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WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA: VOLUME I - BACKGROUND AND THEORY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA: VOLUME I - BACKGROUND AND THEORY

by

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WEIGHTED SENSITIVITY ANALYSIS OF EMISSIONS DATA

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PREFACE

The project described in this report was performed under the auspices of the Environmental Protection Agency in conformance with Task Order No. 1, BOA68-01-0398.

The work performed as the Weighted Sensitivity Analysis of Emissions Data project proceeded with unusual effectiveness because of the excellent support provided by the Technical Project Monitor, Mr. John Bosch, and his associates. During the course of the project, Mr. Bosch gave much valuable assistance and guidance which led to the timely and successful completion of the project. Because of these efforts, it was possible to develop additional programs beyond those originally contemplated. The support of Mr. Gerald Nehls to provide basic and test data from the NEDS data was greatly appreciated and directly contributed to the capability to extend the study to include the SCC summarization program.

WEIGHTED SENSITIVITY ANALYSIS (WSA) OF EMISSION INVENTORIES

The IBM contractual report on weighted sensitivity analysis (WSA) allows users to quantitatively analyze the effects of potential inaccuracies in their air pollution source/emissions inventories. This enables the user to quantify the amount and direction of future resources he must allocate to maintain a given accuracy for his entire emissions inventory. The WSA is one of a series of management tools provided by EPA to effectively interpret emission and source inventories of air pollutant emitters.

WSA is based on the format used and data contained in the National Emissions Data System (NEDS), the official air pollution data base used by EPA. Because a number of States are patterning their emission inventories according to NEDS, the WSA with subsequent modifications is also expected to be useful to non-EPA users, especially to the pollution control agencies using the Comprehensive Data Handling System (CHDS).

The primary objective of WSA is to calculate the maximum allowable variation in emissions for each of the component sub-categories of the emission inventory. This is accomplished by the user first specifying an acceptable error in the total emissions of any criteria pollutant for the geographical area of interest (County, AQCR, State, U. S.). (This is referred to as θ in the WSA report.)

WSA then applies standard statistical techniques to the NEDS inventory for that geographical area and delivers an "allowable" error for over 100 sub-categories comprising all components of the emission inventory.

WSA calculates the maximum variance in emissions for each sub-category in order to maintain the previously=-specified error for the total inventory. It must be emphasized that WSA does not estimate the actual or existing emission errors for each sub-category: this can only be accomplished by accessing the rew data files of NEDS and estimating the errors due to emission calculations on an individual point and area source basis. An EPA contract is currently underway to perform this function (Source Inventory and Emission Factor Analysis; SIEFA) which will be complementary with WSA and will provide users with an integrated system for error analysis.

Four major assumptions were required for the successful development of WSA:

1. The "on-paper" inventory represents the "real-world" emissions. The necessity of this assumption is apparent: analysis of any data base presupposes that that data base is correct. Any analytical tool becomes more useful to users as the data which it utilizes become more complete.

2. The allowable errors calculated for each sub-category are assumed to be independent of each other. This assumption was necessary to develop the WSA analysis and is justified because any error interdependencies between sub-categories (e.g. population biases) are

considered to be minor compared to the numerous other causes of emission errors for a given sub-category. It should be noted that the sub-category errors are considered to be independent and not the sub-category emissions.

3. Sub-category errors are considered to be random in nature. It is felt that this assumption is, in general, a valid one and WSA was designed with this definition. As described in the WSA report, however, there is a capability to "fix" sub-category errors when known by the user. In this manner, biased or random errors for an individual sub-category can be inserted into WSA whenever they are available. (In such cases, WSA recalculates allowable errors for the remaining sub-categories.)

4. WSA assumes that the distribution of component errors is unknown. This provides for a conservative estimate of the confidence limits to be attached to the θ's (defined in the WSA report as overall errors). There are no known means of estimating the distribution of emission inventory errors although SIEFA will eventually provide such a mechanism; thus the assumption of a normal error distribution seems inappropriate at this time.

It must be emphasized that in analyzing a small subset of inventory data the user should reevaluate the validity of the above WSA assumptions for his project before relying on the technique.

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Section I

INTRODUCTION

This final report documents the work performed under contract BOA 68-01-0398, "Weighted Sensitivity Analysis of Emissions Data". It presents a body of analytical techniques appropriate for determining accuracy requirements of component parts of an emissions inventory so as to insure (at a given confidence level) an overall acceptable accuracy in the total inventory. Selected numerical analyses are presented to illustrate application of the techniques to Nationwide Emissions Report (NER) data at different levels of aggregation. Contract work included development of the necessary software to implement the results of the analysis. The results are believed to constitute a significant step in the development of techniques for making reliable forecasts of air pollutant emissions, and have already been applied for such purposes to emissions in region 5 of the State of Virginia. A report on that application is also included in the present document.

PROJECT BACKGROUND

In 1969, NAPCA established a project called "Projected Growth Data for the Air Quality Control Regions"; in support of this project the U.S. Department of Commerce, Office of Business Economics (OBE), prepared the document, "Economic Projections for Air Quality Control Regions," (PB195805) in June 1970, in ample time to support the nationwide preparation of state air quality control implementation plans.

The preparation of these projections entailed the application of sophisticated techniques by expert econometricians and the utilization of esoteric methodologies by specialists in the Regional Economics Division of OBE.

Although these projections were the best possible, there was no way of predetermining their accuracy or relating economic projection errors to predicted air pollutant emission errors. On the basis of the OBE report's nationwide projections to 1970, the error in projected gross national product was just under 6%, the error in the projected population was 0.75%. The significance of these errors with respect to projected emissions is unkown.

The National Source Inventory Section of EPA processes and publishes data on point and area source emissions of air pollutants, and is responsible for determining the quality of the data used. The emissions inventory is a basic requirement of states' implementation plans and provides EPA with a valuable management tool in the decision-making process associated with the administration of air pollution control activity. It is no longer satisfactory to merely provide an inventory; it is necessary to quantitatively state in statistical terms error existent in a specified inventory. This being the case, the National Source Inventory Section actively sought development of statistical methodology to establish the quality of emissions data.

The methods of weighted sensitivity analysis were chosen as the most flexible approach to develop the necessary techniques, and the Federal Systems Center of IBM Corporation was engaged to perform the necessary theoretical and numerical analyses, as well as to develop the necessary software and its documentation.

PROJECT OBJECTIVES

It is appropriate to summarize at the outset the objectives sought in undertaking the project, as mutually agreed upon between EPA and IBM. The goals to be achieved in the project, as stated in the work scope, were as follows:

1. Analysis

   In this activity, a methodology is to be formally derived whereby accuracy requirements of component parts of an emission inventory can be calculated so as to insure an overall acceptable accuracy in the total inventory. The techniques of weighted sensitivity analysis are to be applied in the performance of this task.

2. Program Development

   In this activity, a FORTRAN computer program for weighted sensitivity analysis is to be designed, coded, tested and debugged. The resulting software will provide a means to evaluate the maximum permissible errors in emissions data with sufficient flexibility to be applicable to both source categories and geographical areas, for a given maximum permissible error of the nationwide inventory. Complete compatibility with NEDS will be assured.

3. Numerical Validation

   In order to demonstrate the adequacy of the analysis and the usage of the computer program, three sample analyses shall be performed (using 1970 nationwide emissions data) to indicate the maximum error in source categories and subcategories (nationwide) for three different nationwide inventory maximum errors to be provided by EPA.

SUMMARY OF RESULTS

Project objectives and requirements as set forth above have been fully achieved. Furthermore, significant developments in both analysis and programming beyond the original goals have been accomplished. A summary of the addtional results obtained is as follows:

1. Refinement of the theoretical weighted sensitivity analysis to distribute both percentage and physical errors in emissions according to their respective weightings.
2. Extension of the analysis to cover the case where one or more of the error components in a given level are to be fixed by the analyst.
3. Modification and/or extension of the software to implement developments 1 and 2 as part of the deliverable program.
4. Parameterization of the software to allow the analyst to apply the program to alternative hierarchial configurations of the emissions data.
5. Extension of the software to permit application of the weighted sensitivity analysis to emissions data at the SCC level of aggregation.
6. Preparation of a comprehensive set of numerical analyses to demonstrate applicability of the technique and adequacy of the computer program. Numerical analyses were conducted for different areas (e.g., county, state, AQCR, U.S.), for different emissions data configurations (e.g., point and area fuel combustion emissions restructured by fuel usage).
7. Consolidated application of weighted sensitivity analysis techniques and Chebyshev's inequality to establish confidence levels for emission inventories.

Section II

GENERAL ANALYSIS

The section presents the techniques developed for weighted sensitivity analysis and its application to emissions data as contained in the National Emissions Data System (NEDS) reports. The presentation will be focused on the application of the analytical technique to emissions data, rather than the theoretical development of the technique itself. The reader interested in the latter is referred to Appendix A for a full discussion of the theoretical analysis. An annotated numerical example is also included in this section, to provide insight on how the propagation of random error throughout the inventory is accounted for in the application of the weighted error formulae.

HIERARCHIAL STRUCTURE OF EMISSIONS DATA

The reports of the National Emissions Data System (NEDS) constitute the primary source of data for this project. In fact, the weighted sensitivity analysis technique introduced below was specifically developed for the treatment of random error in these sets of data, although it can also be applied to any other set of data processing the same properties.

Figure 2.1 displays a sample nationwide emissions report from NEDS. Emissions as of April 19, 1973, are listed by source categories for five classes of air pollutants: particulates, sulfur oxides, nitrogen oxides, hydrocarbons and carbon monoxide. The source categorization is uniform for other area reports, i.e., county, AQCR, and state emissions reports.

NATIONAL EMISSIONS DATA SYSTEM
****

ENVIRONMENTAL PROTECTION AGENCY
****

NATIONWIDE EMISSIONS REPORT
****
UNITED STATES

RUN DATE: MAY 11, 1973
EMISSIONS AS OF: APRIL 19, 1973

	PARTICULATES (TONS/YR)	SOX (TONS/YR)	NOX (TONS/YR)	HC (TONS/YR)	CO (TONS/YR)
FUEL COMBUSTION					
EXTERNAL COMBUSTION					
RESIDENTIAL FUEL (AREA)					
ANTHRACITE COAL	12344	32313	3703	3086	111094
BITUMINOUS COAL	79062	307600	11859	79062	355781
DISTILLATE OIL	72879	382[illegible]36	87454	21864	36439
RESIDUAL OIL	295	2417	513	38	3
NATURAL GAS	47[illegible]27	1513	126125	2218[illegible]	50450
WOOD	52377	1049	20951	4190	4190
TOTAL (RESIDENTIAL)	264885	727227	250606	123421	557957
ELEC GENERATION (POINT)					
ANTHRACITE COAL	19246	47636	12831	152	3417
BITUMINOUS COAL	3314[illegible]	13997368	3437582	[illegible]	151896
LIGNITE	27872	59896	757295	0	5895000
RESIDUAL OIL	27500	1168726	531673	1073[illegible]	215
DISTILLATE OIL	3519	21026	19392	399	7
NATURAL GAS	20348	11410	603619	62955	1123
PROCESS GAS	46	10160	3105	102	0
SOLID WASTE/COAL	240	0	200	50	40
OTHER	2527	2080	0	0	0
TOTAL (ELEC GEN)	3416197	15317302	5365898	121528	6051697

Figure 2.1 NEDS Data in Tabular Format

ANTHRACITE COAL					
POINT SOURCES	10088	23698	6151	56	1745
BITUMINOUS COAL					
AREA SOURCES	135782	903767	175953	11700	23460
POINT SOURCES	1233810	2644058	582521	17106	53929
RESIDUAL OIL					
AREA SOURCES	13156	48799	52623	2631	175
POINT SOURCES	54042	759386	166784	[illegible]	605
DISTILLATE OIL					
AREA SOURCES	24531	247475	63994	3200	213
POINT SOURCES	23899	34578	103645	[illegible]	329
NATURAL GAS					
AREA SOURCES	[illegible]	743	222516	[illegible]	495
POINT SOURCES	[illegible]	30178	1433016	170225	4634
PROCESS GAS					
AREA SOURCES	5	0	71	12	0
POINT SOURCES	10885	94790	8295	56	2
COKE					
POINT SOURCES	1143	1706	0	0	0
WOOD					
AREA SOURCES	1460	29	584	117	117
POINT SOURCES	147086	9695	97072	21104	19487
LIQUID PETROL GAS					
POINT SOURCES	256	24	1703	561	1
OTHER					
POINT SOURCES	5066	3341	237	29	7723
TOTAL (INDUSTRIAL)					
AREA SOURCES	1412216	1200813	516042	67205	24461
POINT SOURCES	1562142	3601454	2449426	223016	88455
COMM-INSTITUTIONAL FUEL					
ANTHRACITE COAL					
AREA SOURCES	504	551	221	4	133
POINT SOURCES	236	[illegible]	86	2	114
BITUMINOUS COAL					
AREA SOURCES	144322	221777	26351	5728	20623
POINT SOURCES	58973	86857	17330	1657	4882
RESIDUAL OIL					
AREA SOURCES	51432	596161	134300	6715	448
POINT SOURCES	7730	80474	20031	954	84
DISTILLATE OIL					
AREA SOURCES	60861	217820	243443	12172	811
POINT SOURCES	743	4355	2611	132	10
NATURAL GAS					
AREA SOURCES	[illegible]	560	93352	7468	18670
POINT SOURCES	20888	2965	124134	8575	20585
WOOD					
AREA SOURCES	102	2	41	8	8
POINT SOURCES	586	49	625	140	125
LIQUID PETROL GAS					
POINT SOURCES	2	0	10	1	2
TOTAL (COMM-INST)					
AREA SOURCES	275008	1036922	497708	32096	40693
POINT SOURCES	89158	176071	164827	11461	25803
OTHER (POINT)	2741	211	246	0	0
TOTAL (EXTERNAL COMB)					
AREA SOURCES	1952109	2964961	1264356	227722	623111
POINT SOURCES	[illegible]	19095039	7980397	356005	6165954

Figure 2.1 (cont.)

INTERNAL COMBUSTION (POINT)					
ELECTRIC GENERATION					
DISTILLATE OIL	1043	2371	8287	62	92
NATURAL GAS	13	0	3523	0	0
DIESEL	94	196	2687	269	1634
TOTAL (ELEC GEN)	1151	2567	14498	331	1726
INDUSTRIAL FUEL					
DISTILLATE OIL	86	408	920	35	212
NATURAL GAS	1285	7299	828953	27637	10423
GASOLINE	9	4	168	491	1228
DIESEL FUEL	48	87	1245	128	729
TOTAL (INDUSTRIAL)	1429	7799	831285	28291	12592
COMM-INSTITUTIONAL					
DIESEL	47	97	1328	133	808
OTHER	6	2	11	9	3
TOTAL (COMM-INST)	53	99	1339	142	811
ENGINE-TESTING					
AIRCRAFT	172	72	397	377	940
OTHER	151	0	0	0	0
TOTAL (ENG TESTNG)	323	72	397	377	940
OTHER (POINT)	0	0	0	220	0
TOTAL (INTERNAL COMB)	2956	10537	847519	29360	16069
TOTAL (FUEL COMBUSTION)					
AREA SOURCES	1952109	2964961	1264356	227722	623111
POINT SOURCES	5073194	19105576	8827916	385365	6182023
INDUSTRIAL PROCESS (POINT)					
**************************					
CHEMICAL MANUFACTURING	194243	431773	91649	2151455	5799504
FOOD/AGRICULTURAL	215492	912	2989	22255	548
PRIMARY METAL	1476560	3792555	15060	111779	2980138
SECONDARY METALS	144426	89535	1776	2264	1393596
MINERAL PRODUCTS	4589503	305369	99161	7559	18723
PETROLEUM INDUSTRY	1432023	1832762	3020727	865146	7254689
WOOD PRODUCTS	323630	81283	2230	12764	527647
EVAPORATION	881	2545	545	1598193	2110
METAL FABRICATION	4035	2266	905	1002	38
LEATHER PRODUCTS	0	0	0	380	0
TEXTILE MANUFACTURING	501	40	0	4778	0
INPROCESS FUEL	20592	30513	16618	12479	4881
OTHER/NOT CLASSIFIED	8364	10908	433	93637	30860
TOTAL (INDUSTRIAL)	8410250	6580464	3252095	4883692	18012733

Figure 2.1 (cont.)

SOLID WASTE DISPOSAL
****

GOVERNMENT (POINT)					
MUNICIPAL INCINERATION	34619	5323	4268	12453	64403
OPEN BURNING	26039	1597	9503	48278	137467
TOTAL (GOVERNMENT)	60658	6920	13771	60731	201869
RESIDENTIAL (AREA)					
ON SITE INCINERATION	179419	2990	5981	598064	1794192
OPEN BURNING	114906	7182	43090	244174	610436
TOTAL (RESIDENTIAL)	294325	10172	49070	842238	2404628
COMMERCIAL-INSTITUTIONAL					
ON SITE INCINERATION					
AREA SOURCES	31949	3994	5325	26624	53248
POINT SOURCES	1263	761	534	1341	10989
OPEN BURNING					
AREA SOURCES	38554	2410	14458	81928	204820
POINT SOURCES	1159	0	136	273	3409
APARTMENT					
POINT SOURCES	1104	19	116	552	740
TOTAL (COMM-INST)					
AREA SOURCES	70503	6403	19783	108552	258068
POINT SOURCES	3527	779	786	2166	15138
INDUSTRIAL					
ON SITE INCINERATION					
AREA SOURCES	147877	18485	24646	123230	246461
POINT SOURCES	62791	17945	7788	55589	587646
OPEN BURNING					
AREA SOURCES	104570	6536	39214	222212	555530
POINT SOURCES	14246	255	2766	34923	48957
AUTO BODY INCINERATION					
POINT SOURCES	14	0	1	3	17
OTHER					
POINT SOURCES	38	3150	8	79	22
TOTAL (INDUSTRIAL)					
AREA SOURCES	252447	25020	63860	345443	801991
POINT SOURCES	77089	21350	10562	90594	636643
OTHER (POINT)	7	0	0	0	0
TOTAL (SOLID WASTE DISP)					
AREA SOURCES	617275	41595	132713	1296233	3464687
POINT SOURCES	141280	29049	25119	153482	853650

Figure 2.1 (cont.)

TRANSPORTATION (AREA)					
********************					
LAND VEHICLES					
GASOLINE					
LIGHT VEHICLES	344770	206862	4941699	10522889	57097621
HEAVY VEHICLES	20573	12344	635779	1397178	5754393
OFF HIGHWAY	11900	7437	261797	822577	4507067
TOTAL (GASOLINE)	377243	226643	5889274	12742645	67359081
DIESEL					
HEAVY VEHICLES	40210	80421	1139292	115929	670172
OFF HIGHWAY	15494	32180	440984	44098	268166
RAIL	52197	135712	156591	104394	146151
TOTAL (DEISEL)	107901	248312	1736867	262421	1084489
AIRCRAFT					
MILITARY	147475	28161	70847	343120	368317
CIVIL	8438	1676	7622	37369	213538
COMMERCIAL	55226	12235	34551	132542	314362
TOTAL (AIRCRAFT)	211138	42071	113021	513031	896217
VESSELS					
BITUMINOUS COAL	1273	3183	191	1273	5729
DIESEL FUEL	13607	35535	41002	27334	38268
RESIDUAL OIL	6036	26242	15745	787	52
GASOLINE	823	514	18095	56656	311523
TOTAL (VESSELS)	21799	65474	75033	86250	355573
GAS HANDLING EVAP LOSS	0	0	0	913375	0
TOTAL (TRANSPORTATION)	718081	582501	7814195	14517727	69695361
MISCELLANEOUS (AREA)					
********************					
SLASH BURNING	220278	0	25915	259150	777451
SOLVENT EVAPORATION LOSS	0	0	0	1383855	0
TOTAL (MISCELLANEOUS)	220278	0	25915	1543005	777451
OTHER (POINT)	8	0	0	0	0
************					
GRAND TOTAL					
***********					
AREA SOURCES	3507743	3589057	9237179	17684687	74560610
POINT SOURCES	13624732	25715089	12105130	5422538	25048407
TOTAL	17132475	29304146	21342309	23107225	99609017

Figure 2.1 (cont.)

From the viewpoint of analysis, the most important property of these sets of data is their hierarchial nature. In fact, the tabular source categorization of the NEDS reports can be best understood if its hierarchial structure is explicitly recognized. This can be effectively done by converting the tabular format of Figure 2.1 to a tree format, as shown in Figure 2-2. Taking the grand total of the very bottom of the table in Figure 2.1 as the starting point or highest level, the tree unfolds back hierarchially through four and sometimes five successively lower levels of aggregation, the lowest level being the elementary emissions data for each segment of the tree.

The tree format of Figure 2.2 provides a convenient, systematic representation of an emissions inventory for analysis purposes. Each node of the tree, together with the branches coming out of it, constitutes a level of error propagation in the inventory. Therefore, the weighted sensitivity analysis must be applied hierarchially, starting with the allowable error for the grand total (i.e., the overall allowable error), so as to compute allowable errors for each one of the branches which, if satisfied, insure that the overall allowable error is not exceeded.

Figure 2.2 displays the tree of source nodes and branches, numerically annotated to facilitate the discussion. Thus, for example, node 1.1 (fuel combustion-point) has two branches denoted as 1.1.1 and 1.1.2 (external combustion and internal combustion, respectively). The emission quantity (in tons/year) associated with each branch throughout the tree is of course read from the appropriate total, subtotal or elementary data item in the NEDS table of Figure 2.1. This is illustrated in Figure 2.3, which displays a segment of the tree with the actual particulate emission quantities for each branch. For example, 3416197 tons/year of particualte emissions is shown as originating from electricity generation through external fuel

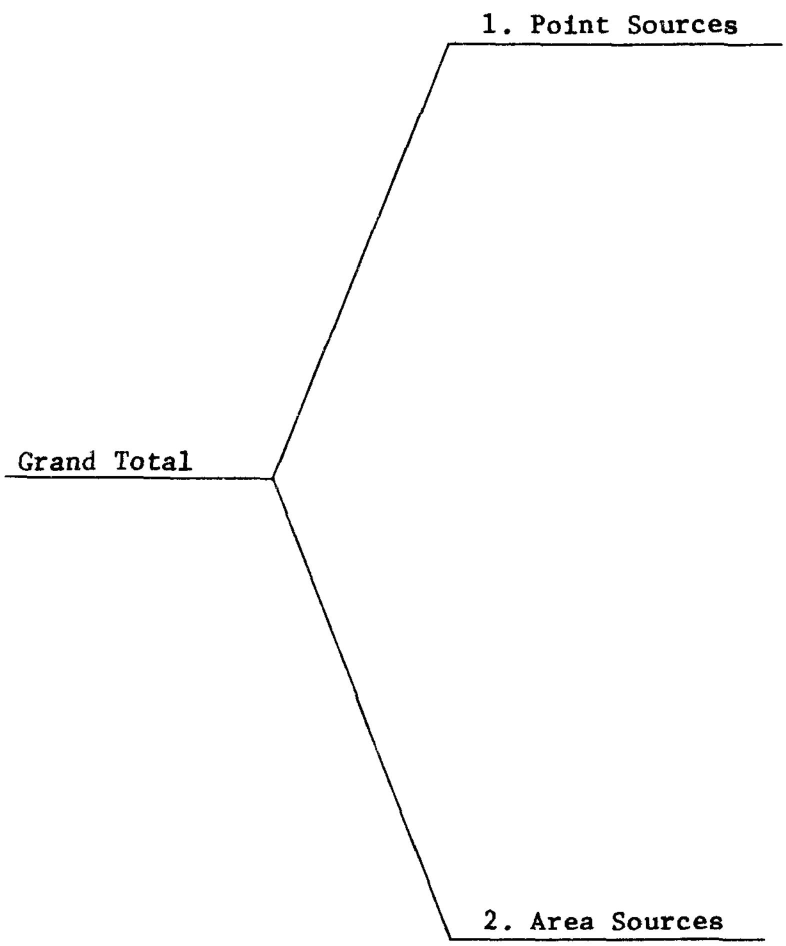


Figure 2.2 NEDS source categories in tree format

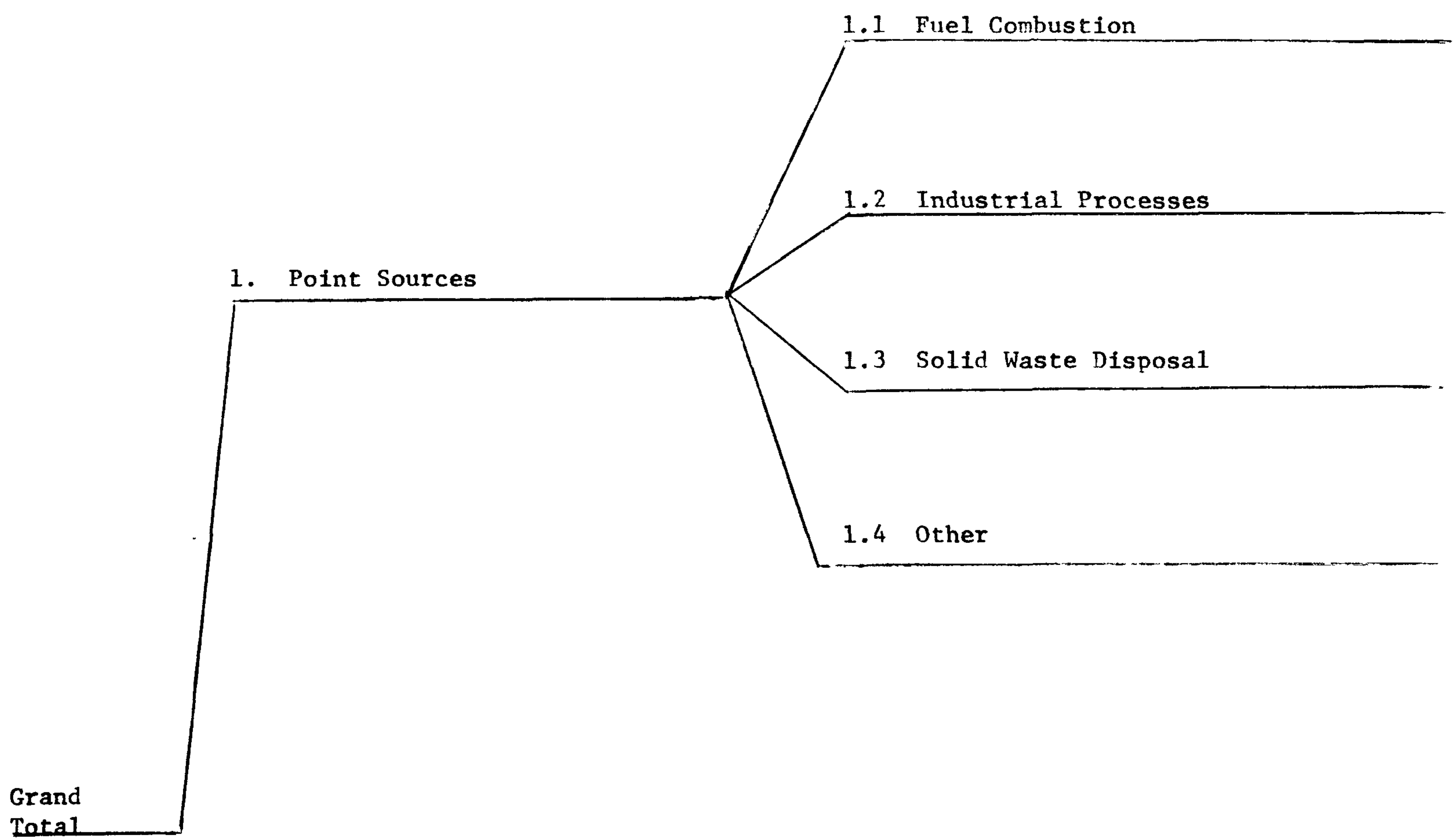


Figure 2.2 (cont.)

