for α and β listed earlier:

$$f_1 = \alpha e^{\beta R} = (1.723 \times 10^{-4}) e^{(1.48)(1.495)} = 1.58 \times 10^{-3}$$

The effluent mass loading due to solid residual leaching, Y, was defined earlier as:

$$Y = S_G f_1 f_2 \qquad \text{(A-13)}$$

Substituting from above yields:

$$Y = (1.4 \times 10^{7})(1.58 \times 10^{-3})(0.262 \times 10^{-3})$$
$$= 5.8 \text{ tons/yr or } 0.17 \text{ g/s}$$

The hazard potential mass, Z, is calculated as before:

$$Z = V_R D \qquad \text{(A-5)}$$

The drinking water standard, D, for arsenic is 0.05 g/m^3 and the river discharge rate is 957.11 m^3/s.

Hence, $Z = (957.11 \text{ m}^3/\text{s})(0.05 \text{ g/m}^3) = 47.9$ g/s

The relative mass loading factor, A, was defined as:

$$A = \frac{X + Y}{Z} \qquad \text{(A-10)}$$

Since $X = 6.35 \times 10^{-4}$ g/s, $Y = 0.17$ g/s and $Z = 47.9$ g/s,

$$A = \frac{6.35 \times 10^{-4} + 0.17}{47.9} = 3.56 \times 10^{-3}$$

From Table A-3, the ambient level of arsenic in Alabama is noted to be 5×10^{-4} g/m^3. The weighting factor, W, is then:

$$W = \frac{C_A}{D} \qquad \text{(A-7)}$$

$$= \frac{5 \times 10^{-4}}{0.05} = 0.01$$

Since $W \leq 1.0$, let $W = 1.0$. The second term T_{21}, (arsenic in Alabama) is then:

$$T_{21} = A^2W = (3.56 \times 10^{-3})^2(1.0) = 1.27 \times 10^{-5} \quad \text{(A-17)}$$

3. OTHER DISCHARGED MATERIALS

Calculations similar to those described above are then carried out for the remaining discharges in Alabama.

4. IMPACT FACTOR CONTRIBUTION FROM ALABAMA

After the last term for sulfates, $T_{13,1}$, has been calculated, all the terms, are summed, their square root is obtained and multiplied by the population density, P, in Alabama to yield Alabama's contribution to the overall impact factor for this source type:

$$I_{W_1} = P_{Alabama}(T_{1,1} + T_{2,1} + \ldots . T_{13,1})^{1/2} \quad \text{(A-18)}$$

5. OVERALL IMPACT FACTOR FOR SOURCE TYPE

The entire procedure described above is then repeated for each remaining state in an analogous fashion to yield similar state contributions to the overall impact factors designated $I_{W_2} \ldots . I_{W_{50}}$. The overall impact factor for the generation of electricity by the external combustion of dry pulverized bituminous coal is expressed as:

$$I_W = I_{W_1} + I_{W_2} + \ldots . I_{W_{50}} \quad \text{(A-19)}$$

SECTION VI

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16. ABSTRACT The report describes mathematical models that were developed to relatively rank the environmental impact of water and solid residue emissions. The water model, similar to an air prioritization model developed in an earlier study, is based on mass of emission, hazard potential of the emission, ambient water loading, and polulation density in the emission region. Solid emissions were divided into air and water emission components and these contributions were incorporated into air and water prioritization models. The report gives the relative ranking resulting from the application of the models to 56 conventional stationary combustion sources.

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Ranking		Prioritization	12B	
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