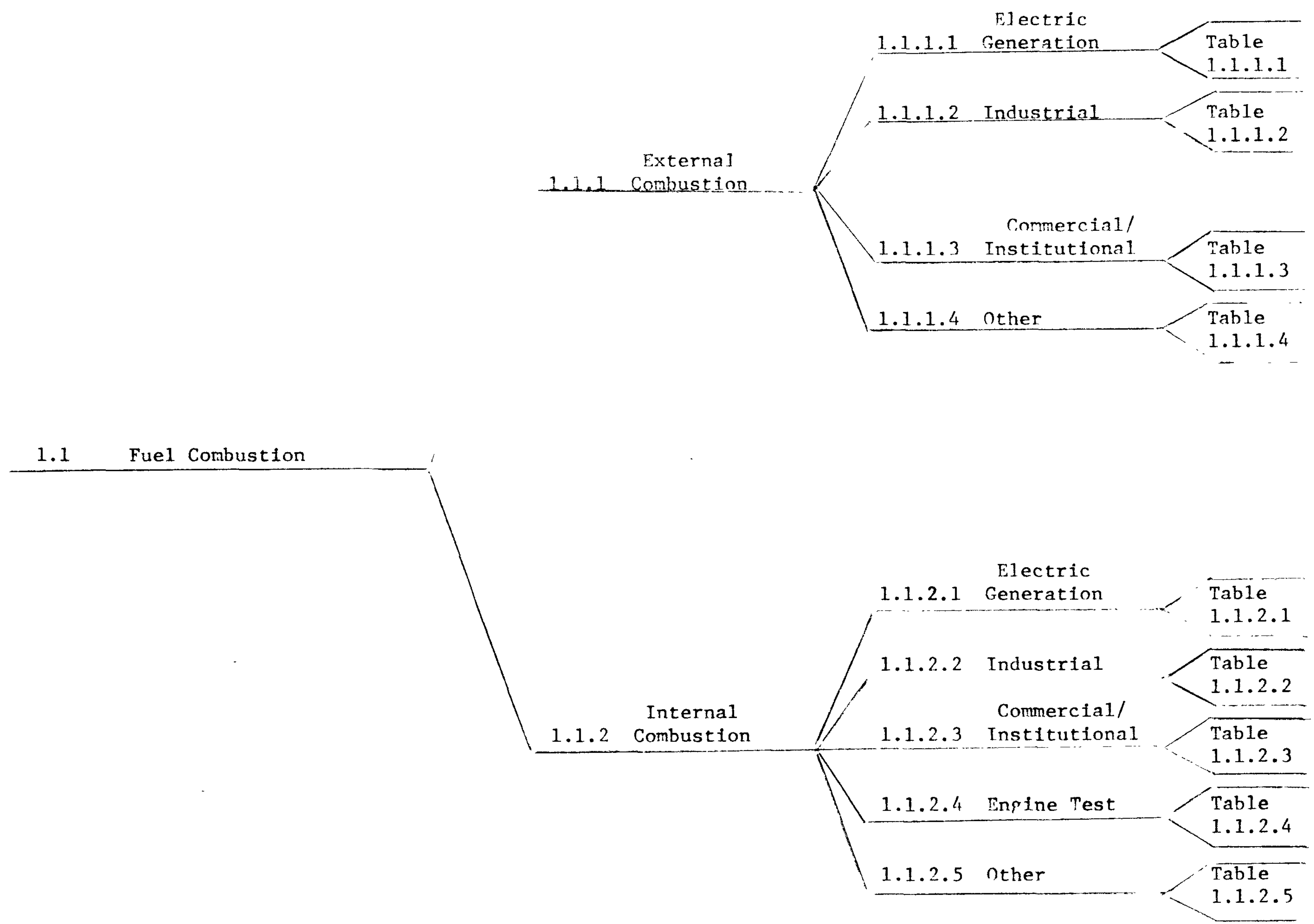


Figure 2.2 (cont.)

TABLE 1.1.1.1

Anthracite Coal	1.1.1.1.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Bagasse	.9
Solid Waste/Coal	.10
Other	.11

TABLE 1.1.1.2

Anthracite Coal	1.1.1.2.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Process Gas	.7
Coke	.8
Wood	.9
Liquid Petrol Gas	.10
Bagasse	.11
Other	.12

TABLE 1.1.1.3

Anthracite Coal	1.1.1.3.1
Bituminous Coal	.2
Lignite	.3
Residual Oil	.4
Distillate Oil	.5
Natural Gas	.6
Wood	.7
Liquid Petrol Gas	.8
Other	.9

TABLE 1.1.2.1

Distillate Oil	1.1.2.1.1
Natural Gas	.2
Diesel	.3
Other	.4

TABLE 1.1.2.2

Distillate Oil	1.1.2.2.1
Natural Gas	.2
Gasoline	.3
Diesel Fuel	.4
Other	.5

Figure 2.2 (cont.)

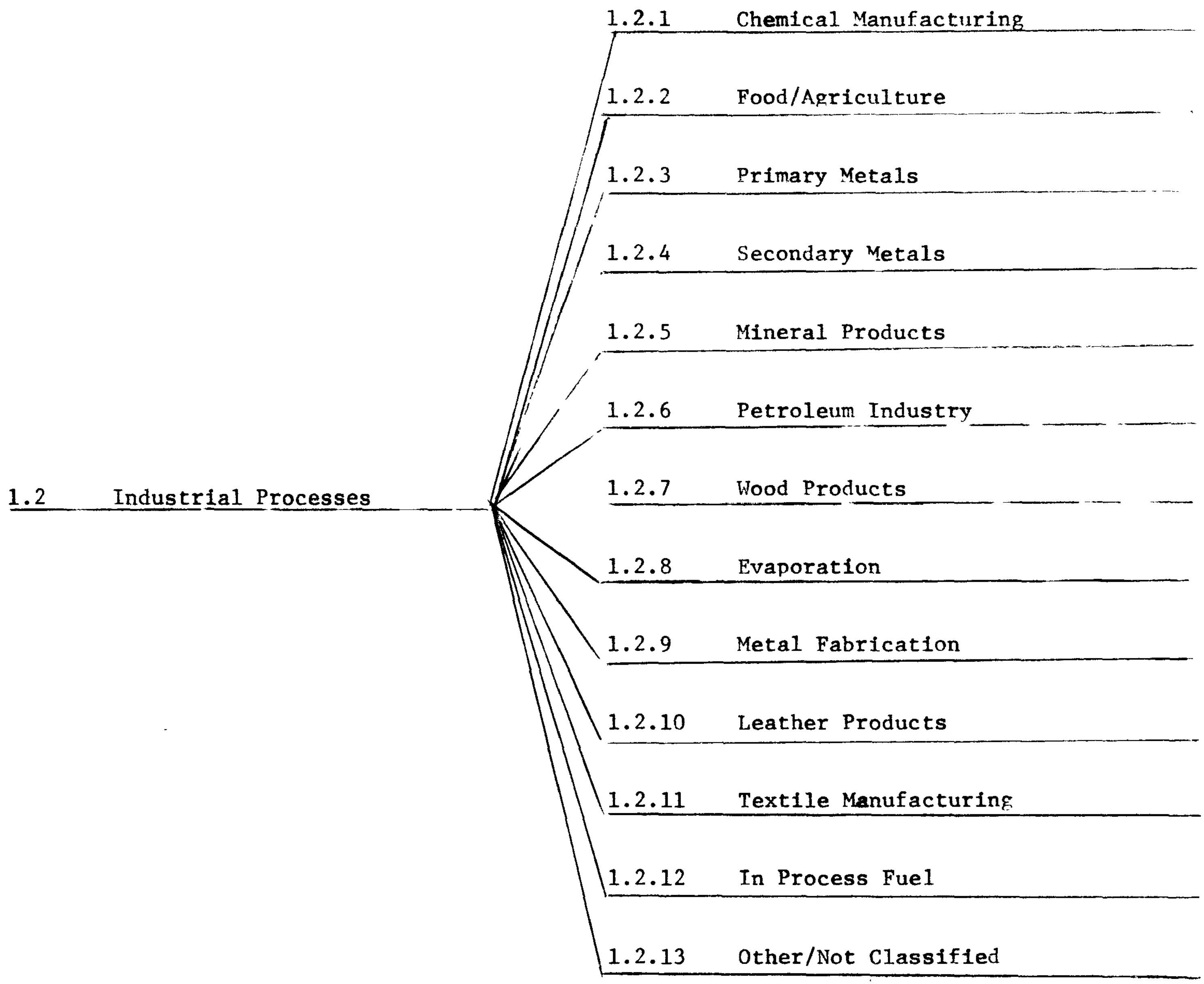


Figure 2.2 (cont.)

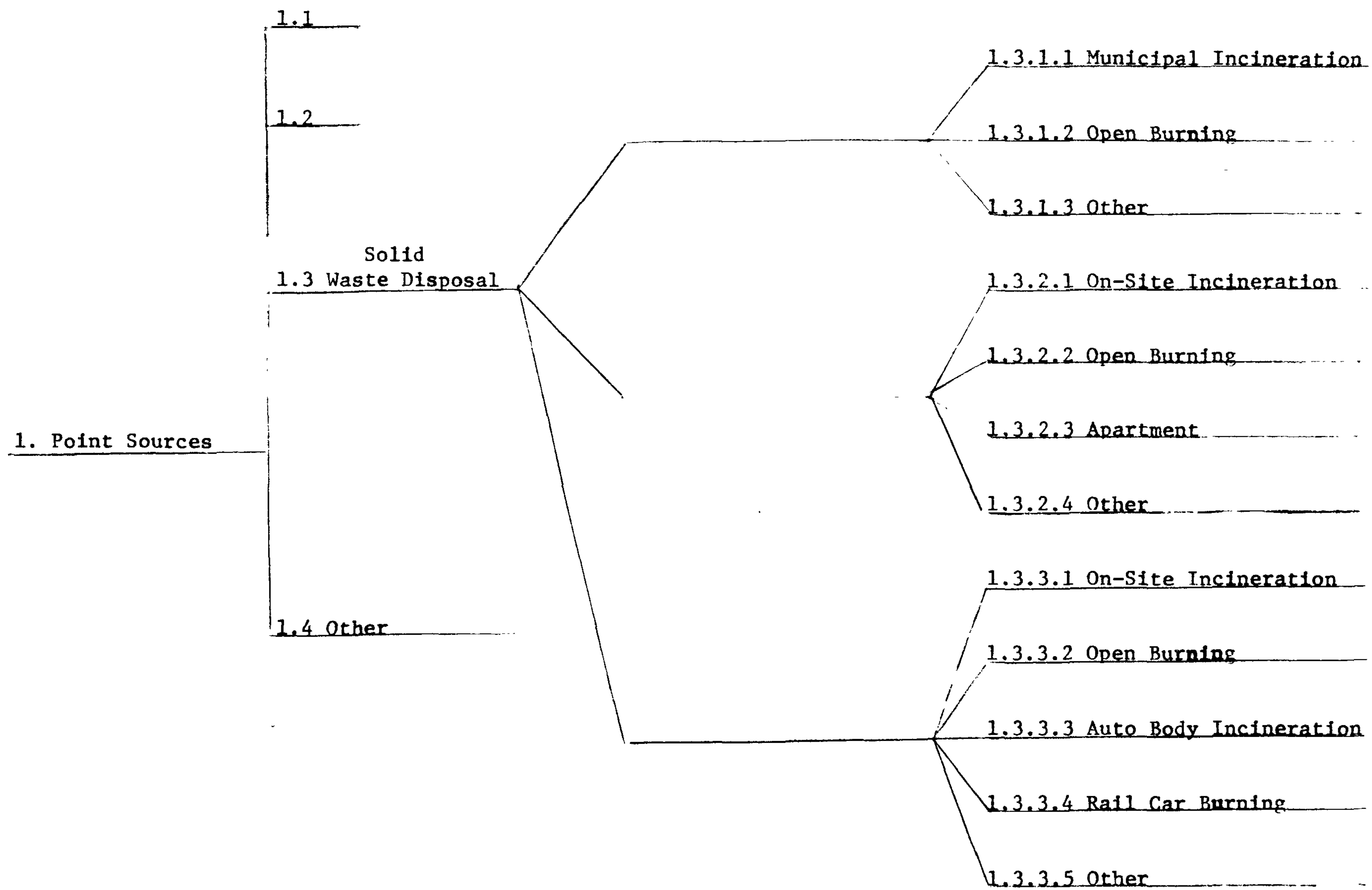


Figure 2.2 (cont.)

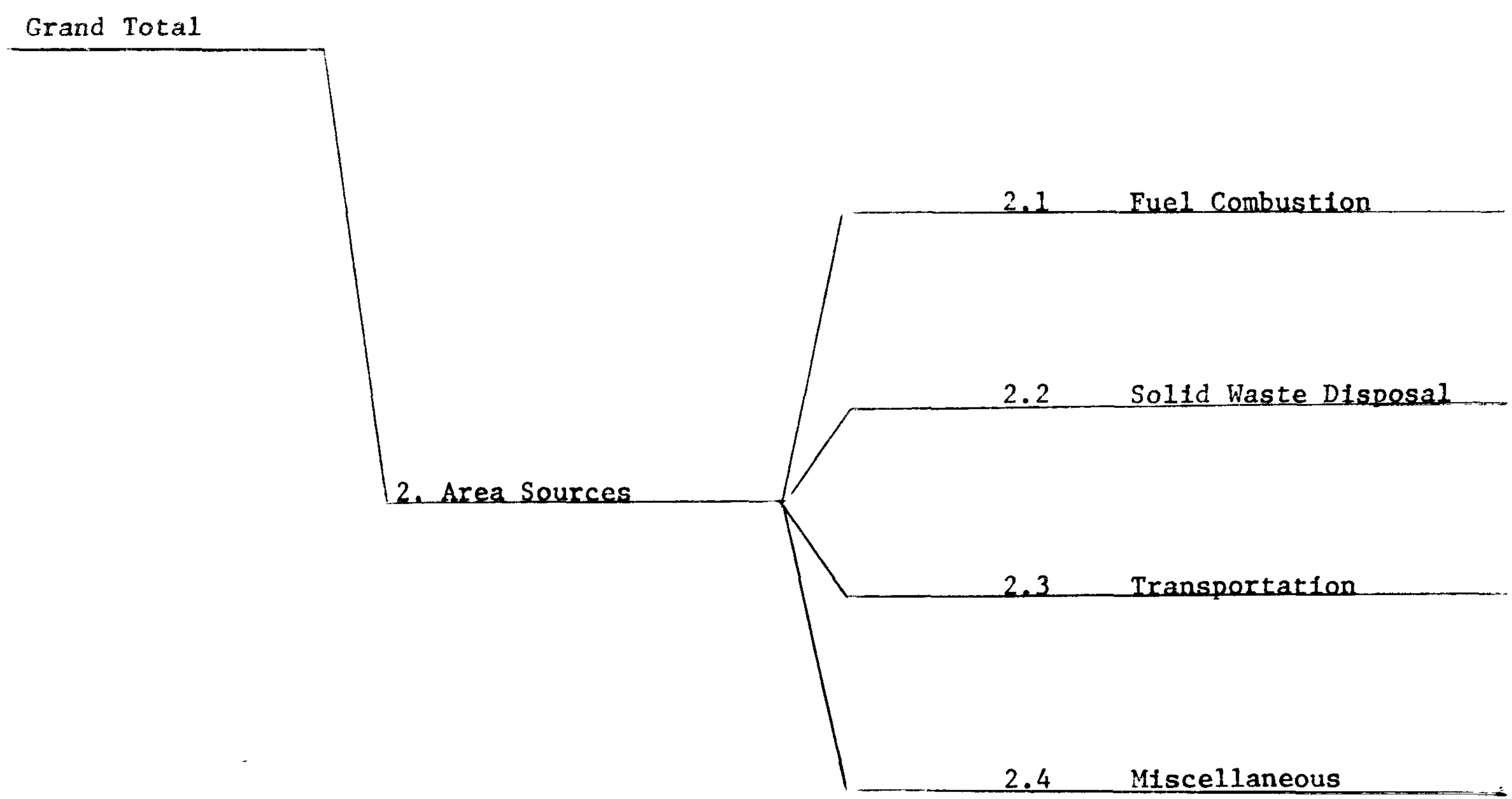


Figure 2.2 (cont.)

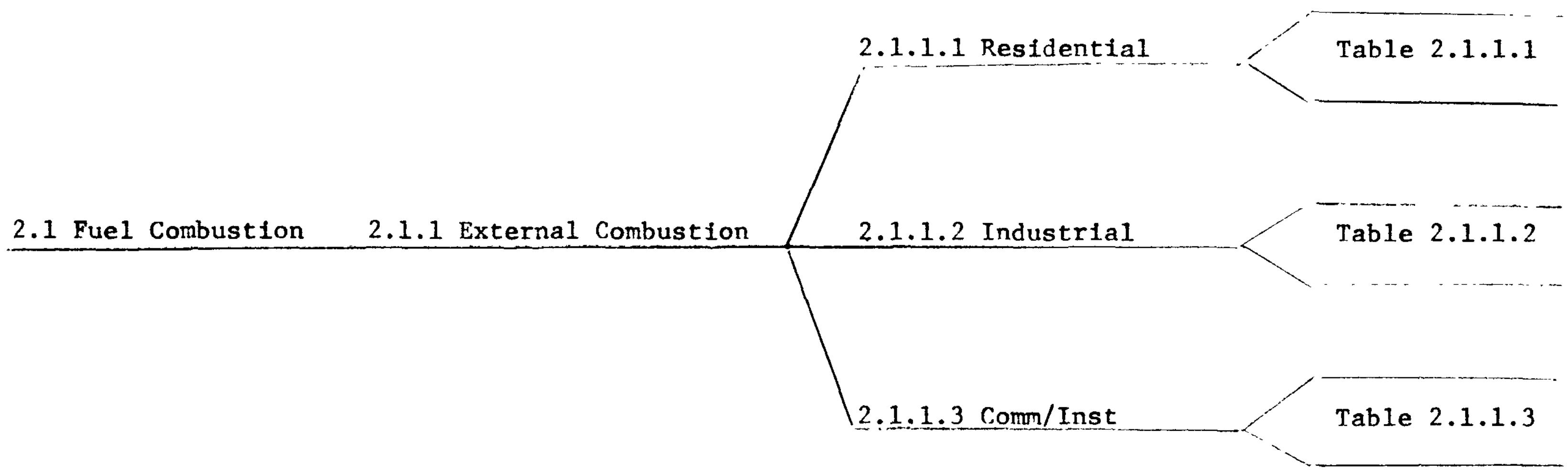


Figure 2.2 (cont.)

TABLE 2.1.1.1

Anthracite Coal	2.1.1.1.1
Bituminous Coal	2.1.1.1.2
Distillate Oil	2.1.1.1.3
Residual Oil	2.1.1.1.4
Natural Gas	2.1.1.1.5
Wood	2.1.1.1.6

TABLE 2.1.1.2

Anthracite Coal	2.1.1.2.1
Bituminous Coal	2.1.1.2.2
Residual Oil	2.1.1.2.3
Distillate Oil	2.1.1.2.4
Natural Gas	2.1.1.2.5
Process Gas	2.1.1.2.6
Coke	2.1.1.2.7
Wood	2.1.1.2.8

TABLE 2.1.1.3

Anthracite Coal	2.1.1.3.1
Bituminous Coal	2.1.1.3.2
Residual Oil	2.1.1.3.3
Distillate Oil	2.1.1.3.4
Natural Gas	2.1.1.3.5
Wood	2.1.1.3.6

Figure 2.2 (cont.)

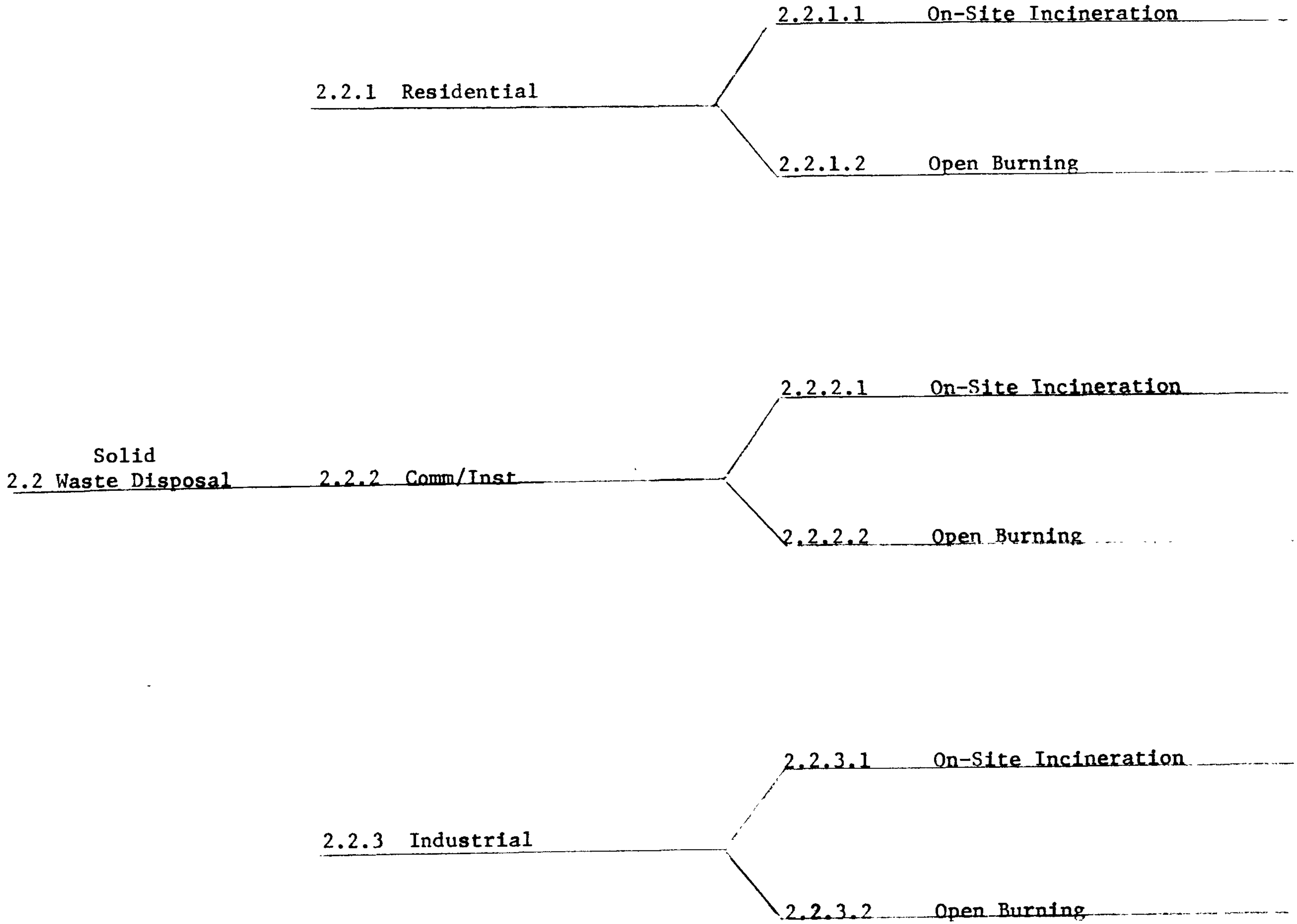


Figure 2.2 (cont.)

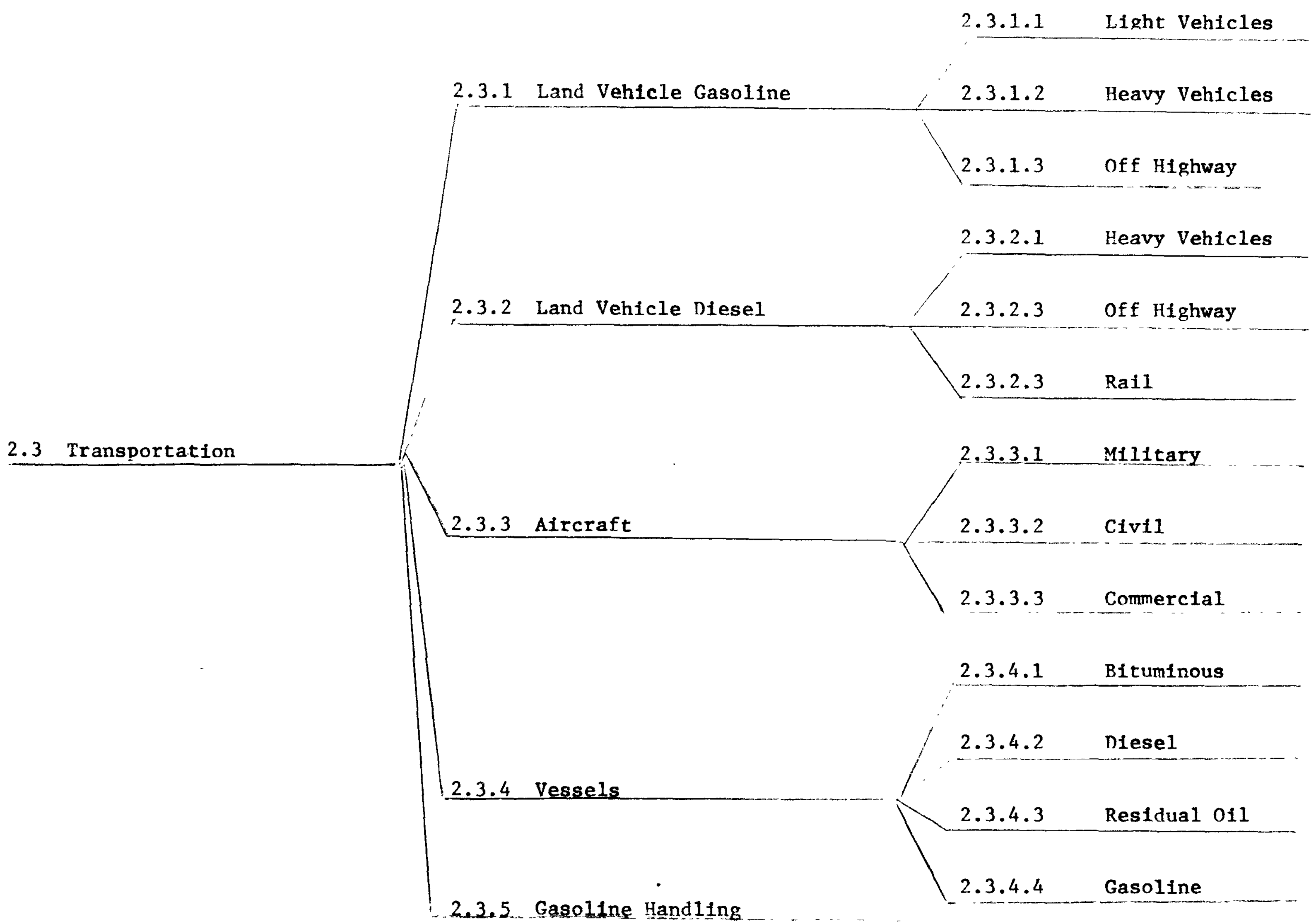


Figure 2.2 (cont.)

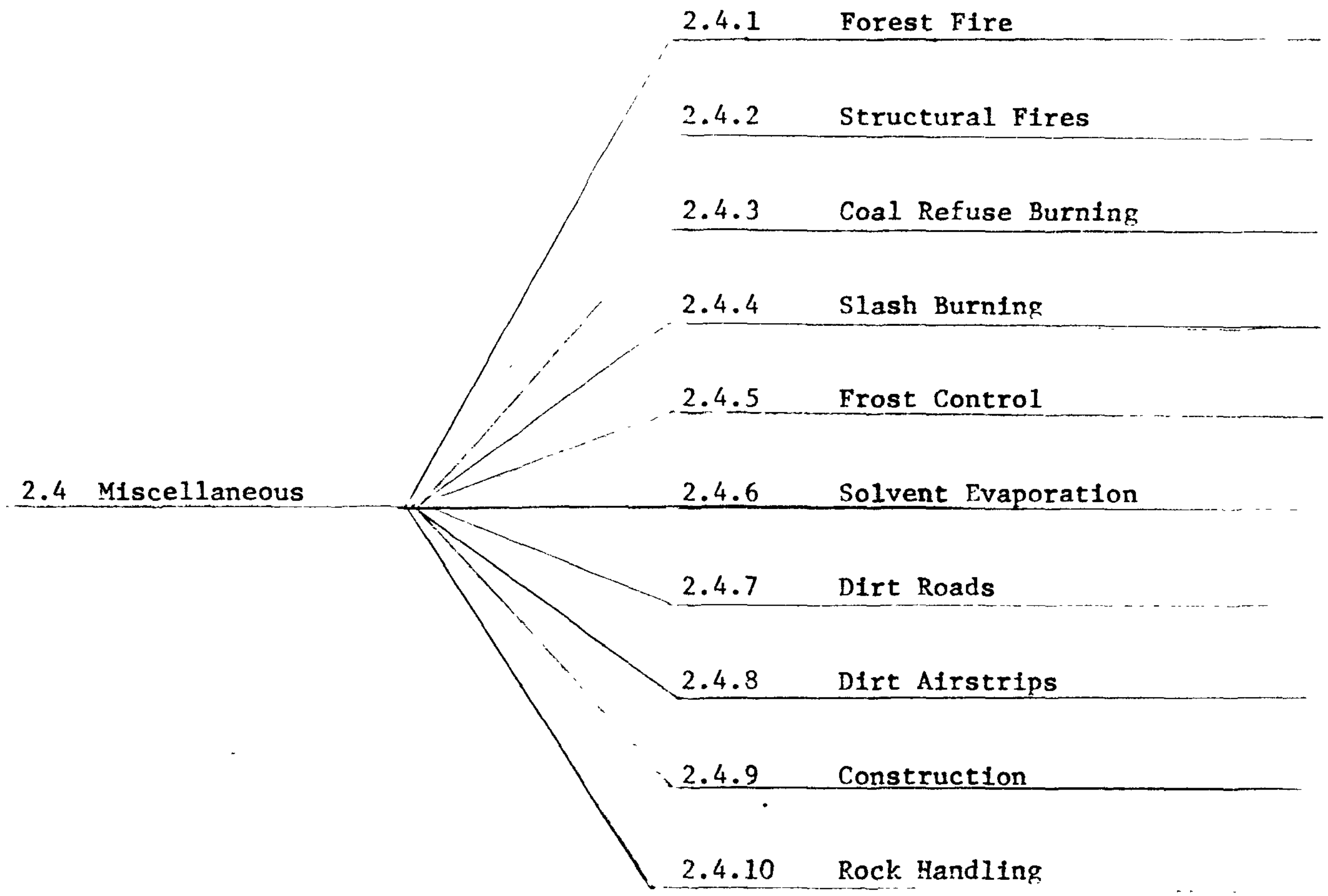


Figure 2,2 (cont.)

combustion at point sources. Observe that the summation of the emissions associated with their node. This relationship will be the basis for the weightings to be used below in computing allowable errors for each branch of the tree.

WEIGHTED SENSITIVITY ANALYSIS

In this project, the mathematics of sensitivity analysis were directed to the development of accuracy requirements for the component parts of an emissions inventory such that a given accuracy requirement for the overall inventory is satisfied. The objective of sensitivity analysis is to determine the effect (changes) on some measure of performance due to changes in each component that makes up the measure of performance. In the simplest case the measure of performance is the sum of component measures. In the case of an emissions inventory, it was shown above that the total emissions for a given source class is always equal to the sum of the emissions from the source subclasses in that class. Furthermore, since each one of these emissions have been independently measured, it follows that the overall squared error for the source class is a linear function of the squared errors of the source subclasses.

This analysis is based on statistical linear models and their application to represent propagation of error in sets of data (References 1,2,5). For clarity of presentation, the discussion in this subsection will be focused on the main analytical results, their statistical interpretation, and their practical implications. Detailed mathematical derivations of all formulae are given in Appendix A.

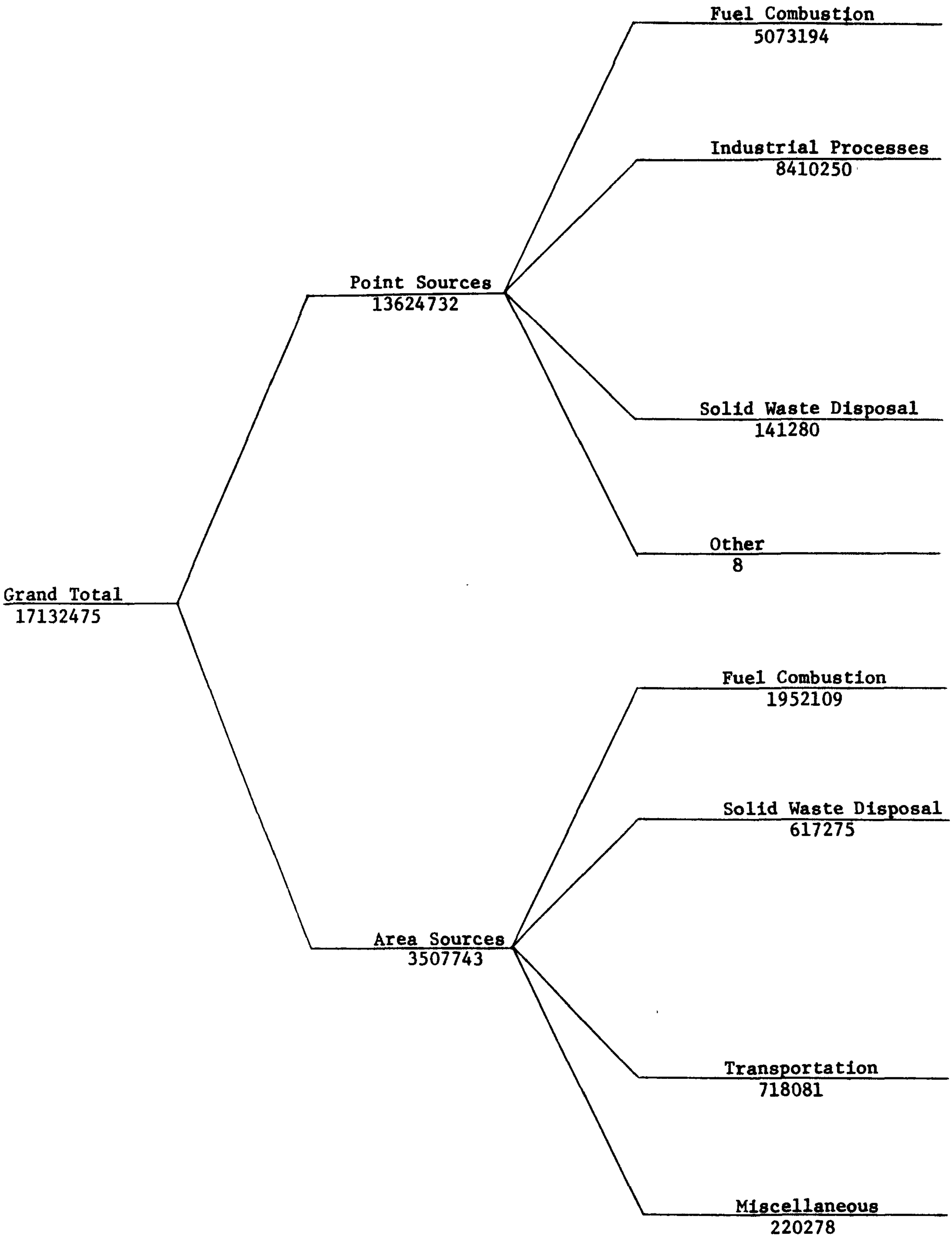


Figure 2.3 NEDS data in tree format

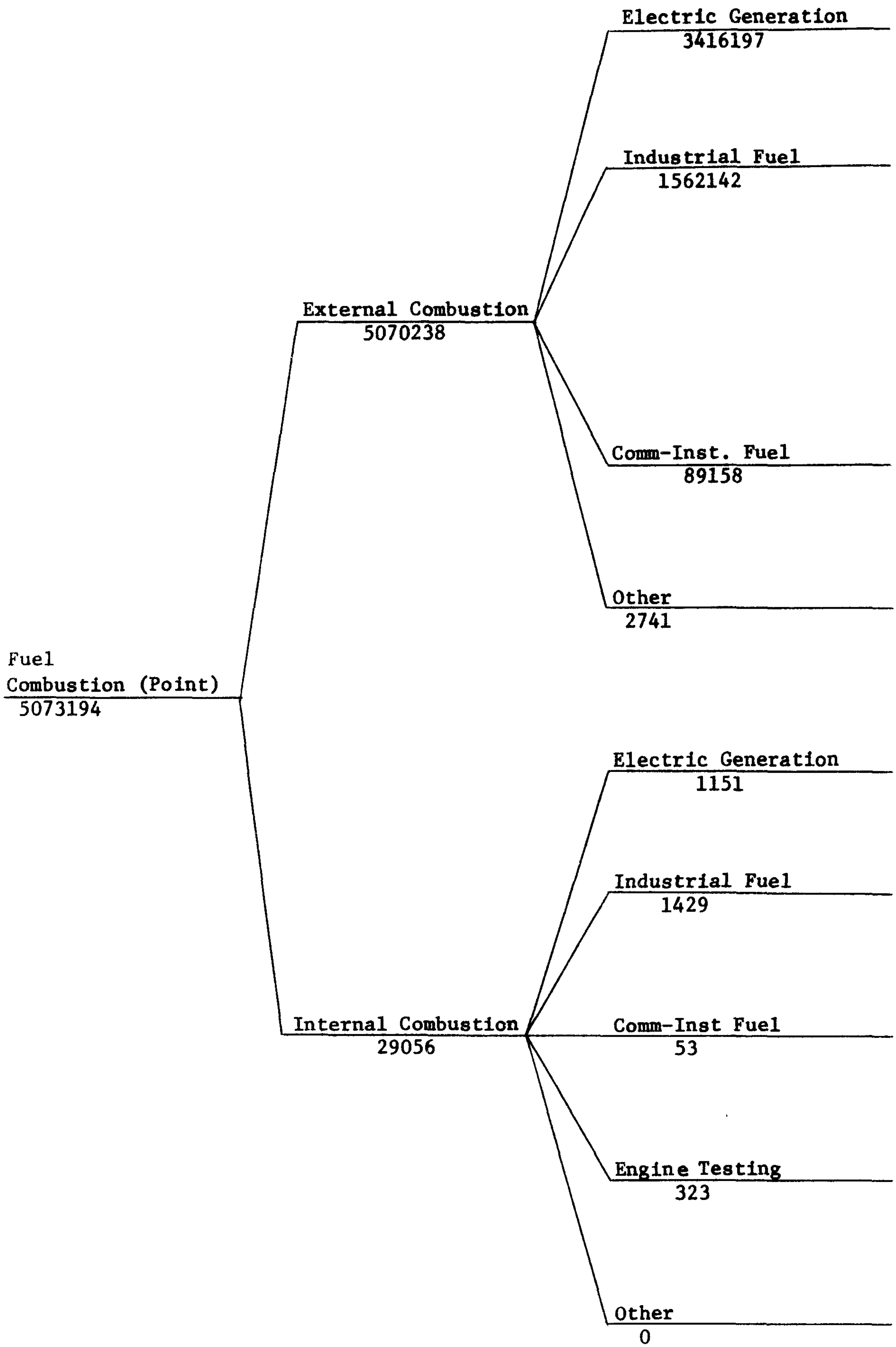


Figure 2.3 (cont.)

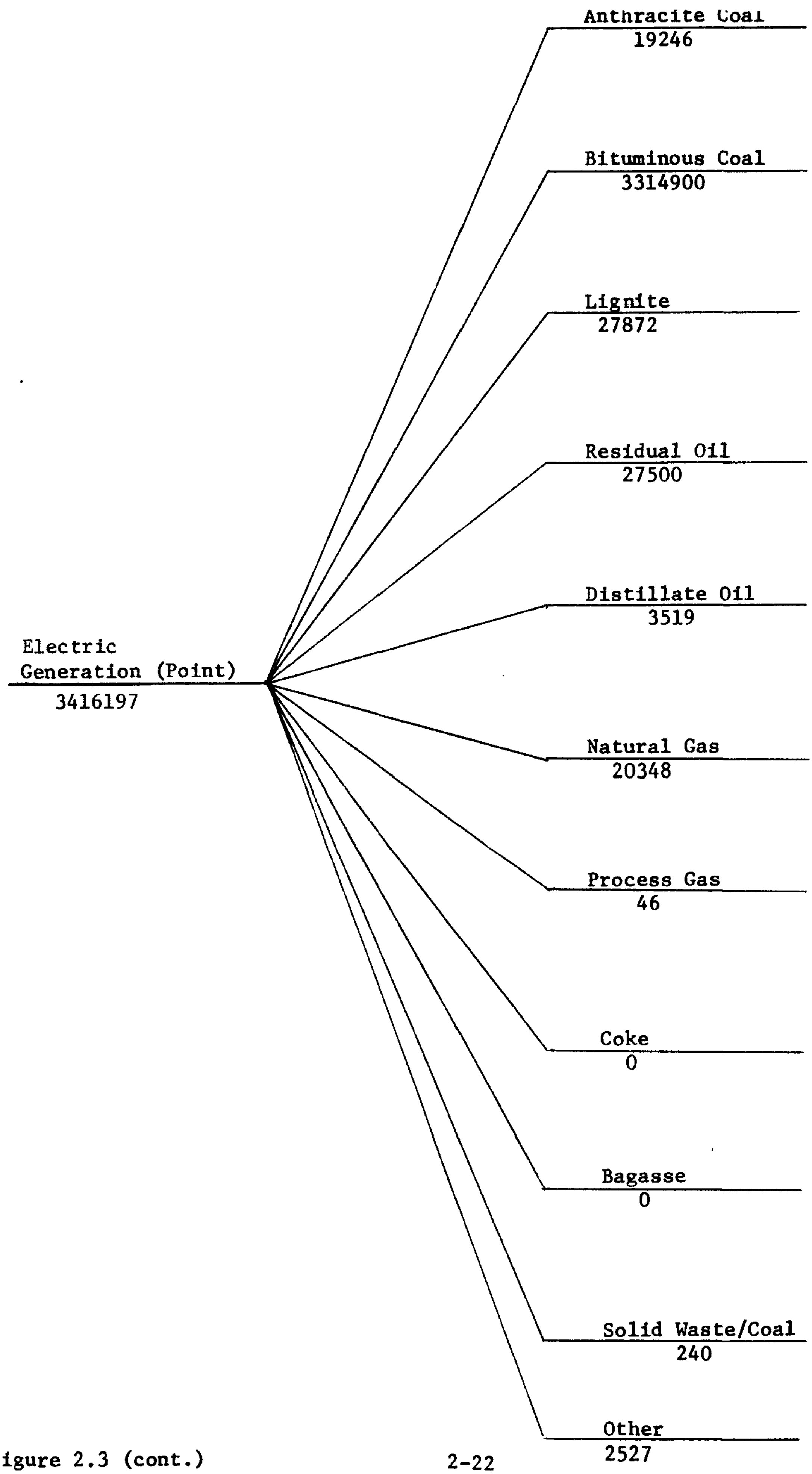


Figure 2.3 (cont.)

The basic theoretical development proceeds as follows. The linear model

$$Q^2 \Theta^2 = \sum_{K=1}^{N} Q_K^2 \sigma_K^2 \qquad (1)$$

where

Q_K = air pollutant produced by source subclass K

$100\ \sigma_K$ = percentage error associated with Q_K

$Q = \sum_{K=1}^{N} Q_K$

$100\ \Theta$ = percentage error associated with Q

N = number of subclasses in the source class

is postulated as an appropriate model to analyze propogation of error throughout the emissions inventory, for hte reasons stated above. For example, with reference to the external combustion node of Figure 2.3, we would have

Q_1 = 3416197 tons/yr.

Q_2 = 1562142 tons/yr.

Q_3 = 89158 tons/yr.

Q_4 = 2741 tons/yr.

$Q = \sum_{K=1}^{4} Q_K$ = 5070238 tons/yr.

Dividing both sides of equation (1) by $Q^2\Theta^2$

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{2}$$

The objective of this analysis is to obtain σ_K for each class k according to some value of Θ (error in total). As a first approximation we can assume that each term in Equation (2) contributes the same amount to the total.

$$\frac{1}{N} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \tag{3}$$

whence

$$\sigma_K = \frac{\Theta}{\sqrt{N}\,(Q_K/Q)}$$

where N is the number of source classes.

As a second approximation, the analysis can be modified to recognize the fact that each source class k contributes to the total error an amount proportional to its relative physical contribution to the total pollutant emission Q, as given by the ratio Q_K/Q. Analytically, it is only necessary to note that

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = 1$$

Therefore, from equation (2):

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \qquad (5)$$

Equating both sides of ea. (5) term-by-term is equivalent to assuming that each term contributes to the total an amount proportional to Q_K/Q:

$$\frac{Q_K}{Q} = \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\Theta}\right)^2 \qquad (6)$$

whence

$$\sigma_K = \Theta \sqrt{\frac{Q}{Q_K}} \qquad (7)$$

We can interpret Equation (7) as indicating the percent error allowable (σ_K) in forecasting emissions from source class K given the percent error desired (Θ) in forecasting total emissions. σ_K can be modified either by changing Θ or by regrouping the source classes, which changes Q/Q_K . The latter method is particularly useful in that it allows modification of σ_K without changing Θ . A useful policy for regrouping the source classes is to assemble the classes with the smallest emissions into one or more classes; however, this policy should be applied with some discretion in order to have groups or classes that can be successfully forecast.

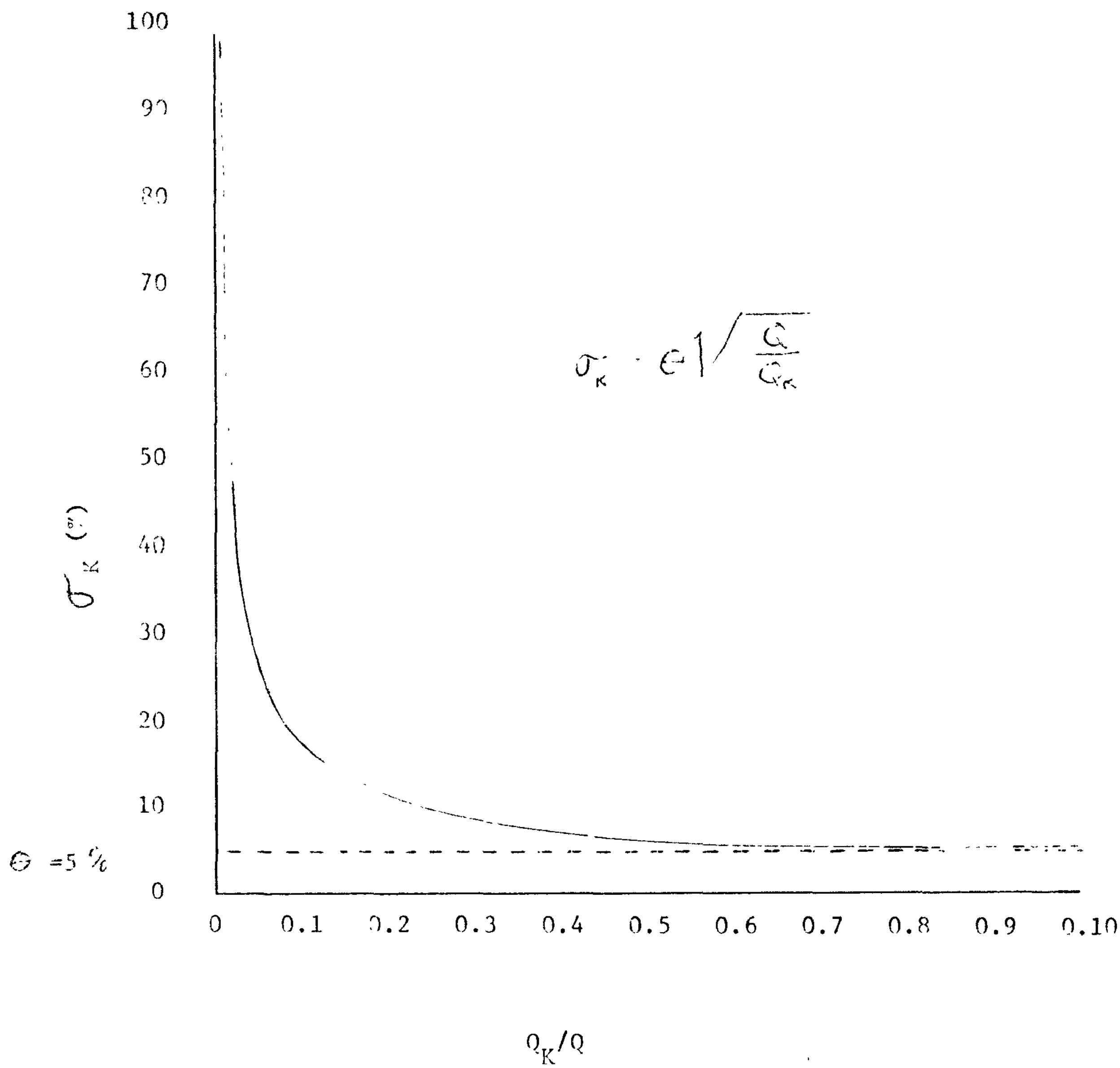
In order to illustrate the application of the technique, let Θ = 5% for the external combustion node of Figure 2.3. The allowable errors for the component branches as computed from equation (7) are as follows:

$$\sigma_1 = 5\sqrt{\frac{5070238}{3416197}} = 6.09\%$$

$$\sigma_2 = 5\sqrt{\frac{5070238}{1562142}} = 9.01\%$$

$$\sigma_3 = 5\sqrt{\frac{5070238}{89158}} = 37.70\%$$

$$\sigma_4 = 5\sqrt{\frac{5070238}{2741}} = 215.04\%$$



RELATIONSHIP BETWEEN σ_K AND Q_K/Q

Figure 2.4

The allowable errors in physical units are:

$\sigma_1 Q_1 = \pm$ 208046.39 tons/year

$\sigma_2 Q_2 = \pm$ 140748.99 tons/year

$\sigma_3 Q_3 = \pm$ 33612.56 tons/year

$\sigma_4 Q_4 = \pm$ 5894.24 tons/year

The analysis demonstrates that, to obtain a known level of precision in the total emissions for a source class, not all source subclasses need to be measured with the same precision. Furthermore, the analysis shows that the probable error of the sum of emissions is less than the sum of the probable error of the component emissions. In fact, it is the square root of the weighted sum of the squared probable errors of the components, as can be readily observed by solving equation (1) for θ to obtain

$$\theta = \sqrt{\sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \sigma_K^2} \qquad (8)$$

Figure 2.4 displays the resulting relationship between σ_K and Q_K/Q in graphic form. When Q_K is a very small fraction of Q, the allowable value of σ_K is much larger than the allowable overall error θ, increasing exponentially as Q_K/Q approaches zero. On the other hand, σ_K approaches θ asymptotically as Q_K/Q approaches one. In general,

$\sigma_K \geq \Theta$, k = 1,.., N, with the equality sign holding only in the limiting case where there is only a single source subclass. Naturally, if there is a single source subclass, $Q_K = Q$ and σ_K must be equal to Θ if the latter is to be satisfied. Otherwise, the component emission errors σ_K will be allowed to have values greater than the overall emission error Θ . With respect to Figure 2.4, it is also interesting to note that the shape of the function is invariant to the value of Θ , i.e., perturbing the value of Θ would merely shift the horizontal asymptote of the curve. This conclusion has a significant practical implication, i.e., for any given value of Θ , the σ_K's can be allowed to have values greater than Θ . This conclusion has significant impact in determining the required accuracy of measurement of emission rates, and emission factors for individual source classes. In turn, these conclusions are useful in allocating resources to the determination or measurement of various emission parameters. Hierarchial application of the technique to the complete emissions data tree will result in σ_K's much greater than the grand total Θ as the computations proceed to successively lower levels of aggregation. Sample numerical analyses for complete emission inventories will be presented in the next section.

In the case where one or more of the σ_K's in a group are to be fixed by the analyst, it is shown in Appendix A that equation (7) changes to

$$\sigma_K = \Theta \sqrt{\frac{Q}{Q_K}\left(\frac{1 - D \cdot \tilde{Q}}{1 - \tilde{Q}}\right)} \tag{8}$$

where

$$D = \sum_{K=m+1}^{N} \left[\left(\frac{Q_K \sigma_K}{Q \Theta} \right)^2 - \frac{Q_K}{Q} \right] \tag{9}$$

and

$$\tilde{Q} = \sum_{K=m+1}^{N} \frac{Q_K}{Q} \tag{10}$$

in the general case where σ_K is unknown for k = 1, 2, ..., m and fixed for k = m + 1, ..., N. Even assuming $\sigma_K \doteq +0$ for k = 1, ..., m, there is, of course, a maximum value that σ_K can be fixed at for k = m + 1, ..., N and still satisfy a given overall error Θ . This upper bound is also shown in Appendix A to be given by the formula

$$\sigma_K = \Theta \sqrt{\frac{Q}{Q_K} \left(\frac{Q}{Q - \sum_{K=1}^{m} Q_K} \right)} \tag{11}$$

These extensions of the basic weighted sensitivity analysis will provide the analyst valuable guidance in performing the hierarchial error analysis of the emissions inventory so as to retain the integrity of the allowable error at the grand total level of emissions.

CONFIDENCE LEVEL FOR THE EMISSIONS INVENTORY

The weighted sensitivity analysis technique presented in the previous section serves to compute accuracy requirements for the component parts of an emissions inventory so as to insure that a given accuracy requirement for the overall inventory is not violated. By using Chebyshev's inequality it is possible to go one step further and establish in formal probabilistic terms the confidence level for the inventory, i.e., what is in fact the probability that the actual overall error in emissions will not exceed θ .

Chebyshev's theorem (Reference 3) states that if a probability distribution has mean $\bar{Q}$ and standard deviation θ , the probability of obtaining a value which deviates from the mean by more than λ standard deviations is less than λ^{-2}. Symbolically, in percentage error terms

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \lambda\theta\right) < \frac{1}{\lambda^2} \tag{12}$$

where Q is the measured grand total emissions, as before. It is important to note that Chebyshev's result is distribution-free. In other words, inequality (12) applies regardless of what probability distribution is associated with the emissions data. This is critically important because the actual probability distributions of the various emissions are generally unknown.

Letting $\alpha = \lambda\theta$, inequality (12) becomes

$$P\left(\frac{|Q-\bar{Q}|}{Q} > \alpha\right) < \frac{\theta^2}{\alpha^2} \tag{13}$$

and the fraction θ^2/α^2 gives a percentage confidence level for the inventory, i.e., the probability that the actual percentage error exceeds α is less than $\epsilon = \theta^2/\alpha^2$. As a numerical example, if it is desired to attain a 95% confidence level that the percentage emissions error will be within a 20% interval of the true value, then setting

$$\theta = \alpha\sqrt{\epsilon} = 0.20\sqrt{1-0.95} = 4.47\%$$

and applying the weighted sensitivity analysis technique to compute the σ_{π}'s results in a set of precision requirements which, if satisfied, insure that the 95% confidence level for the emissions inventory has been attained. Using the same technique, Table 2-1 summarizes the required value

Confidence Level

Acceptance Internal: α \ 1-C	90%	95%	99%
5%	1.58%	1.12%	0.5%
10%	3.16%	2.24%	1.0%
20%	6.32%	4.47%	2.0%

Table 2.1 Values of Θ for selected pairs (α, 1-C)

of for selected trade-offs between confidence level and accuracy of the for selected trade-offs between confidence level and accuracy of the emissions inventory. For example, θ must be set at 2.24% to attain 95% confidence level for the overall inventory error to be within 10%, 6.32% for 90% assurance of it being within 20%, etc.

In summary, the analysis of random error in emissions data should be undertaken as a two-step procedure: first, establish the desired value of the overall allowable error θ as a trade-off between confidence level and acceptable error interval, by means of Chebyshev's theorem; second, compute the required values for all component errors σ_k so as to preserve the integrity of θ, using the weighted sensitivity analysis technique.

Section III

NUMERICAL ANALYSES

This section presents a sample numerical analysis for a complete emissions data tree, using the Ohio State Emissions Report with emissions as of February 23, 1973 as sample data. The discussion will cover numerical analysis of both the nominal hierarchy or tree (as in Figures 2.1 and 2.2) and some alternative trees.

During the project, weighted sensitivity analyses were run for each of the nine values of overall error θ in Table 2.1, and for each of the following summaries: county emissions report (Franklin County, Ohio), AQCR emissions report (Metropolitan Columbus, Ohio), state emissions report (Ohio) and nationwide emissions report (United States). Complete numerical analyses for the nationwide emissions report (with emissions as of April 19, 1973) using three different values of θ are reproduced in Appendix B of this final report. Other numerical analyses conducted during the project are available as computer printouts. The annotated numerical analysis given in this section is presented to illustrate the application of the techinique from the analyst's viewpoint.

ANALYSIS OF THE STANDARD TREE

A complete weighted sensitivity analysis for the Ohio State Emissions Report (with emissions as of February 23, 1973) is tabulated in Table 3.1.

Table 3.1 Weighted Sensitivity Analysis of Ohio State Emissions Report with ϵ =5%

OHIO
****
STATE EMISSIONS REPORT (RUN DATE: APRIL 3, 1973)
EMISSIONS AS OF FEBRUARY 23, 1973
50773
17 4 19.6

SOURCE HIERARCHY

SOURCE CLASS AND SUBCLASSES	WEIGHTED SENSITIVITY ANALYSIS									
	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
233 GRAND TOTAL	2094254	5.00	3266037	5.00	1428729	5.00	1271409	5.00	13744109	5.00
235 AREA SOURCES	492906	10.31	401632	14.26	556745	8.01	1078272	5.43	4277065	8.96
236 POINT SOURCES	1601348	5.72	2864405	5.34	871984	6.40	193137	12.83	9467024	6.02

Table 3.1

SOURCE HIERARCHY [1 .]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
236 POINT SOURCES	1601348	5.72	2864405	5.34	871984	6.40	193137	12.83	9467024	6.02
11 FUEL COMBUSTION	626684	9.14	2608288	5.60	507233	8.39	11700	52.12	26977	112.86
130 INDUSTRIAL PROCESS (POINT)	968858	7.35	251403	18.02	363863	9.91	177135	13.40	9427514	6.04
146 SOLID WASTE DISPOSAL	5806	94.96	4714	131.61	887	200.67	4302	85.96	12533	165.58
231 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY

11 FUEL COMBUSTION [1 .1]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
129 POINT SOURCES	626684	9.14	2608288	5.60	507233	8.39	11700	52.12	26977	112.86
13 EXTERNAL COMBUSTION	626672	9.14	2608277	5.60	506990	8.39	11371	52.87	26907	113.00
103 INTERNAL COMBUSTION (POINT)	12	2088.79	12	2608.49	243	383.39	329	310.82	70	2215.54
126 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY [1 .2]

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
130 INDUSTRIAL PROCESS (POINT)	968858	7.35	251403	18.02	363863	9.91	177135	13.40	9427514	6.04
132 CHEMICAL MANUFACTURING	6404	90.42	11312	84.96	2321	124.05	57419	23.53	25691	115.65
133 FOOD/AGRICULTURAL	6121	92.49	0	0.00	0	0.00	385	287.33	16	4369.10
134 PRIMARY METAL	388813	11.60	22461	60.29	215	407.59	21629	38.33	6269525	7.40
135 SECONDARY METALS	14614	59.85	4517	134.45	13	1657.58	188	411.18	218705	39.64
136 MINERAL PRODUCTS	406520	11.35	10476	88.28	753	217.79	12	1627.50	35	3133.24
137 PETROLEUM INDUSTRY	139711	19.36	202171	20.10	360543	9.95	43623	26.99	2907030	10.87
138 WOOD PRODUCTS	1395	193.73	465	419.04	0	0.00	0	0.00	6510	229.74
139 EVAPORATION	0	0.00	0	0.00	0	0.00	50607	25.06	0	0.00
140 METAL FABRICATION	2531	143.83	0	0.00	19	1371.10	4	2818.92	0	0.00
141 LEATHER PRODUCTS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
142 TEXTILE MANUFACTURING	11	2181.67	0	0.00	0	0.00	2858	105.46	0	0.00
143 INPROCESS FUEL	0	0.00	0	0.00	0	0.00	361	296.73	0	0.00
144 OTHER/NOT CLASIED	2739	138.26	0	0.00	0	0.00	50	797.31	0	0.00

SOURCE HIERARCHY [1 .3]

146 SOLID WASTE DISPOSAL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
190 POINT SOURCES	5806	94.96	4714	131.61	987	200.67	4302	85.96	12533	165.58
148 GOVERNMENT (POINT)	4378	109.35	628	360.58	667	231.41	3343	97.51	8766	197.93
157 COMMERCIAL-INSTITUTIONAL	187	529.13	23	1884.16	32	1056.50	210	389.05	1147	547.33
171 INDUSTRIAL	1241	205.40	4063	141.76	138	435.88	749	206.00	2620	362.14
187 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.1

13 EXTERNAL COMBUSTION

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
102 POINT SOURCES	626672	9.14	2608277	5.60	506990	8.39	11371	52.87	26907	113.00
22 ELEC GENERATION (POINT)	343145	12.35	1989919	6.41	385364	9.63	5517	75.90	17645	139.55
35 INDUSTRIAL FUEL	272433	13.86	597857	11.69	117456	17.44	5604	75.31	8459	201.54
71 COMM-INSTITUTIONAL FUEL	11095	68.69	20501	63.11	4170	92.55	250	356.57	803	654.14
99 OTHER (POINT)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
103 INTERNAL COMBUSTION (POINT)	12	2088.79	12	2608.49	243	383.39	329	310.82	70	2215.54
104 ELECTRIC GENERATION	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
110 INDUSTRIAL FUEL	9	2411.92	8	3194.74	216	406.65	329	310.82	70	2215.54
117 COMM-INSTITUTIONAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
121 ENGINE-TESTING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.3.1

146 SOLID WASTE DISPOSAL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
148 GOVERNMENT (POINT)	4378	109.36	628	360.58	667	231.41	3343	97.51	8766	197.93
149 MUNICIPAL INCINERATION	3899	115.88	599	369.20	487	270.82	2445	114.02	6221	235.02
150 OPEN BURNING	479	330.61	30	1649.76	180	445.46	898	188.14	2545	367.44
151 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.3.2

146 SOLID WASTE DISPOSAL
157 COMMERCIAL-INSTITUTIONAL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
170 POINT SOURCES	187	529.13	23	1884.16	32	1056.50	210	389.05	1147	547.33
158 ON SITE INCINERATION	154	583.07	23	1884.16	29	1109.80	202	396.68	1052	571.51
161 OPEN BURNING	32	1279.12	0	0.00	4	2988.24	8	1993.28	95	1901.81
164 APARTMENT	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
166 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.3.3

146 SOLID WASTE DISPOSAL
171 INDUSTRIAL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
195 POINT SOURCES	1241	[illegible]	1063	241.70	138	435.80	749	[illegible]	2620	362.1[illegible]
[illegible]	457	[illegible]	[illegible]	[illegible]	74	681.73	[illegible]	[illegible]	[illegible]	203.23

Table 3.1

SOURCE HIERARCHY 1.1.1.1

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
22 ELEC GENERATION (POINT)	343145	12.35	1989919	6.41	385364	9.63	5517	75.90	17645	139.55
23 ANTHRACITE COAL	657	282.29	6353	113.37	855	204.39	13	1563.66	488	839.11
24 BITUMINOUS COAL	342366	12.37	1982733	6.42	380923	9.68	5234	77.93	17154	141.53
25 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
26 RESIDUAL OIL	18	1705.49	426	437.80	3699	98.27	7	2130.90	0	0.00
27 DISTILLATE OIL	14	1933.84	403	450.12	794	212.10	15	1455.63	0	0.00
28 NATURAL GAS	90	762.72	3	5216.99	2423	121.41	249	357.28	2	10000.00
29 PROCESS GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
30 COKE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
31 BAGASSE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
32 SOLID WASTE/COAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
33 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.1.2

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
35 INDUSTRIAL FUEL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
70 POINT SOURCES	272433	13.86	597857	11.69	117456	17.44	5604	75.31	8459	201.54
36 ANTHRACITE COAL	8	2558.23	739	332.40	63	752.96	1	5637.84	36	3089.42
39 BITUMINOUS COAL	262861	14.11	566189	12.01	91900	19.71	3368	97.15	8385	202.43
42 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
44 RESIDUAL OIL	1191	209.67	12260	81.61	3223	105.27	152	457.29	9	6173.84
47 DISTILLATE OIL	104	709.53	314	509.94	1087	181.27	54	767.21	3	10000.00
50 NATURAL GAS	1638	178.78	25	1807.22	19340	42.98	2020	125.44	17	4495.77
53 PROCESS GAS	6533	89.52	18324	66.75	1799	140.91	0	0.00	0	0.00
56 COKE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
59 WOOD	98	730.92	7	3415.32	44	900.99	9	1879.28	9	6178.84
62 LIQUID PETROL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
64 BAGASSE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
66 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.1.3

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
71 COMM-INSTITUTIONAL FUEL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
98 POINT SOURCES	11095	68.69	20501	63.11	4170	92.55	250	356.57	803	654.14
72 ANTHRACITE COAL	32	1279.12	1295	251.10	65	741.29	2	3986.55	108	1783.68
75 BITUMINOUS COAL	10909	69.28	18396	66.62	3613	99.43	219	380.97	672	715.06
78 LIGNITE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
80 RESIDUAL OIL	100	723.58	690	344.00	261	369.93	13	1553.56	1	10000.00
83 DISTILLATE OIL	32	1279.12	119	828.34	108	575.09	6	2301.64	0	0.00
86 NATURAL GAS	22	1542.67	1	9036.09	124	536.70	9	1679.28	22	3952.00
89 WOOD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
92 LIQUID PETROL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
94 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.1

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
104 ELECTRIC GENERATION	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
105 DISTILLATE OIL	4	3617.88	3	5216.99	27	1150.17	0	0.00	0	0.00
106 NATURAL GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
107 DIESEL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 1.1.2.2

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
110 INDUSTRIAL FUEL	9	2411.92	8	3194.74	216	406.65	329	310.82	70	2215.54
111 DISTILLATE OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
112 NATURAL GAS	0	0.00	0	0.00	1	5976.47	0	0.00	0	0.00
113 GASOLINE	5	3235.93	0	0.00	101	594.68	317	316.65	0	0.00
114 DIESEL FUEL	4	3617.88	8	3194.74	115	557.31	11	1699.87	70	2215.54
115 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.3

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
117 COMM-INSTITUTIONAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
118 DIESEL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
119 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

SOURCE HIERARCHY 1.1.2.4

11 FUEL COMBUSTION
103 INTERNAL COMBUSTION (POINT)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
121 ENGINE-TESTING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
122 AIRCRAFT	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
123 OTHER	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY [2.]

SOURCE CLASS AND SUBCLASSES — *WEIGHTED SENSITIVITY ANALYSIS*

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
235 AREA SOURCES	492906	10.31	401632	14.26	556745	8.01	1078272	5.43	4277085	8.96
11 FUEL COMBUSTION	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.58
146 SOLID WASTE DISPOSAL	47322	33.26	3303	157.23	9564	61.11	97123	18.09	259850	36.36
191 TRANSPORTATION (AREA)	28368	42.96	25143	56.99	436715	9.04	804507	6.29	3969199	9.30
217 MISCELLANEOUS (AREA)	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.00

SOURCE HIERARCHY [2.1]

11 *FUEL COMBUSTION*

SOURCE CLASS AND SUBCLASSES — *WEIGHTED SENSITIVITY ANALYSIS*

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
128 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.58
101 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.58

SOURCE HIERARCHY [2.2]

146 *SOLID WASTE DISPOSAL*

SOURCE CLASS AND SUBCLASSES — *WEIGHTED SENSITIVITY ANALYSIS*

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
199 AREA SOURCES	47322	33.26	3303	157.23	9564	61.11	97123	18.09	259850	36.36
153 RESIDENTIAL (AREA)	20046	51.11	601	308.59	2601	115.86	59775	23.06	173129	44.55

Table 3.1

SOURCE HIERARCHY [2.3]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
191 TRANSPORTATION (AREA)	28368	42.96	25143	56.99	436715	9.04	804507	6.29	3969199	9.30
193 LAND VEHICLES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
194 GASOLINE	19439	51.90	11689	83.58	324499	10.49	725084	6.62	3834397	9.47
199 DIESEL	3904	115.81	8038	100.79	106078	18.35	10925	53.94	63469	73.58
204 AIRCRAFT	3146	129.00	652	353.88	1995	133.81	8725	60.36	26808	113.21
209 VESSELS	1881	166.84	4764	130.92	4143	92.85	9088	59.14	44525	87.85
215 GAS HANDLING EVAP LOSS	0	0.00	0	0.00	0	0.00	50685	25.04	0	0.00

SOURCE HIERARCHY [2.4]

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
217 MISCELLANEOUS (AREA)	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.00
219 FOREST FIRE/AGRIC BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
220 STRUCTURAL FIRES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
221 COAL REFUSE BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
222 SLASH BURNING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
223 FROST CONTROL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
224 SOLVENT EVAPORATION LOSS	0	0.00	0	0.00	0	0.00	158987	14.14	0	0.00
225 DUST SOURCES	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
226 DIRT ROADS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
227 DIRT AIRSTRIPS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
228 CONSTRUCTION	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
229 ROCK HANDLING/STORING	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 2.1.1

13 EXTERNAL COMBUSTION

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

Source class and subclasses	Particulates Tons/Yr	Particulates Sigma Percent	Sulfur Oxides Tons/Yr	Sulfur Oxides Sigma Percent	Nitrogen Oxides Tons/Yr	Nitrogen Oxides Sigma Percent	Hydrocarbons Tons/Yr	Hydrocarbons Sigma Percent	Carbon Monoxide Tons/Yr	Carbon Monoxide Sigma Percent
101 AREA SOURCES	417216	11.20	373186	14.79	110465	17.98	17655	42.43	48036	84.58
14 RESIDENTIAL FUEL (AREA)	13843	61.50	41175	44.53	15867	47.45	8822	60.02	36377	97.19
35 INDUSTRIAL FUEL	364627	11.98	261455	17.67	64275	23.57	6242	71.36	6381	232.05
71 COMM-INSTITUTIONAL FUEL	38746	36.76	70556	34.02	30323	34.32	2590	110.78	5277	255.17

SOURCE HIERARCHY 2.2.1

146 SOLID WASTE DISPOSAL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

Source class and subclasses	Particulates Tons/Yr	Particulates Sigma Percent	Sulfur Oxides Tons/Yr	Sulfur Oxides Sigma Percent	Nitrogen Oxides Tons/Yr	Nitrogen Oxides Sigma Percent	Hydrocarbons Tons/Yr	Hydrocarbons Sigma Percent	Carbon Monoxide Tons/Yr	Carbon Monoxide Sigma Percent
153 RESIDENTIAL (AREA)	20046	51.11	601	368.59	2661	115.86	59775	23.06	173129	44.55
154 ON SITE INCINERATION	14215	60.69	237	586.96	474	274.51	47383	25.90	142150	49.16
155 OPEN BURNING	5831	94.76	364	473.62	2187	127.80	12391	50.65	30978	105.32

SOURCE HIERARCHY 2.2.2

146 SOLID WASTE DISPOSAL
157 COMMERCIAL-INSTITUTIONAL

SOURCE CLASS AND SUBCLASSES — WEIGHTED SENSITIVITY ANALYSIS

Source class and subclasses	Particulates Tons/Yr	Particulates Sigma Percent	Sulfur Oxides Tons/Yr	Sulfur Oxides Sigma Percent	Nitrogen Oxides Tons/Yr	Nitrogen Oxides Sigma Percent	Hydrocarbons Tons/Yr	Hydrocarbons Sigma Percent	Carbon Monoxide Tons/Yr	Carbon Monoxide Sigma Percent
169 AREA SOURCES	3841	116.75	359	476.91	1045	184.88	5713	74.59	13492	159.58
158 ON SITE INCINERATION	1896	166.17	237	586.96	316	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 3.1

SOURCE HIERARCHY 2.2.3

146 SOLID WASTE DISPOSAL
171 INDUSTRIAL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
185 AREA SOURCES	23435	47.27	2344	136.64	5858	78.09	31636	31.70	73230	68.50
172 ON SITE INCINERATION	14062	61.02	1758	215.51	2344	123.44	11718	52.08	23437	121.08
175 OPEN BURNING	9373	74.74	586	373.28	3515	100.81	19917	39.95	49793	83.07

SOURCE HIERARCHY 2.3.1

191 TRANSPORTATION (AREA)
193 LAND VEHICLES

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
194 GASOLINE	19439	51.90	11689	83.58	324499	10.49	725084	6.62	3834397	9.47
195 LIGHT VEHICLES	16413	56.48	9848	91.06	235250	12.32	513303	7.87	2856158	10.97
196 HEAVY VEHICLES	2001	161.76	1201	260.74	66706	23.14	140950	15.02	590138	24.13
197 OFF HIGHWAY	1025	226.01	640	357.18	22543	39.81	70832	21.18	388101	29.75

SOURCE HIERARCHY 2.3.2

191 TRANSPORTATION (AREA)
193 LAND VEHICLES

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
199 DIESEL	3904	115.81	8038	100.79	106078	18.35	10925	53.94	63469	73.58
200 HEAVY VEHICLES	2167	155.44	4334	137.26	61404	24.12	6140	71.95	36120	97.53
201 OFF HIGHWAY	1550	183.79	3219	159.26	44115	28.45	4412	84.88	26827	113.17
202 RAIL	186	530.55	485	410.31	559	252.78	373	291.92	522	811.32

Table 3.1

SOURCE HIERARCHY 2.3.3

191 TRANSPORTATION (AREA)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
204 AIRCRAFT	3146	129.00	652	353.88	1995	133.81	8725	60.36	26808	113.21
205 MILITARY	993	229.62	190	655.55	477	273.64	2310	117.30	2480	372.22
206 CIVIL	616	291.54	122	818.09	556	253.46	2726	107.98	15579	148.51
207 COMMERCIAL	1537	184.56	341	489.33	962	192.69	3689	92.82	8749	198.18

SOURCE HIERARCHY 2.3.4

191 TRANSPORTATION (AREA)

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
209 VESSELS	1881	166.84	4764	130.92	4143	92.85	9088	59.14	44525	87.85
210 BITUMINOUS COAL	1177	210.91	2942	166.59	177	449.22	1177	164.33	5290	254.71
211 DIESEL FUEL	495	325.22	1238	251.78	1486	155.04	990	179.18	1387	497.73
212 RESIDUAL OIL	108	696.26	471	416.36	283	355.26	14	1506.78	1	10000.00
213 GASOLINE	100	723.58	62	1147.58	2198	127.48	6906	67.84	37842	95.29

Table 3.1

SOURCE HIERARCHY 2.1.1.1

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
14 RESIDENTIAL FUEL (AREA)	13843	61.50	41175	44.53	15867	47.45	8822	60.02	36377	97.19
15 ANTHRACITE COAL	330	398.32	141	760.98	99	600.66	83	618.83	2974	339.91
16 BITUMINOUS COAL	6103	92.62	28217	53.79	915	197.58	6103	72.17	27464	111.85
17 DISTILLATE OIL	2321	150.19	12663	80.30	2785	113.25	696	213.70	1160	544.25
18 RESIDUAL OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
19 NATURAL GAS	4495	107.92	142	758.29	11830	54.95	1893	129.58	4732	269.47
20 WOOD	594	296.89	12	2606.49	237	388.21	47	822.36	47	2703.83

SOURCE HIERARCHY 2.1.1.2

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
35 INDUSTRIAL FUEL

SOURCE CLASS AND SUBCLASSES	PARTICULATES TONS/YR	PARTICULATES SIGMA PERCENT	SULFUR OXIDES TONS/YR	SULFUR OXIDES SIGMA PERCENT	NITROGEN OXIDES TONS/YR	NITROGEN OXIDES SIGMA PERCENT	HYDROCARBONS TONS/YR	HYDROCARBONS SIGMA PERCENT	CARBON MONOXIDE TONS/YR	CARBON MONOXIDE SIGMA PERCENT
69 AREA SOURCES	364627	11.98	261455	17.67	64275	23.57	6242	71.36	6381	232.05
36 ANTHRACITE COAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
39 BITUMINOUS COAL	362393	12.02	258263	17.78	47549	27.41	3170	100.13	6340	232.80
44 RESIDUAL OIL	935	236.63	3149	161.03	3741	97.71	187	412.28	12	5351.03
47 DISTILLATE OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
50 NATURAL GAS	1298	200.84	43	1377.99	12984	52.45	2885	104.96	29	3442.15
53 PROCESS GAS	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
56 COKE	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
59 WOOD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table 3.1

SOURCE HIERARCHY 2.1.1.3

11 FUEL COMBUSTION
13 EXTERNAL COMBUSTION
71 COMM-INSTITUTIONAL FUEL

SOURCE CLASS AND SUBCLASSES

WEIGHTED SENSITIVITY ANALYSIS

	PARTICULATES		SULFUR OXIDES		NITROGEN OXIDES		HYDROCARBONS		CARBON MONOXIDE	
	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT	TONS/YR	SIGMA PERCENT
97 ARIÀ SOURCES	38746	36.76	70556	34.02	30323	34.32	2590	110.78	5277	255.17
72 ANTHRACITE COAL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
75 BITUMINOUS COAL	32816	39.94	52059	39.60	5866	78.03	1275	157.89	4591	273.57
[illegible] RESIDUAL OIL	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
83 DISTILLATE OIL	5345	98.97	18479	66.47	21381	40.87	1069	172.43	71	2199.88
86 NATURAL GAS	585	299.16	18	2129.83	3077	107.74	246	359.46	615	747.46
89 WOOD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

The table displays the σ_K's which result from setting θ = 5% for each of the five classes of air pollutants. For clarity of presentation, Table 3.1 is structured so as to give the Q_K's and σ_K's in adjacent columns for the five pollutants, with the source breakdown on the left following the standard NEDS categorization of emissions sources as shown in Figure 2.1 and Figure 2.2. Each grouping of emission sources in the table is labeled by line number and title (refer to Figure 2.1) as well as by node (refer to Figure 2.2).

These numerical results fully illustrate the characteristics of the weighted sensitivity analysis as discussed in the previous section. Starting at the grand total (highest) level of aggregation, the formula of equation (7) is applied in a hierarchial fashion, working through nodes and branches down to elementary emissions data. It is possible to appreciate a significant relaxation of precision requirements as the analysis progresses from top to bottom of the hierarchy. It is also possible to appreciate the effect of the weightings as allowable errors are allocated in proportion to the relative dominance of the various emissions in any given group. With reference to the relationship between the weightings Q_K/Q and the allowable errors σ_K, it is possible to observe in the results the well-behaved asymptotic character of the technique, as anticipated in Figure 2.4. Any σ_K approaches its corresponding when the ratio Q_K/Q approaches one; see, for example, the allowable error for sulfur oxides emissions in source hierachy [1.], the allowable error for particulate emissions in source hierarchy [1.3.2], and of course any of the cases where there is a single nonzero subclass of emissions in a given group. On the other hand, any σ_K increases exponentially to the assumed maximum of 10,000% when Q_K/Q approaches zero; this is the case, for example, in the computation of the allowable error for carbon monoxide in source hierarchy [2.3.4]. In general, $\theta \leq \sigma_K \leq$ 10,000 for any value of (10,000% is an arbitrary upper bound on σ_K).

ANALYSIS OF ALTERNATIVE TREES

There are two types of structural changes which can be of interest in working with the emissions data tree of Figure 2.2. On the other hand, it may be desired to eliminate a node of the tree. For example, the fuel combustion subtrees of Figure 2.2 could be restructured by classes of fuels, thus eliminating two intermediate nodes and permitting a direct analysis of fuel combustion emissions broken down by type of fuel combusted regardless of what activity the fuel was consumed for. On the other hand, it may be convenient to aggregate the branches of a given node into a smaller number of branches. This could be useful, for example, to reduce forecasting effort by consolidating into a single forecast sources with the smallest emissions so that the new error requirement can still be satisfied.

The first case is illustrated in Figure 3.1 and the numerical results are summarized in Table 3.2 for the modified point sources subtree. In order to obtain the σ_K's of Table 3.2, the Q_K for each of the fifteen types of fuels first had to be computed by summing the emission contributions from usage of that fuel in all branches of the subtree. The results are indicative of the predominance of bituminous coal users as the source of air pollutants released through fuel combustion, and therefore the need for better forecasting and control of these sources.

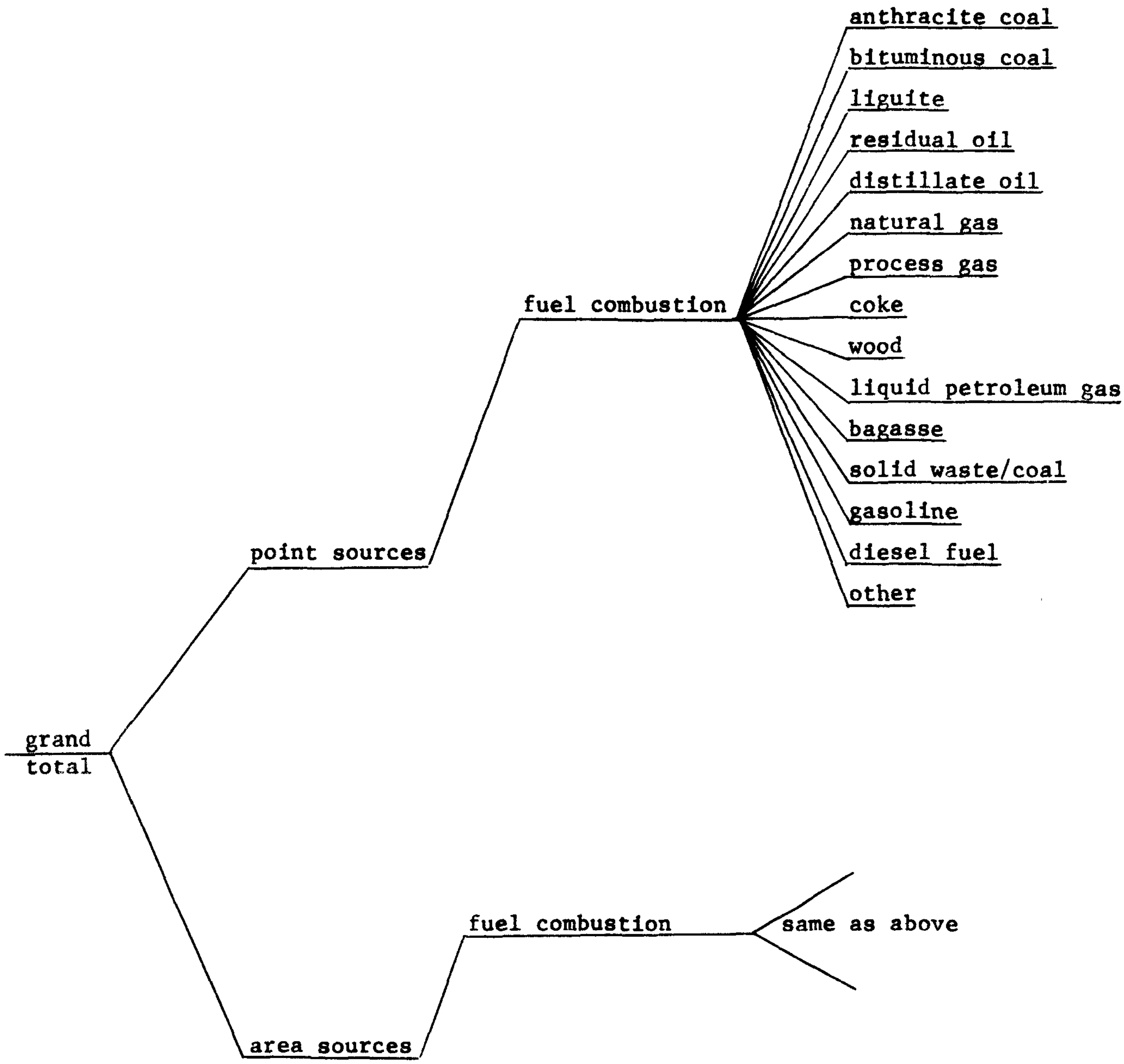


Figure 3.1 Fuel combustion subtrees
restructured by classes of fuels

	Particulates θ =9.14	Sulfur Oxides θ =5.60	Nitrogen Oxides θ =8.39	Hydrocarbons θ =52.12	Carbon Monoxide θ =112.8
antracite coal	274.06	98.75	190.58	1409.35	737.34
bituminous coal	9.22	5.64	8.65	60.02	114.49
liguite	-----	-----	-----	-----	-----
residual oil	199.98	78.19	96.26	429.84	5861.77
distillate oil	583.06	312.23	133.08	650.95	10000.00
natural gas	172.96	1679.44	40.39	118.11	2894.92
process gas	89.52	66.81	140.88	-----	-----
coke	-----	-----	-----	-----	-----
wood	730.90	3418.35	900.82	1879.13	6178.84
liquid pet/gas	-----	-----	-----	-----	-----
bagasse	-----	-----	-----	-----	-----
solid waste/coal	-----	-----	-----	-----	-----
gasoline	3235.83	-----	594.57	316.62	-----
diesel fuel	3617.77	3197.57	557.21	1699.74	2215.54
other	-----	-----	-----	-----	-----

Table 3.2 Weighted Sensitivity Analysis (σ_K) of Point Fuel Combustion Subtrees restructured by classes of fuels

The second case can be illustrated with reference to source hierarchy [1.2] in Table 3.1, particularly the carbon monoxide column. The dominant Q_K's correspond to primary metals (6269525 tons/yr) and the petroleum industry (2907030 tons/yr). Consolidating carbon monoxide emissions from all other industrial processes into a single group yields the following results:

	Q_K (tons/yr)	σ_K (%)
primary metals	6269525	7.40
petroleum industry	2907030	10.87
other industrial processes	250957	37.02

The results above were computed, of course, using the same θ=6.04%. The value of σ_K for the aggregated "other industrial processes" is not very restrictive and could be an indication that detailed forecasts of carbon monoxide emissions for specific industries other than primary metals and petroleum are not necessary to preserve the integrity of the emissions inventory. Generally speaking, forecasting effort can be reduced by regrouping the source classes with the smallest emissions into one or more classes; however, this policy should be applied with some discretion in order to have groups or classes which are meaningful and which can be successfully forecast.

Section IV

WEIGHTED SENSITIVITY ANALYSIS PROGRAM (WSAP)

This section documents the software developed to implement the weighted sensitivity analysis technique. The program provides a means to evaluate (hierarchially) the maximum permissible errors in emissions data for source categories when given the maximum permissible errors for the total emission inventory. The system is coded in FORTRAN IV for the IBM System/360. The material below is structured in consonance with EPS's outline for software documentation.

Program Abstract

Program Name: WSAP

Programmer: L. J. Rushbrook

Program Written for: John Bosch

Section/Branch: National Air Data

Language: Fortran IV

Size: 66K

Normal Execution Time: 7 secs for summary (state, county) Class A

Input: Control Cards 1, Data Cards Ø, Tape: 1, Disk: Ø

Explanation: The single control card contains the percent error of the total emission (Theta) for each of the five pollutants. The input tape is a NEDS print tape.

Function: To provide a means of evaluating the maximum allowable error in emission data (Sigma) for source categories when given the maximum allowable error for the total emission inventory (Theta). The techniques of weighted sensitivity analysis are employed.

Output: Cards Ø, Tape Ø, Disk Ø, Printer 1

Explanation: The "Weighted Sensitivity Analysis Program" report is printed according to the hierarchical structure of the NEDS report and lists the tons of emission (QK), the percent of allowable error and the amount of allowable error for each pollutant.

Programmed Diagnostics:

RUN TERMINATED: Invalid control card, invalid tape, tape read error.
SUMMARY PROCESSING TERMINATED: Input line not acceptable to program, negative pollutant field on input.

RUN DESCRIPTION:

This program provides a means to evaluate the maximum permissable errors in emission data for source categories when given the maximum permissable error for the total Emission Inventory. The techniques of weighted sensitivity analysis are employed.

The system is coded in Fortran IV for the IBM System 360.

The program reads the "National Emissions Data System" print tape, stores the entire amount of data for one report (state, county) in memory, and under the control of a driver table selects the lines of the report to calculate the allowable errors (σ_K) and the amount of allowable error ($\sigma_K Q_K$) for each pollutant. The output is according to the hierarchical structure of the NEDS report that is designed into the Driver Table and lists the amount (Q), the percent of allowable error sigma (σ_K) and the amount of allowable error ($\sigma_K x Q_K$) for each pollutant. The formula used for the computation is:

$$\sigma_K = \theta \sqrt{Q/Q_K}$$

where σ_K = percent allowable error for a given source

θ = percent allowable error for total emission

Q_K = amount of emissions for a given source

$Q = \sum Q_K$ for a particular category.

Method:

Figure 1 and 2 in Section 2 describe the overall system flow and the General Program flow.

A. Initialization of the Driver Table (IDRIVR)

At compile time the Driver Table is initialized. This table (IDRIVR) determines the hierarchical level for processing by selecting the lines of data to be processed from the standard National Emissions Data System input tape. The table contains values that control processing actions by specifying hierarchical headings, source class labels and references to data for processing within each hierarchy.

The Driver table is a series of sub-tables which correspond to one hierarchical level or sublevel. One sub-table thus represents the data to process for a given Theta (θ or σ). There are 33 sub-tables within IDRIVR. Normally, all 33 sub-tables will be used to process each state or county.

The contents of IDRIVR is a continuous stream of 3 digit numbers containing indicators and line numbers related to the standard "National Emissions Data System" report.

The indicators are of two types. One type is depicted by a numerical value greater than 799. The other indicator is a positional relationship within the sub-table and is a numerical count of the number of line numbers immediately following the indicator on which the program must act for this event.

See Appendix A for a layout of the Driver Table (IDRIVR) and an example of its use. A clear understanding of this table is essential to understanding the program.

B. Initialization of the Title Table

At compile time the Title Table (ITITL) is initialized to the values shown in Appendix B. It is a 2 dimensional array (8,238) containing the 32 character title of each possible line on the NEDS report. These titles are positioned precisely as they are on the NEDS report and each is identically spelled.

C. Setup

A parameter card is read which contains the maximum permissable error (θ) for each pollutant in the total emission inventory. It is a five digit number of two decimal places. Its maximum value is 999.99. These 5 theta (θ) values, one for each pollutant, are stored in array TH and are used to compute the sigmas (σ_K) of the lower levels.

Table TDATA is set to Ø. This table will contain the amount fields to be read from tape, the calculated allowable errors (σ_K) and its allowable amounts ($\sigma_K \cdot QK$).

D. Read One NEDS State (county)

The NEDS tape is read until the first line is found. Each record is scanned until the words "National Emissions Data System" is found and this record or line is assigned line number 1. All succeeding lines are assigned the values 2-237. Blank lines are ignored.

Lines 1-6 are stored as read in IHEAD and used as is for the header of the report.

Lines 8, 9, 10 contain the columnar headings for the 5 pollutants and are stored in IPOLL. Only the 13 characters each of pollutant name are stored.

Lines 11-237 constitute data lines and are used to build the amount (QK) field of table TDATA.

Since the program which generates the NEDS tape suppresses (fails to output) all lines in which the 5 pollutant amounts are each zero, the lines of data on the NEDS tape will rarely equal the maximum number of lines (237) for a standard report. To circumvent this problem table ITITL contains all the titles for each line (11-237) of the standard NEDS report.

Progression of the read in routine is by line number (11-237) down the ITITL table. The routine will compare the standard line title in ITITL with the NEDS input line title. If equal the NEDS data for each pollutant is stored in the TDATA array, the line counter is incremented and another line is read from the NEDS tape. If unequal no data is stored (the amount fields in TDATA remain zero) the line counter is incremented and the next title in ITITL is compared to the NEDS input title. This procedure repeats itselt until line 238 is reached in the ITITL table. At this time the complete state or county has been stored in TDATA in the standard NEDS sequence and the Driver Table (IDRIVR) is ready to select lines for processing.

A change in the NEDS print program (a spelling or word repositioning change) will cause that word to never find its match in the WSAP program and insufficient data will be loaded.

To detect this possibility an error check is made at line 233, the "GRAND TOTAL" line. It is assumed that all NEDS reports have an entry for "GRAND TOTAL" (line 233). When line 233 is reached a match between NEDS and WSAP (on "GRAND TOTAL") is mandatory or WSAP will print an error, fail to process the summary (state or county) and go on to the next state. The number of errors detected during the run is printed on the first line of the last page of the run. If this number is not Ø the report is incomplete.

E. Process One State or County

The IDRIVR table contains 33 sub-tables. The program will start with sub-table 1 and continue through until table 33 or the last table is processed. The counter KTS is used to indicate the table desired (table separators encountered) and the array JTSTBL contains the start position in the IDRIVR table for each of the 33 sub-tables. The contents of KTS are used as the index for JTSTBL to determine the start point for the proper table in IDRIVR.

The first entry of the sub-table is checked for a table separator (>799) or the end of table (999). If neither, the start point for IDRIVR is stored in KJTS and is used to calculate the start points of the other key positions in the IDRIVR sub-table (see Appendix A).

The IDRIVR table is now used to drive the program. It determines what to do and which line number in the TDATA table or ITITL table to do it to. By using the indicator and line numbers in the IDRIVR table the calculation of and σ x QK begins. The line number to act on in the TDATA table (QK) is found in the IDRIVR table. This line number

(NN) in IDRIVR is used as the TDATA index [TDATA(NN)] to find the amount (QK). TDATA is a 3 dimensional array hence Sigma (σ_K) is calculated and placed next to the amount (QK) in TDATA and Sigma (σ_K) x the amount (QK) is placed next to sigma in TDATA.

After all the calculations have been made for each pollutant the report for this sub-table is printed in pollutant sequence.

The sub-table report requires the following:

1. A main header

   This consists of lines 1-7 of the NEDS report.

2. A sub-table title describing the hierarchical level of the sub-table.

   This title is obtained from the ITITL array using the offset (line numbers) found in the IDRIVR array entries IH.

3. Type of pollutant

   This is taken from line 8 of the NEDS report.

4. Theta (θ or σ) used in this calculation

   Obtained from input θ or from a σ in TDATA as directed from IDRIVR entries IDH.

5. **Labels for data lines**

These labels are taken from the ITITL array as directed by the IDRIVR table entries IL.

6. **Calculations**

Data is obtained from TDATA array as directed by the IDRVR table entries ID.

After printing the report for this sub-table the next sub-table is processed and printed. This cycle continues until all 33 sub-tables have been processed.

A new state (county) is read in from the NEDS tape and the main cycle repeats until an end of file is reached on the tape.

F. Major Program Tables

			BYTES
B5	(5)	5x4	20

Stores BETA (β) for 5 pollutants.

IDRIVR	(720)	720x4	2,880

A continuous stream of 3 digit numbers representing indicators and line numbers used to drive the program. Initialized at compilation. See Appendix A.

IHEAD	(33, 7)	4x231	924

Contains characters 2-133 of the first 7 lines, excluding blank lines, of the NEDS report tape. The carriage control character is not stored. Format is 33A4 for each line.

			BYTES
IPOLL	(15, 3)	54x4	180

Stores the columnar headings for each of the 5 pollutants (lines 8, 9, 10 of NEDS report).

ITITL	(8, 237)	(4x8)x237)	7,584

Stores the row title for each of the 237 lines of the Standard NEDS table. Initialized at compilation. See Appendix B.

JTSTBL	(50)	50x4	200

Contains the start points for each sub-table in IDRIVR. Start point is determined by the Table Separator indicator (an integer greater than 799) in the IDRIVR table.

Q5	(5)		20

Stores Q for 5 pollutants.

TDATA	(3, 5, 237)	4x15x237	14,220

(data, pollutant, line number)
Contains the 3 amounts (QK, σ , σxQK) for each of the 5 pollutants for each of the 237 lines.

TH	(5)	5x4	20

Stores the input theta for each pollutant.

THETA5	(5)	5x4	20

Stores active THETA (θ) for 5 pollutants.

			BYTES
TN5	(5)	5x4	20

Stores pollutant fields from NEDS tape.

QTHETA	(5)	5x4	20

Stores (Q/100)* Theta for each active pollutant in the sub-table used in printing total line.

Total bytes	26,108

FORMULAE USED

The formulas utilized at the various levels in the hierarchical structure of the NEDS file are:

Q Total Emission: $$Q = \sum_{K=1}^{N} QK$$

Beta: $$\beta = \theta\sqrt{Q}$$

Sigma: $$\sigma = \theta\sqrt{Q/QK} = \beta/\sqrt{QK}$$

θ = Percent error contained in the total emission Q.

K = A particular source class for level.

Each pollutant (maximum of 5 per run) will have its own values for the above variables. The initial input θ applies to its pollutant at the highest level (IDRIVR table 1). The σ of the preceding level then becomes the θ for the active level.

RESTRICTIONS

The input theta (on card) must be positive and no greater than 999.99.

The maximum sigma internally generated is 10,000. Anything higher defaults to 10,000.

OPTIONS

Five input thetas must be inserted in the parameter card for use by IDRIVR Table 1. A Ø.ØØ theta entry for a pollutant will cause that pollutant to be bypassed in processing and printing for each table.

ACCURACY

All internal calculations are made in floating point and converted to fixed point for printing.

FLOW CHARTS

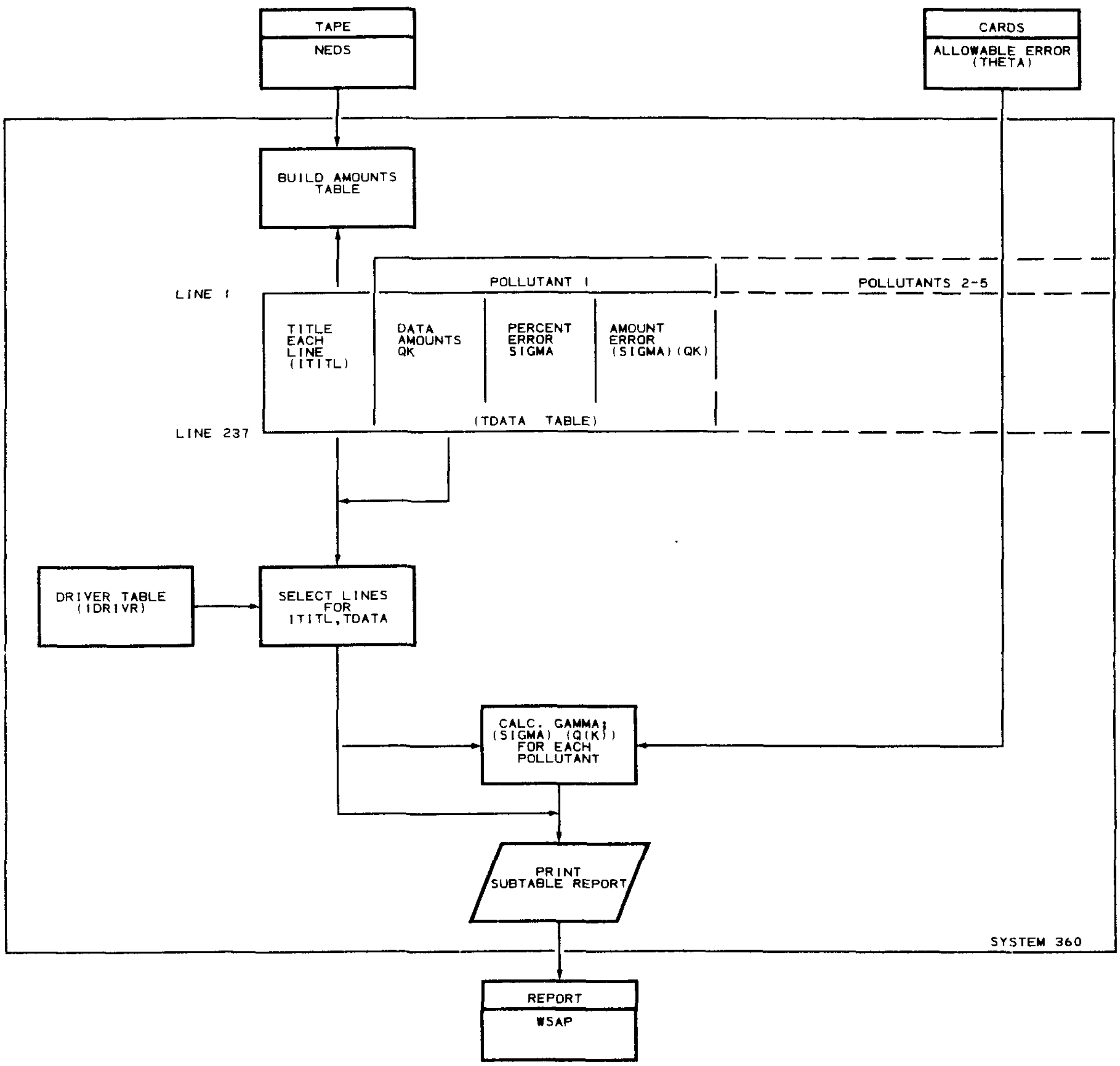
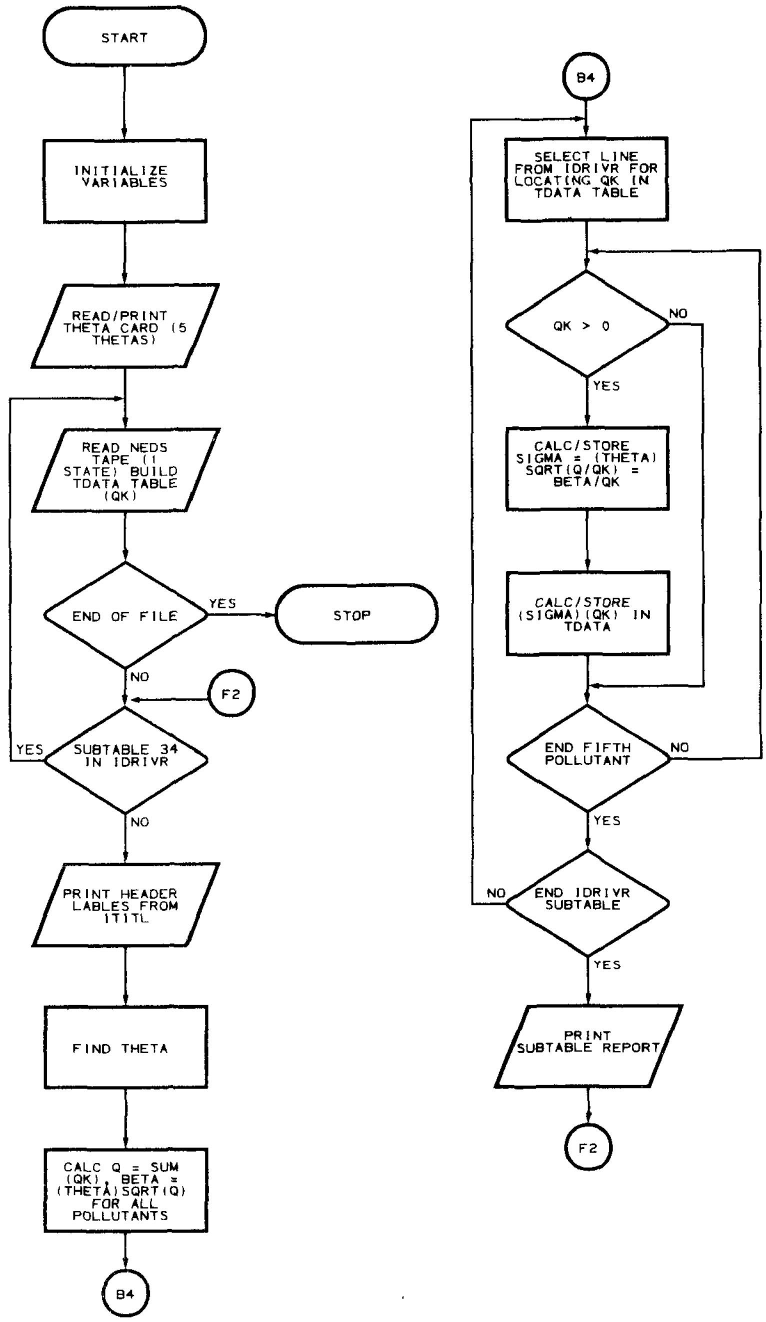
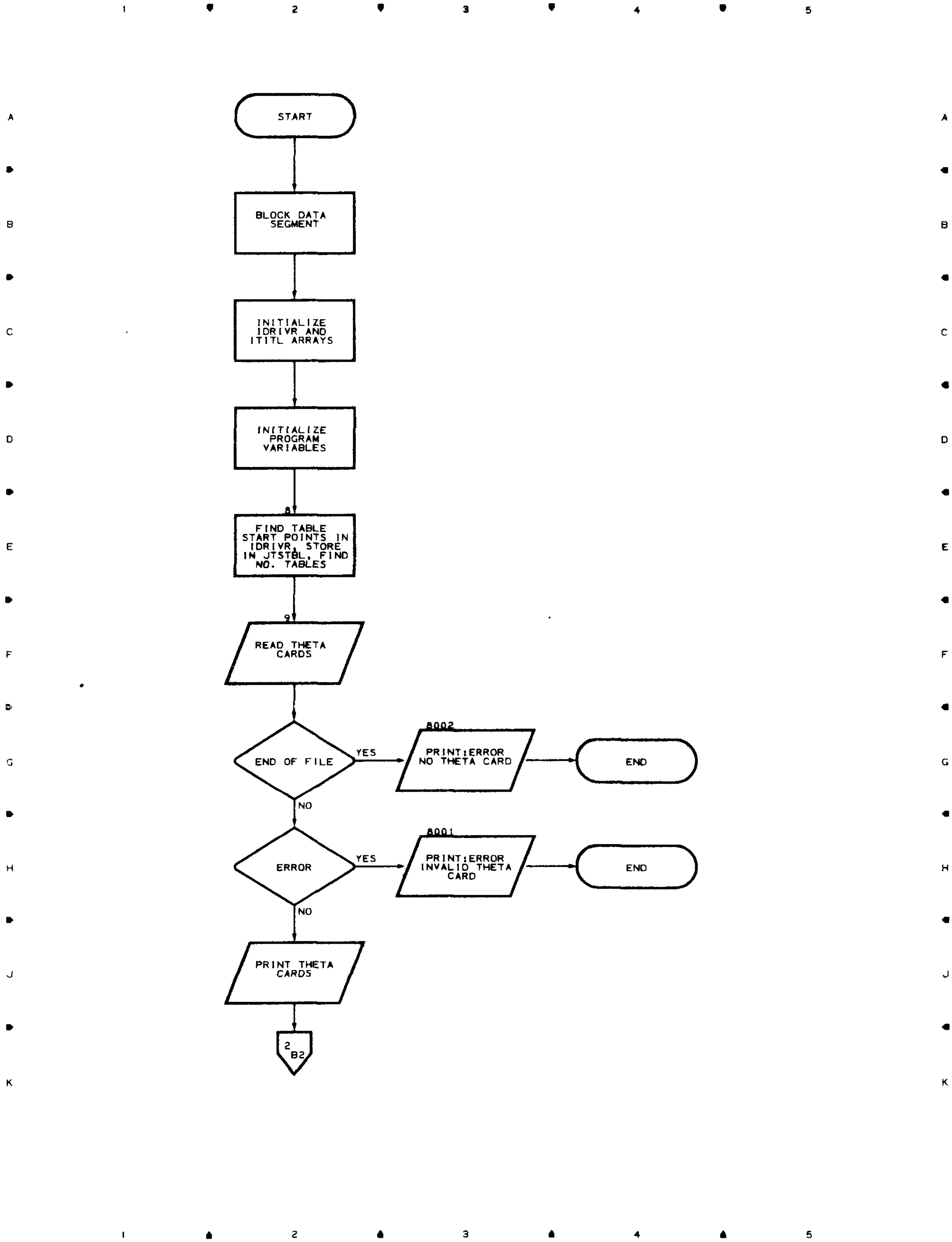
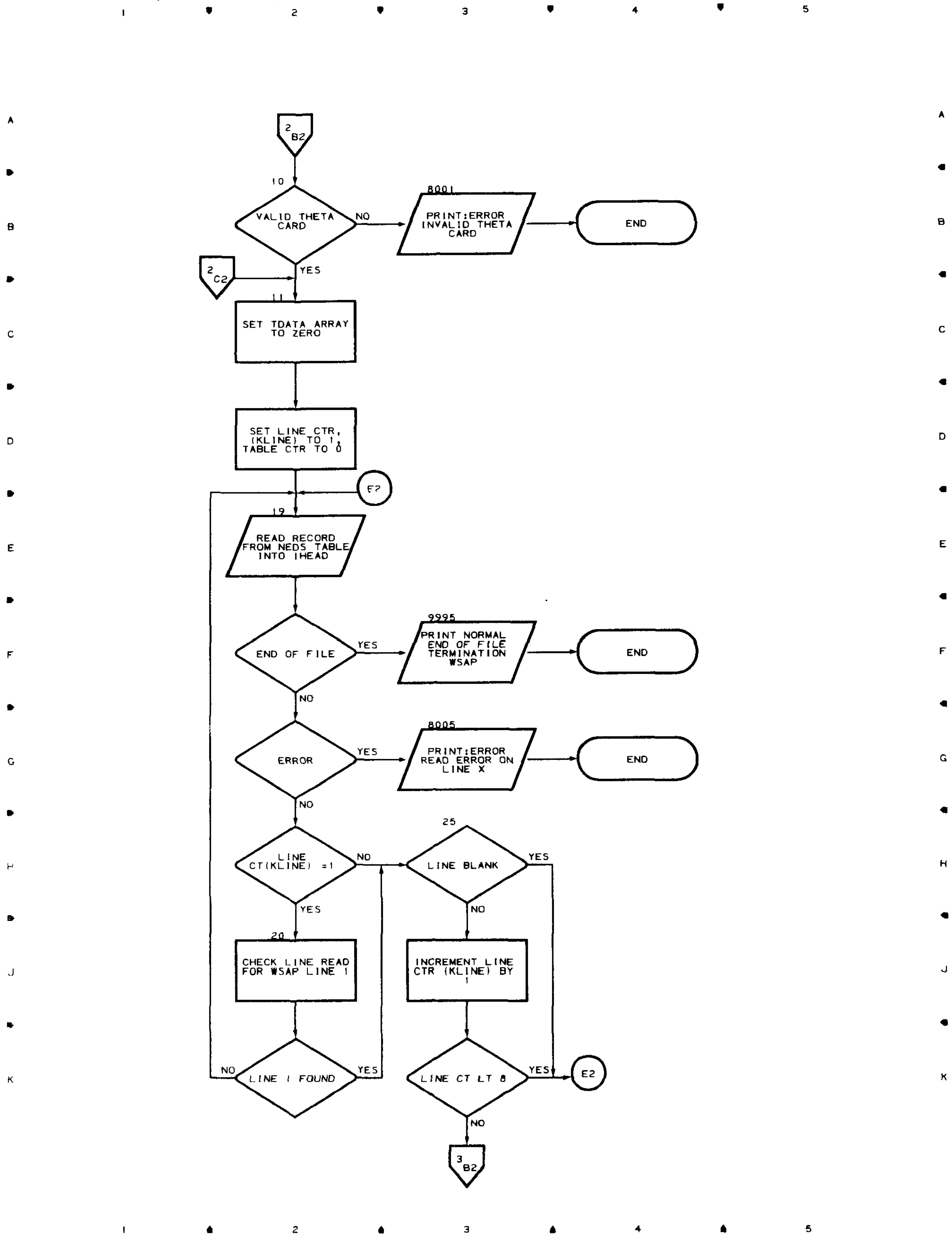
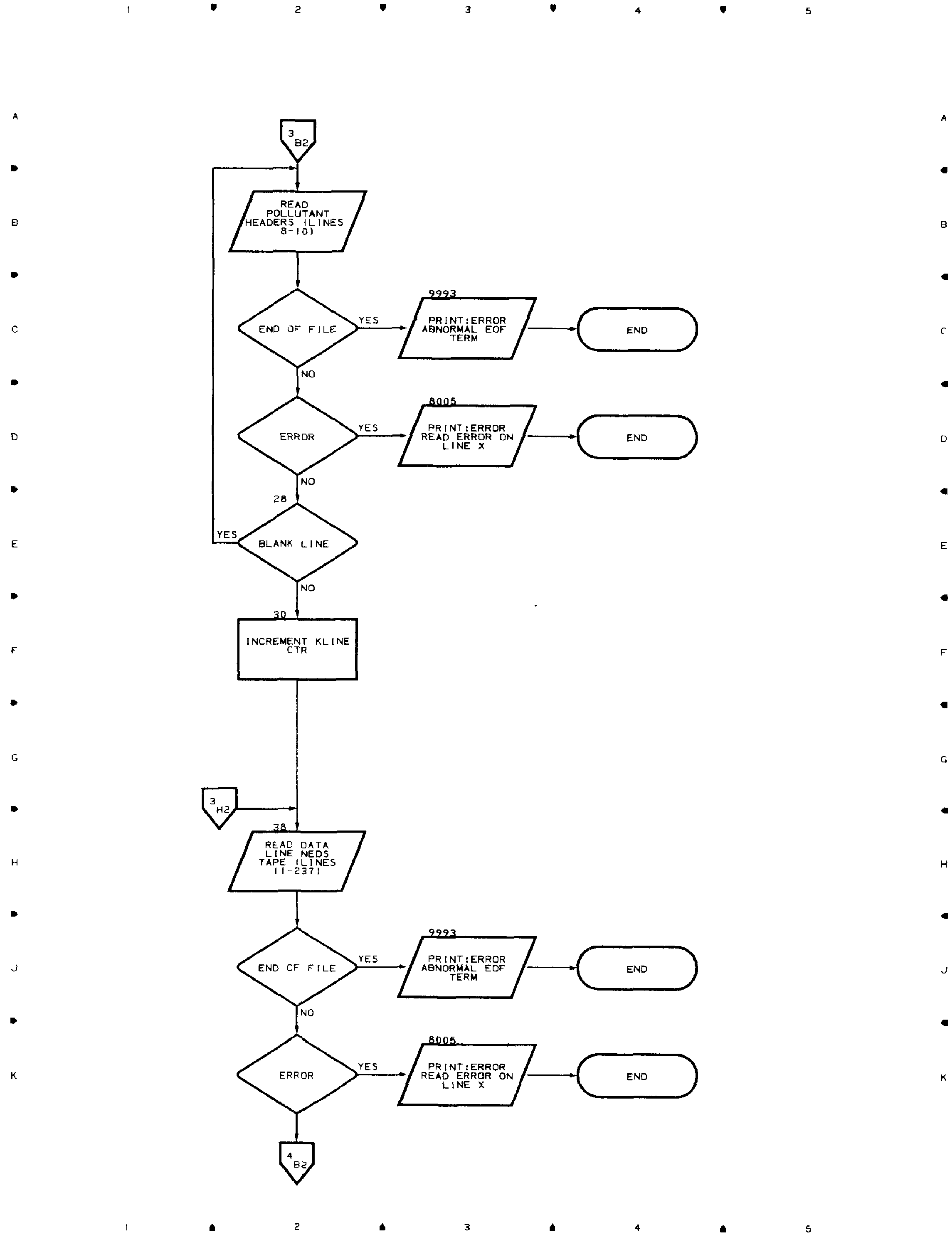

TAPE
NEDS
CARDS
ALLOWABLE ERROR (THETA)
BUILD AMOUNTS TABLE
LINE 1
LINE 237
POLLUTANT 1
POLLUTANTS 2-5
TITLE EACH LINE (ITITL)
DATA AMOUNTS QK
PERCENT ERROR SIGMA
AMOUNT ERROR (SIGMA)(QK)
(TDATA TABLE)
DRIVER TABLE (IDRIVR)
SELECT LINES FOR ITITL,TDATA
CALC. GAMMA; (SIGMA) (Q(K)) FOR EACH POLLUTANT
PRINT SUBTABLE REPORT
SYSTEM 360
REPORT
WSAP

Chart 006 GENERAL PROGRAM FLOW WEIGHTED SENSITIVITY ANALYSIS PROGRAM

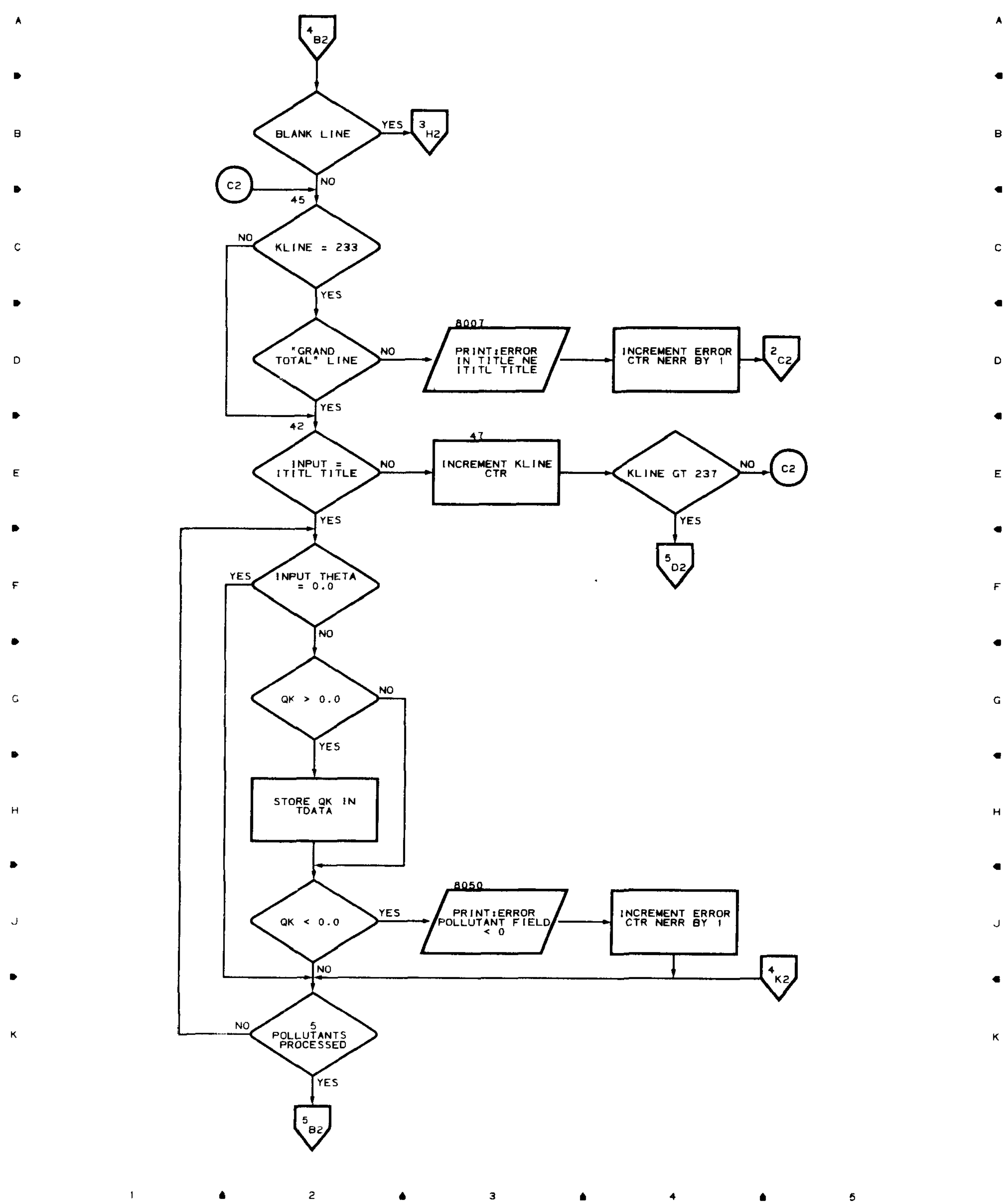


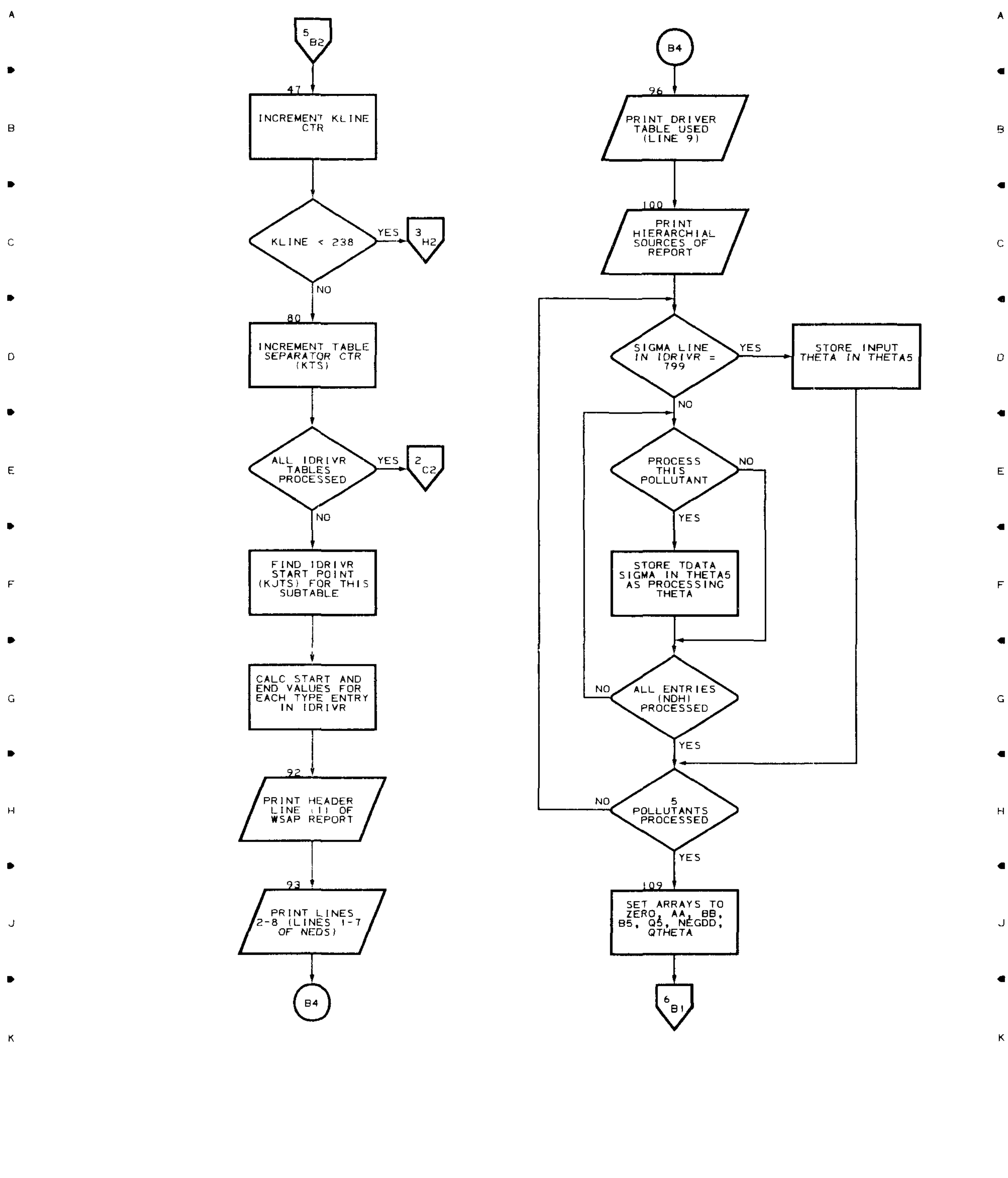

START
BLOCK DATA SEGMENT
INITIALIZE IDRIVR AND ITITL ARRAYS
INITIALIZE PROGRAM VARIABLES
8
FIND TABLE START POINTS IN IDRIVR, STORE IN JTSTBL, FIND NO. TABLES
9
READ THETA CARDS
END OF FILE
YES
8002
PRINT:ERROR NO THETA CARD
END
NO
ERROR
YES
8001
PRINT:ERROR INVALID THETA CARD
END
NO
PRINT THETA CARDS
2 B2

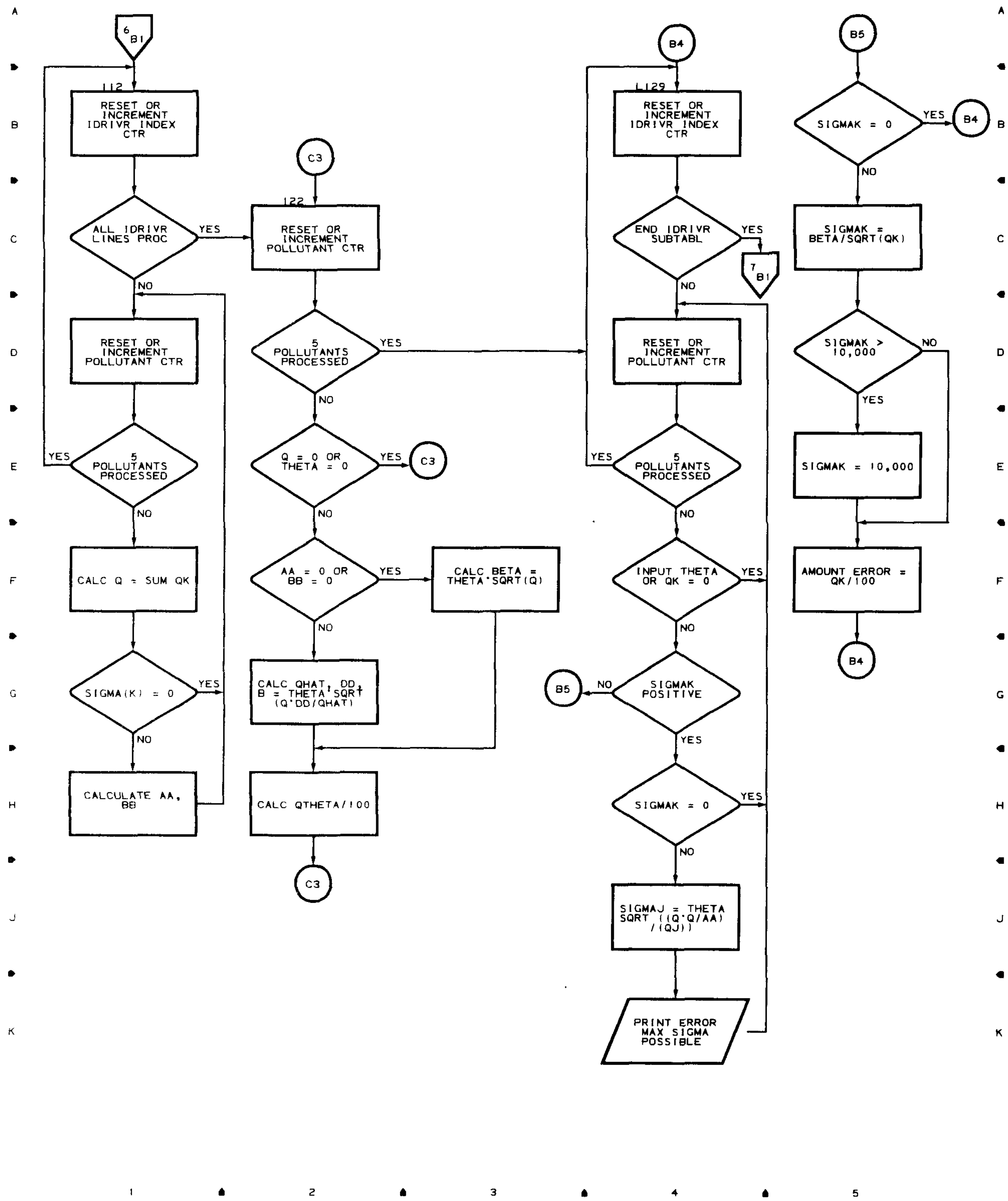

2 B2
10
VALID THETA CARD
NO
8001
PRINT:ERROR INVALID THETA CARD
END
YES
2 C2
11
SET TDATA ARRAY TO ZERO
SET LINE CTR, (KLINE) TO 1, TABLE CTR TO 0
E2
19
READ RECORD FROM NEDS TABLE INTO IHEAD
END OF FILE
YES
9995
PRINT NORMAL END OF FILE TERMINATION WSAP
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
NO
LINE CT(KLINE) =1
NO
25
LINE BLANK
YES
YES
20
CHECK LINE READ FOR WSAP LINE 1
NO
INCREMENT LINE CTR (KLINE) BY 1
NO
LINE 1 FOUND
YES
LINE CT LT 8
YES
E2
NO
3 B2



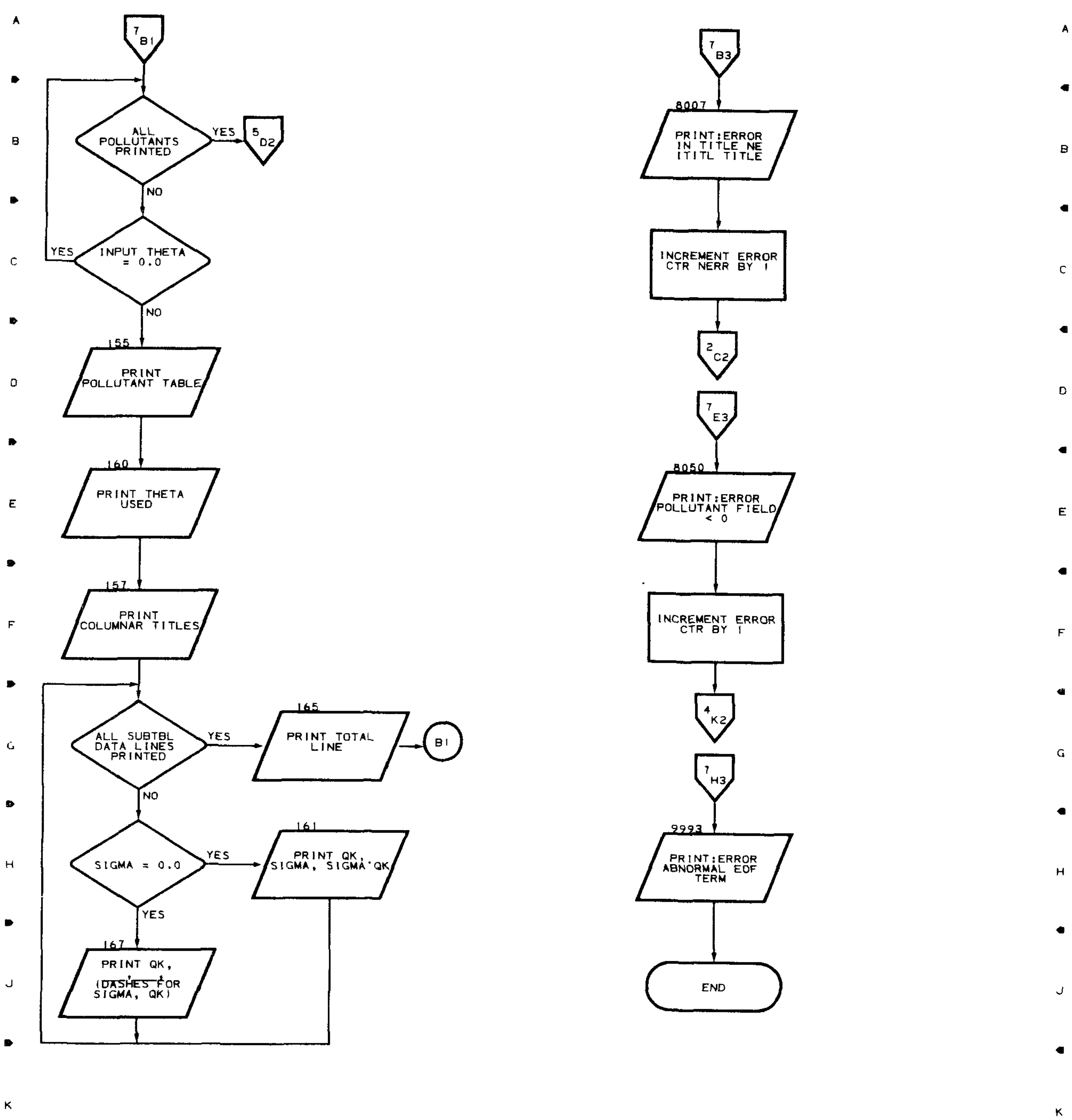
3 B2
READ POLLUTANT HEADERS (LINES 8-10)
END OF FILE
YES
9993
PRINT:ERROR ABNORMAL EOF TERM
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
NO
28
BLANK LINE
YES
NO
30
INCREMENT KLINE CTR
3 H2
38
READ DATA LINE NEDS TAPE (LINES 11-237)
END OF FILE
YES
9993
PRINT:ERROR ABNORMAL EOF TERM
END
NO
ERROR
YES
8005
PRINT:ERROR READ ERROR ON LINE X
END
4 B2


4 B2
BLANK LINE
YES
3 H2
NO
C2
45
KLINE = 233
NO
YES
"GRAND TOTAL" LINE
NO
8007
PRINT:ERROR IN TITLE NE ITITL TITLE
INCREMENT ERROR CTR NERR BY 1
2 C2
YES
42
INPUT = ITITL TITLE
NO
47
INCREMENT KLINE CTR
KLINE GT 237
NO
C2
YES
5 D2
YES
INPUT THETA = 0.0
YES
NO
QK > 0.0
NO
YES
STORE QK IN TDATA
QK < 0.0
YES
8050
PRINT:ERROR POLLUTANT FIELD < 0
INCREMENT ERROR CTR NERR BY 1
NO
4 K2
5 POLLUTANTS PROCESSED
NO
YES
5 B2


5 B2
47
INCREMENT KLINE CTR
KLINE < 238
YES
3 H2
NO
80
INCREMENT TABLE SEPARATOR CTR (KTS)
ALL IDRIVR TABLES PROCESSED
YES
2 C2
NO
FIND IDRIVR START POINT (KJTS) FOR THIS SUBTABLE
CALC START AND END VALUES FOR EACH TYPE ENTRY IN IDRIVR
92
PRINT HEADER LINE (1) OF WSAP REPORT
93
PRINT LINES 2-8 (LINES 1-7 OF NEDS)
B4
B4
96
PRINT DRIVER TABLE USED (LINE 9)
100
PRINT HIERARCHIAL SOURCES OF REPORT
SIGMA LINE IN IDRIVR = 799
YES
STORE INPUT THETA IN THETA5
NO
PROCESS THIS POLLUTANT
NO
YES
STORE TDATA SIGMA IN THETA5 AS PROCESSING THETA
ALL ENTRIES (NDH) PROCESSED
NO
YES
5 POLLUTANTS PROCESSED
NO
YES
109
SET ARRAYS TO ZERO, AA, BB, B5, Q5, NEGDD, QTHETA
6 B1



6 B1
112
RESET OR INCREMENT IDRIVR INDEX CTR
ALL IDRIVR LINES PROC
YES
NO
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
CALC Q = SUM QK
SIGMA(K) = 0
YES
NO
CALCULATE AA, BB
C3
122
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
Q = 0 OR THETA = 0
YES
C3
NO
AA = 0 OR BB = 0
YES
CALC BETA = THETA*SQRT(Q)
NO
CALC QHAT, DD, B = THETA*SQRT (Q*DD/QHAT)
CALC QTHETA/100
C3
B4
L129
RESET OR INCREMENT IDRIVR INDEX CTR
END IDRIVR SUBTABL
YES
7 B1
NO
RESET OR INCREMENT POLLUTANT CTR
5 POLLUTANTS PROCESSED
YES
NO
INPUT THETA OR QK = 0
YES
NO
SIGMAK POSITIVE
NO
B5
YES
SIGMAK = 0
YES
NO
SIGMAJ = THETA SQRT ((Q*Q/AA) /(QJ))
PRINT ERROR MAX SIGMA POSSIBLE
B5
SIGMAK = 0
YES
B4
NO
SIGMAK = BETA/SQRT(QK)
SIGMAK > 10,000
NO
YES
SIGMAK = 10,000
AMOUNT ERROR = QK/100
B4



7 B1
ALL POLLUTANTS PRINTED
YES
5 D2
NO
INPUT THETA = 0.0
YES
NO
155
PRINT POLLUTANT TABLE
160
PRINT THETA USED
157
PRINT COLUMNAR TITLES
ALL SUBTBL DATA LINES PRINTED
YES
165
PRINT TOTAL LINE
B1
NO
SIGMA = 0.0
YES
161
PRINT QK, SIGMA, SIGMA·QK
YES
167
PRINT QK, (DASHES FOR SIGMA, QK)
7 B3
8007
PRINT:ERROR IN TITLE NE ITITL TITLE
INCREMENT ERROR CTR NERR BY 1
2 C2
7 E3
8050
PRINT:ERROR POLLUTANT FIELD < 0
INCREMENT ERROR CTR BY 1
4 K2
7 H3
9993
PRINT:ERROR ABNORMAL EOF TERM
END

INPUT-OUTPUT DESCRIPTION

A. Input

1. Card Input

The first and only card is the Theta (θ) card which contains the percent error in the total emission for each pollutant. It has the following format:

Col	Contents	Comment
1-5	THETA	Card identifier
6	blank	
7-12	NNN.NN	θ Pollutant 1
13	blank	
14-19	NNN.NN	θ Pollutant 2
20	blank	
21-26	NNN.NN	θ Pollutant 3
27	blank	
28-33	NNN.NN	θ Pollutant 4
34	blank	
35-40	NNN.NN	θ Pollutant 5

All N's must be an integer (Ø-9) and the decimal point must be present.

A Ø.ØØ theta will cause that pollutant to be bypassed in processing and printing.

2. National Emissions Data System (NEDS) Print Tape

The description of this NEDS tape can be found in the EPA library as it is generated by another program. Program is presently set up for:

LRECL = 133
BLKSIZE = 2660
RECFM = FBA
LABEL = 1
DENSITY = 1600 BP1

B. Output

The printed report will be in IDRIVR hierarchical table order (table 1 through table 33). Table 4.1 is a sample of the output.

WEIGHTED SENSITIVITY ANALYSIS REPORT
NATIONAL EMISSIONS DATA SYSTEM
****
ENVIRONMENTAL PROTECTION AGENCY
****

COUNTY EMISSIONS REPORT
****
FRANKLIN COUNTY, OHIO

RUN DATE: MAY 11, 1973
EMISSIONS AS OF: APRIL 19, 1973

SOURCE HIERARCHY — GRAND TOTAL

DRIVER TABLE 1

PARTICULATES

THETA = 1.00

DATA NO.	SOURCE CLASSES	TONS / YR	ALLOWABLE ERROR PERCENT	ALLOWABLE ERROR TONS / YR
235	AREA SOURCES	31786.	1.36	433.
236	POINT SOURCES	27093.	1.47	399.
	TOTAL	58879.	1.00	589.

SOX

THETA = 1.00

DATA NO.	SOURCE CLASSES	TONS / YR	ALLOWABLE ERROR PERCENT	ALLOWABLE ERROR TONS / YR
235	AREA SOURCES	18368.	1.65	304.
236	POINT SOURCES	31853.	1.26	400.
	TOTAL	50221.	1.00	502.

Table 4.1 SAMPLE WSAP OUTPUT

WEIGHTED SENSITIVITY ANALYSIS REPORT
NATIONAL EMISSIONS DATA SYSTEM
****
ENVIRONMENTAL PROTECTION AGENCY
****

COUNTY EMISSIONS REPORT
****
FRANKLIN COUNTY, OHIO

RUN DATE: MAY 11, 1973
EMISSIONS AS OF: APRIL 19, 1973

SOURCE HIERARCHY
GRAND TOTAL

DRIVER TABLE I

PARTICULATES

THETA = 1.00

DATA NO.	SOURCE CLASSES	TONS / YR	ALLOWABLE ERROR PERCENT	ALLOWABLE ERROR TONS / YR
235	AREA SOURCES	31786.	1.36	433.
236	POINT SOURCES	27093.	1.47	399.
	TOTAL	58879.	1.00	589.

SOX

THETA = 1.00

DATA NO.	SOURCE CLASSES	TONS / YR	ALLOWABLE ERROR PERCENT	ALLOWABLE ERROR TONS / YR
235	AREA SOURCES	18368.	1.65	304.
236	POINT SOURCES	31853.	1.26	400.
	TOTAL	50221.	1.00	502.

Table 4.1 (cont.)

TEST DATA

The test input is a National Emissions Data System print tape for 4 states (Illinois, New Jersey, Ohio, Texas). Run date for the tape is April 3, 1973 for emissions as of February 23, 1973. A listing of the tape is furnished with the program listing and the original test tape is delivered with the program.

The following test checks have been made:

1. A Ø.ØØ input Theta cancels processing and printing for that pollutant.

2. An invalid Theta card. THETA missing in columns 1-5.

3. No Theta card present, hopper empty.

4. A no match between input line title and the standard line title in ITITL array.

1. All mathematical calculations have been checked for validity.

2. All IDRIVR tables are correct.

3. The ITITL table agrees with the NEDS test tape.

4. The report is printing correctly, including the printing of dashes for sigma if it equals zero.

KEYPUNCH INSTRUCTIONS:

Prepare the THETA parameter data and punch the card to the following format:

Col	Contents	Comment
1-5	THETA	
6	blank	
7-12	NNN.NN	θ for Pollutant 1
13	blank	
14-19	NNN.NN	θ for Pollutant 2
20	blank	
21-26	NNN.NN	θ for Pollutant 3
27	blank	
28-33	NNN.NN	θ for Pollutant 4
34	blank	
35-40	NNN.NN	θ for Pollutant 5

All N's must be an integer Ø-9 and the decimal point must be present.

A Ø.ØØ theta will cause that pollutant to be bypassed in processing and printing.

INPUT-OUTPUT COORDINATOR INSTRUCTIONS:

Obtain the NEDS report tape for processing.

CONSOLE INSTRUCTIONS:

Mount NEDS tape
Insert THETA card in hopper
Run WSAP program.

SUGGESTIONS, WARNINGS AND CHANGES

SUGGESTIONS:

Improvements to be added:

WSAP has been modified to incorporate the following in WSAP 2:

- o Ability to load the ITITL table from cards.
- o Capability to load the IDRIVR table from cards.
- o Capability to load a known sigma at any category level for any pollutant from cards.

PROGRAM LISTING

The program listed is given under separate cover, together with the users' manual for WSAP. The driver and title tables are given in this section as appendices IV-A and IV-B.

APPENDIX IV-A

DRIVER TABLE (IDRIVR)

The IDRIVR table is a continuous stream of 3 digit integers which controls the selection of data for processing within the WSAP program. It consists of 33 subtables that correspond to the hierarchical levels in the NEDS report.

Each subtable begins with a Table Separator indicator (an integer greater than 799). Following the Table Separator is a series of indicators and line numbers.

Each indicator is an integer which tells the program how many following table entries there are concerning this event. These entries are the actual line numbers in the ITITL table and the TDATA table where the program must go to obtain the data for processing and printing. The ITITL table provides Titles for headings and data lines while the TDATA table provides the amount (QK), sigma and sigma X QK fields.

The number of line number entries in each subtable is variable but the number of indicators and their relative positions within each subtable are fixed.

By calculating the start position of a desired subtable and the start position for each event within the subtable the Driver table can now provide control information (line numbers) to the program.

The following pages provide a more detailed description of the IDRIVR table.

APPENDIX IV-A (continued)

Layout of Driver Table (IDRIVR)

JTS	Table Separator indicator. It is an integer greater than 799 and identifies the beginning of a new table. A 999 entry is used to denote "end of tables".
NH	Count of following (IH) line numbers used for report header information. (1 entry number)
IH	Line numbers used to obtain the heading label information in ITITL. (NH entries)
NDH	Count of following (IDH) line numbers used to obtain θ (or σ) (normally this number is 1)
IDH	Line number where θ or σ data is obtained in TDATA table (NDH entries, usually only 1). If this number is 799 the input θ on card is used.
NL	Count of following (IL) line numbers used for labeling next consecutive lines (1 entry number)
IL	Line numbers where the labeling words are obtained in ITITL table. (NL entries)
ND	Count of following (ID) line numbers used for obtaining the data which is associated with IL (1 entry number)
ID	Line number where the amount data is to be located in TDATA table. (IL entries)

The number of entries for NL and ND should be identical.

APPENDIX IV-A (continued)

Example use of IDRIVR Table stream for 1 sublevel

IDRIVR POSITION	POSITION VARIABLE NAME	IDRIVR DATA	DATA VARIABLE NAME	COMMENT
1	KJTS	801	JTS	Table separator, Begin Table 1
2	KNH	1	NH	There is 1 label item next
3	KIH	233	IH	Use label on line 233 of ITITL
4	KNDH	1	NDH	There is 1 θ line item next
5	KIDH	237	IDH	Use on line 237 of TDATA as θ
6	KNL	2	NL	There are 2 lines of label data next
7	KIL	235	IL	Use label on line 235 of ITITL
8		236		Use label on line 236 of ITITL
9	KND	2	ND	There are 2 lines of amt. data next
10	KID	235	ID	Use the 5 pollutant amts. on line 235 of TDATA
11		236		Use the 5 pollutant amts. on line 236 of TDATA
12	KJTS	802	JTS	Table separator - Begin Table 2
13	KNH	1	NH	

If IDH were 799 the input Theta would be used instead of the sigma on line 237 of the TDATA table.

By using the data in the IDRIVR subtable example on the preceding page the program calculates the following variables.

					Value
KJTS	=	JTSTBL (KTS)	=		1
KNH	=	KJTS + 1	=		2
NH	=	IDRIVR (KNH)	=		1
KIH	=	KNH + 1	=		3
IH	=	IDRIVR (KIH)	=		233
KNDH	=	KIH + NH	=		4
NDH	=	IDRIVR (KNDH)	=		1
KIDH	=	KNDH + 1	=		5
IDH	=	IDRIVR (KIDH)	=		237
KNL	=	KIDH + NDH	=		6
NL	=	IDRIVR (KNL)	=		2
KIL	=	KNL + 1	=		7
IL	=	IDRIVR (KIL)	=		235
KND	=	KIL + NL	=		9
ND	=	IDRIVR (KND)	=		2
KID	=	KND + 1	=		10
ID	=	IDRIVR (KID)	=		235

Once the above variables are calculated for any given IDRIVR subtable (1-33) the processing of data for that table can begin.

801	1	233	1	793	2	235	236	2	235	236	802	1	236	1	236	4	11	130	146
231	4	129	145	192	231	803	1	235	1	235	4	11	146	191	217	4	128	189	216
230	804	2	11	129	1	129	2	13	103	2	102	126	0	0	805	1	130	1	145
13	132	133	134	135	136	137	138	139	140	141	142	143	144	13	132	133	134	135	136
137	138	139	140	141	142	143	144	806	2	146	190	1	190	4	148	157	171	187	4
152	170	186	187	807	2	11	128	1	128	1	191	1	191	808	2	146	189	1	189
3	153	157	171	3	156	169	185	809	1	191	1	216	6	193	194	199	204	209	215
6	193	198	203	208	214	215	810	1	217	1	220	11	219	220	221	222	223	224	225
226	227	228	229	11	219	220	221	222	223	224	225	226	227	228	229	811	2	13	102
1	102	4	22	35	71	99	4	34	70	98	99	812	1	103	1	126	5	104	110
117	121	125	5	109	116	120	124	125	813	2	146	148	1	152	3	149	150	151	3
149	150	151	814	3	146	157	170	1	170	4	158	161	164	166	4	160	163	165	167
815	2	146	171	186	1	186	5	172	175	178	180	182	5	174	177	179	181	183	0
816	2	13	101	1	101	3	14	35	71	3	21	65	97	0	0	0	0	0	0
817	2	146	153	1	156	2	154	155	2	154	155	0	0	0	0	0	0	0	0
818	3	146	157	169	1	169	2	158	161	2	159	162	0	0	0	0	0	0	0
819	3	146	171	185	1	185	2	172	175	2	173	176	0	0	0	0	0	0	0
820	2	191	193	194	1	198	3	195	196	197	3	195	196	197	0	0	0	0	0
821	2	191	193	199	1	203	3	200	201	202	3	200	201	202	0	0	0	0	0
822	2	191	204	1	208	3	205	206	207	3	205	206	207	0	0	0	0	0	0
823	2	191	209	1	214	4	210	211	212	213	4	210	211	212	213	0	0	0	0
824	3	11	13	22	1	34	11	23	24	25	26	27	28	29	30	31	32	33	11
23	24	25	26	27	28	29	30	31	32	33	0	0	0	0	0	0	0	0	0
825	4	11	13	35	70	1	70	13	36	39	42	44	47	50	53	56	59	62	64
66	12	38	41	43	46	49	52	55	58	61	63	65	67	0	0	0	0	0	0
826	4	11	13	71	98	1	98	9	72	75	78	80	83	86	89	92	94	9	74
77	79	82	85	88	91	93	95	0	0	827	3	11	103	104	1	109	4	105	106
107	108	4	105	106	107	108	0	0	0	828	3	11	103	110	1	116	5	111	112
113	114	115	5	111	112	113	114	115	0	829	3	11	103	117	1	120	2	118	119
2	118	119	0	0	0	0	0	0	0	830	3	11	103	121	1	124	2	122	123
2	122	123	0	0	0	0	0	0	0	831	3	11	13	14	1	21	6	15	16
17	18	19	20	6	15	16	17	18	19	20	0	0	0	0	0	0	0	0	0
232	4	11	13	35	69	1	69	8	36	39	44	47	50	53	56	59	8	37	40
45	48	51	54	57	60	0	0	0	0	833	4	11	13	71	97	1	97	6	72
75	80	83	86	89	6	72	76	81	94	37	90	0	0	0	0	0	0	0	999

DRIVER TABLE
(IDRIVR)

APPENDIX IV-B

LABEL TABLE

LINE NO.	LABEL
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	FUEL COMBUSTION
12	***************
13	EXTERNAL COMBUSTION
14	RESIDENTIAL FUEL (AREA)
15	ANTHRACITE COAL
16	BITUMINOUS COAL
17	DISTILLATE OIL
18	RESIDUAL OIL
19	NATURAL GAS
20	WOOD
21	TOTAL (RESIDENTIAL)
22	ELEC GENERATION (POINT)
23	ANTHRACITE COAL
24	BITUMINOUS COAL
25	LIGNITE
26	RESIDUAL OIL
27	DISTILLATE OIL
28	NATURAL GAS
29	PROCESS GAS
30	COKE
31	BAGASSE
32	SOLID WASTE/COAL
33	OTHER
34	TOTAL (ELEC GEN)
35	INDUSTRIAL FUEL
36	ANTHRACITE COAL
37	AREA SOURCES
38	POINT SOURCES
39	BITUMINOUS COAL
40	AREA SOURCES
41	POINT SOURCES
42	LIGNITE
43	POINT SOURCES
44	RESIDUAL OIL

LABEL TABLE (cont.)

```
45              AREA SOURCES
46              POINT SOURCES
47          DISTILLATE OIL
48              AREA SOURCES
49              POINT SOURCES
50          NATURAL GAS
51              AREA SOURCES
52              POINT SOURCES
53          PROCESS GAS
54              AREA SOURCES
55              POINT SOURCES
56          COKE
57              AREA SOURCES
58              POINT SOURCES
59          WOOD
60              AREA SOURCES
61              POINT SOURCES
62          LIQUID PETROL GAS
63              POINT SOURCES
64          BAGASSE
65              POINT SOURCES
66          OTHER
67              POINT SOURCES
68          TOTAL (INDUSTRIAL)
69              AREA SOURCES
70              POINT SOURCES
71      COMM-INSTITUTIONAL FUEL
72          ANTHRACITE COAL
73              AREA SOURCES
74              POINT SOURCES
75          BITUMINOUS COAL
76              AREA SOURCES
77              POINT SOURCES
78          LIGNITE
79              POINT SOURCES
80          RESIDUAL OIL
81              AREA SOURCES
82              POINT SOURCES
83          DISTILLATE OIL
84              AREA SOURCES
85              POINT SOURCES
86          NATURAL GAS
87              AREA SOURCES
88              POINT SOURCES
89          WOOD
90              AREA SOURCES
91              POINT SOURCES
92          LIQUID PETROL GAS
93              POINT SOURCES
94          OTHER
95              POINT SOURCES
```

LABEL TABLE (cont.)

```
 96              TOTAL (COMM-INST)
 97                AREA SOURCES
 98                POINT SOURCES
 99           OTHER (POINT)
100          TOTAL (EXTERNAL COMB)
101              AREA SOURCES
102              POINT SOURCES
103       INTERNAL COMBUSTION (POINT)
104           ELECTRIC GENERATION
105              DISTILLATE OIL
106              NATURAL GAS
107              DIESEL
108              OTHER
109              TOTAL (ELEC GEN)
110           INDUSTRIAL FUEL
111              DISTILLATE OIL
112              NATURAL GAS
113              GASOLINE
114              DIESEL FUEL
115              OTHER
116              TOTAL (INDUSTRIAL)
117           COMM-INSTITUTIONAL
118              DIESEL
119              OTHER
120              TOTAL (COMM-INST)
121           ENGINE-TESTING
122              AIRCRAFT
123              OTHER
124              TOTAL (ENG TESTNG)
125           OTHER (POINT)
126           TOTAL (INTERNAL COMB)
127       TOTAL (FUEL COMBUSTION)
128           AREA SOURCES
129           POINT SOURCES
130   INDUSTRIAL PROCESS (POINT)
131   ***************************
132       CHEMICAL MANUFACTURING
133       FOOD/AGRICULTURAL
134       PRIMARY METAL
135       SECONDARY METALS
136       MINERAL PRODUCTS
137       PETROLEUM INDUSTRY
138       WOOD PRODUCTS
139       EVAPORATION
140       METAL FABRICATION
141       LEATHER PRODUCTS
142       TEXTILE MANUFACTURING
143       INPROCESS FUEL
144       OTHER/NOT CLASSIFIED
145       TOTAL (INDUSTRIAL)
146   SOLID WASTE DISPOSAL
147   *********************
```

LABEL TABLE (cont.)

```
148       GOVERNMENT (POINT)
149            MUNICIPAL INCINERATION
150            OPEN BURNING
151            OTHER
152            TOTAL (GOVERNMENT)
153       RESIDENTIAL (AREA)
154            ON SITE INCINERATION
155            OPEN BURNING
156            TOTAL (RESIDENTIAL)
157       COMMERCIAL-INSTITUTIONAL
158            ON SITE INCINERATION
159                 AREA SOURCES
160                 POINT SOURCES
161            OPEN BURNING
162                 AREA SOURCES
163                 POINT SOURCES
164            APARTMENT
165                 POINT SOURCES
166            OTHER
167                 POINT SOURCES
168            TOTAL (COMM-INST)
169                 AREA SOURCES
170                 POINT SOURCES
171       INDUSTRIAL
172            ON SITE INCINERATION
173                 AREA SOURCES
174                 POINT SOURCES
175            OPEN BURNING
176                 AREA SOURCES
177                 POINT SOURCES
178            AUTO BODY INCINERATION
179                 POINT SOURCES
180            RAIL CAR BURNING
181                 POINT SOURCES
182            OTHER
183                 POINT SOURCES
184            TOTAL (INDUSTRIAL)
185                 AREA SOURCES
186                 POINT SOURCES
187       OTHER (POINT)
188       TOTAL (SOLID WASTE DISP)
189            AREA SOURCES
190            POINT SOURCES
191  TRANSPORTATION (AREA)
192  **********************
193       LAND VEHICLES
194            GASOLINE
195                 LIGHT VEHICLES
196                 HEAVY VEHICLES
197                 OFF HIGHWAY
198                 TOTAL (GASOLINE)
199            DIESEL
```

LABEL TABLE (cont.)

```
200                     HEAVY VEHICLES
201                     OFF HIGHWAY
202                     RAIL
203                     TOTAL (DIESEL)
204           AIRCRAFT
205                MILITARY
206                CIVIL
207                COMMERCIAL
208                TOTAL (AIRCRAFT)
209           VESSELS
210                BITUMINOUS COAL
211                DIESEL FUEL
212                RESIDUAL OIL
213                GASOLINE
214                TOTAL (VESSELS)
215           GAS HANDLING EVAP LOSS
216           TOTAL (TRANSPORTATION)
217      MISCELLANEOUS (AREA)
218      *********************
219           FOREST FIRE/AGRIC BURNING
220           STRUCTURAL FIRES
221           COAL REFUSE BURNING
222           SLASH BURNING
223           FROST CONTROL
224           SOLVENT EVAPORATION LOSS
225           DUST SOURCES
226                DIRT ROADS
227                DIRT AIRSTRIPS
228                CONSTRUCTION
229                ROCK HANDLING/STORING
230           TOTAL (MISCELLANEOUS)
231      OTHER (POINT)
232      *************
233      GRAND TOTAL
234      ***********
235           AREA SOURCES
236           POINT SOURCES
237           TOTAL
238
```

Section V

CONCLUSIONS

A weighted sensitivity analysis methodology has been developed in this contract to establish the statistical quality of emission inventories. A summary of the results, including developments beyond the original scope of work, is given in Section I of this final report. Section II presents a detailed explanation of the methodology, and the complete theoretical development is documented in Appendix A. Section III and Appendix B provide numerical analyses to illustrate the application of the technique and demonstrate the adequacy of the software. The latter is fully documented in Section IV, which is structured in consonance with EPA's outline for software documentation. The program listing and user's manual is to be delivered under separate cover.

The utility of the methodology that has been developed is manyfold. It is consistent with activity forecasting requirements and serves to establish percentage error requirements for source categories so as to satisfy given error bounds for the overall emissions inventory at a given level of statistical confidence. It provides results useful for planning air pollution control enforcement activity. For example, suppose that for a given source class k,

$$\frac{\sigma_k Q_k}{100} = q_k$$

is the allowed error quantity (in physical units) that satisfies σ_k, and suppose that field measurements indicate that the actual error quantity is some value $\vec{q}_K > q_K$; then, the fraction

$$\frac{\vec{q}_K - q_K}{\vec{q}_K}$$

immediately gives the percentage reduction in error quantity which is necessary to comple with σ_k, and appropriate corrective action can be planned accordingly.

The versatility and wide range of applicability of the technique is further illustrated in Appendix C to this final report, which shows an application of the technique to assist the Commonwealth of Virginia's State Air Pollution Control Board in achieving an approvable implementation plan for attaining secondary standards for particulate matter by 1975.

The formulation of the weighted sensitivity analysis presented in this report possesses a high degree of generality. It can be applied to compute component error requirements for inventories of emissions (or any other kind of) data which exhibit a hierarchial (tree-like) structure, as exemplified by NEDS reports. A concrete case of interest could arise by multiplying the hierarchial table of emissions data (i.e., the table of Q_k's) by some set of "effect" factors such as the health effect factors provided by Walther [Reference 4]. Denoting the effect factor by f_k and the resulting effect as E_k, $E_k = f_k Q_k$ for each source in a given category, with $E = \sum_{k=1}^{N} f_K Q_K$ giving the total effect for that category. In this case, the ratios E_k/E provide weightings analogous to Qk/Q in the standard application of the technique, i.e., it can be readily extended to perform weighted sensitivity analysis on the contributions of the major air pollutants and their sources by effect as well as by weight or mass. Additional prospective extensions of the analysis are its application to emission factors and to emissions data at the SCC level of aggregation.

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Appendix A

THEORETICAL ANALYSIS

This appendix documents the theoretical development of the basic weighted sensitivity analysis technique for emissions data and its various extensions. These analytical developments are based on well-known theory [References 1, 2, 5] and well-established assumptions. Section II of this final report provides a descriptive discussion of the assumptions adopted, their statistical interpretation, and their practical implications. Concise mathematical notation will be used for the theoretical analysis in this appendix.

A.1 Weighted Sensitivity Analysis

The objective of sensitivity analysis is to determine the effect (changes) on some measure of performance due to changes in each component that makes up the measure of performance. In the simplest case the measure of performance is the sum of component measures. Let T be the total measure of performance and C_K be the K^{th} component. Then,

$$T = \sum_{K=1}^{N} C_K$$

and any change in T (ΔT) due to changes in each of the components (ΔC_K) would be related to these component changes as

$$\Delta T = \sum_{K=1}^{N} \Delta C_K \qquad \text{(A-2)}$$

However, each component may be dependent on one or more primitive parameters so that, for example,

$$C_K = C_K (X) \qquad \text{(A-3)}$$

and

$$\Delta C = \frac{\partial C}{\partial x} \Delta x \qquad \text{(A-4)}$$

if X is a column vector, then with the gradient operator defined as

$$\nabla^T \equiv \left(\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \ldots, \frac{\partial}{\partial x_m} \right) \qquad \text{(A-5)}$$

the propagating change formulation takes on the form

$$\Delta C_K = (\nabla^T C_K) \Delta x \qquad \text{(A-6)}$$

For this exposition we shall use the single variable notation with the understanding that, should multivariable parameters be considered, then the partial derivatives must be thought of as gradients. The relationship of changes indicated in Equation A-2 is valid for deterministic changes. However, if the changes are uncertain or stochastic, the changes must be indicated by a statistical measure of dispersion (e.g., variance, standard deviation) rather than by differentials. Thus,

$$V(T) = \sum_{K=1}^{N} V(\ell_K) \tag{A-7}$$

where v(•) is the statistical variance (the square of the standard deviation) and the component variances are assumed to be uncorrelated with each other. Let

$$V(T) = T^2\theta^2 \quad \text{where } 0 \leq \theta \leq 1 \tag{A-8}$$

and 100 θ is the percent error or deviation of T. Similarly, let

$$V(\ell_K) = \ell_K^2 \gamma_K^2 \quad \text{where } 0 \leq \gamma_K \leq 1 \tag{A-9}$$

and 100 γ_K is the percent error or deviation of C_K. Then Equation A-7 becomes

$$T^2\theta^2 = \sum_{K=1}^{N} \ell_K^2 \gamma_K^2 \tag{A-10}$$

or

$$\theta = \sqrt{\sum_{K=1}^{N} \left(\frac{C_K}{T}\right)^2 \gamma_K^2} \qquad \text{(A-11)}$$

where 100 C_K/T is the percent of C_K in T. Equation A-11 relates the error in T to the errors in each of the components, with all errors represented as fractions (or percentages); moreover, these component errors are weighted according to the contribution of each component measure to the total measure of performance.

Because of this weighting it becomes possible to assess the significance of each component as it relates to the confidence (or error) of the total measure of performance.

The following subsections exhibit the application of this method of analysis to emissions data as well as some numerical examples.

A.2 Application to Emissions Data

This analysis is based upon Equation A-10. Let C_K be replaced by Q_K, where Q_K designates the emissions (e.g., in tons/year) of a specific air pollutant produced by source class K. Also, let σ_K be the error (replacing γ_K) in Q_K. Similarly, let Q replace T for total emissions with error θ. Then in analogy with Equation A-10 we have

$$Q^2 \theta^2 = \sum_{K=1}^{N} Q_K^2 \sigma_K^2 \qquad \text{(A-12)}$$

where

$$Q = \sum_{K=1}^{N} Q_K \tag{A-13}$$

By division we obtain

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q} \right)^2 \left(\frac{\sigma_K}{\theta} \right)^2 \tag{A-14}$$

The objective of this analysis is to obtain σ_K for each class K according to some value of θ (error in total). As a first approximation we can assume that each term in Equation A-14 contributes the same amount to the total. Thus,

$$1/N = (Q_K/Q)^2 \; (\sigma_K/\theta)^2 \tag{A-15}$$

whence,

$$\sigma_K = \theta / [\sqrt{N}\,(Q_K/Q)] \tag{A-16}$$

where N is the number of source classes.

We can interpret Equation A-16 as indicating the present error allowable (σ_K) in forecasting emissions from source class K given the percent error allowable (θ) in forecasting total emissions. σ_K can be modified either by changing θ or by regrouping the source classes, which changes N and Q_K simultaneously.

As a second approximation, the analysis can be modified to allow each source class k to contribute to the total error an amount proportional to its relative physical contribution to the total pollutant emission Q, as given by the ratio Q_k/Q. Analytically, it is only necessary to note that

$$\sum_{K=1}^{N} Q_K/Q = 1$$

i.e., the summation of all the weightings Q_k/Q must necessarily add up to one. Since, from Equation A-14,

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2$$

it follows that:

$$\sum_{K=1}^{N} \frac{Q_K}{Q} = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-17)}$$

or, in expanded form:

$$\frac{Q_1}{Q} + \frac{Q_2}{Q} + \cdots \frac{Q_N}{Q} = \left(\frac{Q_1}{Q}\right)^2 \left(\frac{\sigma_1}{\theta}\right)^2 + \left(\frac{Q_2}{Q}\right)^2 \left(\frac{\sigma_2}{\theta}\right)^2 + \cdots + \left(\frac{Q_N}{Q}\right)^2 \left(\frac{\sigma_N}{\theta}\right)^2$$

Arbitrarily, equating both sides of the equation term by term yields

$$\begin{aligned} Q_1/Q &= (Q_1/Q)^2 (\sigma_1/\theta)^2 \\ Q_2/Q &= (Q_2/Q)^2 (\sigma_2/\theta)^2 \\ &\vdots \\ Q_N/Q &= (Q_N/Q)^2 (\sigma_N/\theta)^2 \end{aligned}$$

or, more concisely:

$$Q_k/Q = (Q_k/Q)^2 \; (\sigma_k/\theta)^2 \qquad \text{(A-18)}$$

for each source class k. This revised formulation assumes that each term contributes to the total an amount proportional to Q_k/Q. Then, from equation A-18

$$1 = (Q_k/Q)(\sigma_k/\theta)^2$$

and we obtain

$$\sigma_k = \theta\sqrt{Q/Q_k} \qquad \text{(A-19)}$$

as the formula to compute σ_k for each source class k. This formulation satisfies the same practical requirements as the original one and, in addition, provides a better working assumption from the viewpoint of interpretation of the results for enforcement purposes. Equation (A-19) is the basic formula of the weighted sensitivity analysis techique. As with equation (A-16), we can interpret Equation A-19 as indicating the percent error allowable (σ_K) in forecasting emissions from source class K given the percent error allowable (θ) in forecasting total emissions. σ_K can be modified either by changing θ or by regrouping the source classes, which changes Q/Q_K.

A.3 Extension to account for fixed errors

Refer back to equation (A-14) and consider the equations

$$1 = \sum_{K=1}^{N} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{Q_K}\right)^2 + \left(\frac{Q_J}{Q}\right)^2 \left(\frac{\sigma_J}{Q_J}\right)^2 \qquad \text{(A-20)}$$

$$1 = \sum_{K \neq J} \frac{Q_K}{Q} \qquad \text{(A-21)}$$

if J . is known apriori, '

$$\frac{Q_J}{Q} + D = \left(\frac{Q_J}{Q}\right)^2 \left(\ldots \right)^2 \qquad \text{(A-22)}$$

where

$$D = \left(\frac{Q_J}{Q}\right)^2 \left(\ldots \right) \ldots \qquad \text{(A-23)}$$

[illegible] (A-20) and (A-21) [illegible] subtracting [illegible] yields

[illegible]

with reference to (A-21) we note

$$1 - \frac{Q_J}{Q} = \sum_{K \neq J}^{N} \frac{Q_K}{Q} \qquad \text{(A-25)}$$

whence

$$1 = \frac{Q}{Q - Q_j} \sum_{k \neq j}^{N} \frac{Q_k}{Q} \qquad \text{(A-26)}$$

so that

$$D = \frac{DQ}{Q - Q_j} \sum_{k \neq j}^{N} \frac{Q_k}{Q} \qquad \text{(A-27)}$$

Substituting (A-27) into (A-24) yields

$$\sum_{k \neq j}^{N} \frac{Q_k}{Q} - \frac{DQ}{Q - Q_j} \sum_{k \neq j}^{N} \frac{Q_k}{Q} = \sum_{k \neq j}^{N} \left(\frac{Q_k}{Q}\right)^2 \left(\frac{\sigma_k}{\theta}\right)^2 \qquad \text{(A-28)}$$

or

$$\left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right] \sum_{k \neq j}^{N} \frac{Q_k}{Q} = \sum_{k \neq j}^{N} \left(\frac{Q_k}{Q}\right)^2 \left(\frac{\sigma_k}{\theta}\right)^2 \qquad \text{(A-29)}$$

with the assumption that

$$\left[\frac{Q(1-D) - Q_j}{Q - Q_j}\right] \frac{Q_k}{Q} \overset{\downarrow}{=} \left(\frac{Q_k}{Q}\right)^2 \left(\frac{\sigma_k}{\theta}\right)^2 \qquad \text{(A-30)}$$

for $k \neq j$

we get

$$\sigma_K^2 = \left[\frac{G(1-D)-Q_j}{G-Q_j}\right]\frac{G^2 G}{Q_K} \qquad (A-31)$$

[illegible]

$$\sigma_K = G\left[\frac{G(1-D)-Q_j}{G-Q_j}\right]^{1/2}\left(\frac{G}{Q_K}\right)^{1/2} \text{[illegible]} \qquad \text{[illegible]}$$

If σ_K is unknown for K = 1, 2, ---, m, but σ_j is known for j = m + [illegible], ---, then (A-20) becomes

$$\text{[illegible]} \qquad (A-33)$$

[illegible] become

$$\text{[illegible]} \sum \frac{Q_K}{G} + \sum^{N} \frac{Q_j}{G} \qquad (A-34)$$

We define D_j to satisfy

$$\frac{Q_j}{Q_K} + D_j = \left(\frac{Q_j}{Q_K}\right)^2\left(\frac{\sigma_j}{G}\right)^2 \qquad (A-35)$$

where

$$D_j = \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^{-2} - \frac{Q_j}{Q} \tag{A-36}$$

Equating (A-33) and (A-34) then subtracting (A-35) for j = m + 1, ---, N yields

$$\sum_{K=1}^{m} \frac{Q_K}{Q} - \sum_{j=m+1}^{N} D_j = \sum_{K=1}^{m} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \tag{A-37}$$

Let

$$D \equiv \sum_{j=m+1}^{N} D_j \tag{A-38}$$

and

$$\tilde{Q} \equiv \sum_{j=m+1}^{N} \frac{Q_j}{Q} \tag{A-39}$$

with reference to (A-34)

$$1 - \tilde{Q} = \sum_{K=1}^{m} \frac{Q_K}{Q} \tag{A-40}$$

whence

$$1 = \frac{1}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-41)}$$

so that

$$D = \frac{D}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-42)}$$

Substitution of (A-38) and (A-39) into (A-37) yields

$$\sum_{K=1}^{m} \frac{Q_K}{Q} - \frac{D}{1-\tilde{Q}} \sum_{K=1}^{m} \frac{Q_K}{Q} = \sum_{K=1}^{m} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-43)}$$

or

$$\left(\frac{1-D-\tilde{Q}}{1-\tilde{Q}}\right) \sum_{K=1}^{m} \frac{Q_K}{Q} = \sum_{K=1}^{m} \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-44)}$$

with the assumption that

$$\left(\frac{1-D-\tilde{Q}}{1-\tilde{Q}}\right) \frac{Q_K}{Q} \triangleq \left(\frac{Q_K}{Q}\right)^2 \left(\frac{\sigma_K}{\theta}\right)^2 \qquad \text{(A-45)}$$

we get

$$\sigma_K^2 = \theta^2 \frac{Q}{Q_K} \left(\frac{1 - D - \tilde{Q}}{1 - \tilde{Q}} \right) \quad \text{(A-46)}$$

or

$$\sigma_K = \theta \sqrt{\frac{Q}{Q_K} \left(\frac{1 - D - \tilde{Q}}{1 - \tilde{Q}} \right)} \quad \text{(A-47)}$$

Equation (A-47) constitutes a generalization of equation (A-19) to cover the case where one or more of the errors associated with the subclasses of a given source class are to be fixed by the analyst. Even assuming zero error for the other components, however, there is of course a maximum value that can be attached to the fixed errors and still satisfy a given overall error for that class. For a given θ, the offer bounds that the σk's to be fixed can assume can be derived as follows.

Consider that $0 \leq \tilde{Q} \leq 1$ by definition. Therefore, $1 - \tilde{Q} \geq 0$. It is also always true that the quotient $Q/Qk \geq 0$. Therefore the product

$$\frac{Q}{Q_K} \left(\frac{1 - D - \tilde{Q}}{1 - \tilde{Q}} \right)$$

in equation (A-47) can assume a nonnegative value if and only if $1 - D - \tilde{Q} \geq 0$. This implies that $1 - \tilde{Q} \geq D$, or, in expanded form

$$1 - \tilde{Q} \geq \sum_{j=m+1}^{N} \left[\left(\frac{Q_j}{Q} \right)^2 \left(\frac{\sigma_j}{\theta} \right)^2 - \frac{Q_j}{Q} \right] \quad \text{(A-48)}$$

or,

$$1 - \tilde{Q} \geq \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q} \right)^2 \left(\frac{\sigma_j}{\theta} \right)^2 - \sum_{j=m+1}^{N} \frac{Q_j}{Q} \quad \text{(A-49)}$$

since $\tilde{Q} = \sum_{j=m+1}^{N} Q_j/Q$;

$$1 \geq \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \qquad \text{(A-50)}$$

and, in the limit:

$$1 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \qquad \text{(A-51)}$$

$$1 = \frac{1}{\theta^2} \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2 \qquad \text{(A-52)}$$

$$\theta^2 = \sum_{j=m+1}^{N} (Q_j/Q)^2 \sigma_j^2 \qquad \text{(A-53)}$$

$$\theta = \sqrt{\sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2} \qquad \text{(A-54)}$$

is the lower bound on θ for all the σ_j, $j = m + 1$, ---, N which are known apriori.

alternatively, from (A-53):

$$\theta^2 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \sigma_j^2 \qquad \text{(A-54)}$$

$$1 = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \qquad \text{(A-55)}$$

note that

$$\sum_{k=1}^{m} \frac{Q_k}{Q} + \sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 \qquad \text{(A-56)}$$

$$\sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 - \sum_{K=1}^{m} \frac{Q_K}{Q} \qquad \text{(A-57)}$$

$$\sum_{j=m+1}^{N} \frac{Q_j}{Q} = \frac{Q - \sum_{k=1}^{m} Q_K}{Q} \qquad \text{(A-58)}$$

hence

$$\left(\frac{Q}{Q - \sum_{k=1}^{m} Q_K}\right) \sum_{j=m+1}^{N} \frac{Q_j}{Q} = 1 \qquad \text{(A-59)}$$

and therefore:

$$\left(\frac{Q}{Q - \sum_{K=1}^{m} Q_K}\right) \sum_{j=m+1}^{N} \frac{Q_j}{Q} = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \qquad \text{(A-60)}$$

letting

$$Q' = \frac{Q}{Q - \sum_{K=1}^{m} Q_K} \qquad \text{(A-61)}$$

and substituting (A-61) into (A-60):

$$\sum_{j=m+1}^{N} \left(\frac{Q'}{Q}\right) Q_j = \sum_{j=m+1}^{N} \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\theta}\right)^2 \qquad \text{(A-62)}$$

or, assuming each term contributes to the total an amount proportional to Q_j/Q:

$$\frac{Q'}{Q} Q_j = \left(\frac{Q_j}{Q}\right)^2 \left(\frac{\sigma_j}{\sigma}\right)^2, \quad j = m+1, \ldots, N \tag{A-63}$$

$$Q' = \frac{Q_j}{Q}\left(\frac{\sigma_j}{\sigma}\right)^2 \tag{A-64}$$

$$\frac{Q' Q}{Q_j}\sigma^2 = \sigma_j^2 \tag{A-65}$$

and,

$$\sigma_j = \sigma\sqrt{\frac{Q' Q}{Q_j}}, \quad j = m+1, \ldots, N \tag{A-66}$$

are upper bounds on σ_j, j = m + 1, ..., N, which can be fixed and still satisfy if σ_j, j = 1, ..., m are assumed to be zero. Equation (A-66) provides the analyst with valuable guidance in the apriori selection of values for one or more of the subclass errors in a source class.

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16. ABSTRACT

This report presents a body of analytical techniques appropriate for determining accuracy requirements of component parts of an emissions inventory so as to insure (at a given confidence level) an overall acceptable accuracy in the total inventory. Selected numerical analyses are presented to illustrate application of the techniques to Nationwide Emissions Report data at different levels of aggregation. The results are believed to constitute a significant step in the development of techniques for making reliable forecasts of air pollutant emissions, and have already been applied for such purposes to emissions in Region 5 of the State of Virginia. A report on that application is also included in the present document.

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