ornl

ORNL/TM-9074

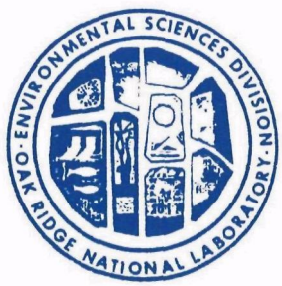
OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Environmental Risk Analysis for Direct Coal Liquefaction

G. W. Suter II
L. W. Barnthouse
C. F. Baes III
S. M. Bartell
M. G. Cavendish
R. H. Gardner
R. V. O'Neill
A. E. Rosen

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2294



Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A08 Microfiche A01

ORNL/TM-9074

ENVIRONMENTAL SCIENCES DIVISION

ENVIRONMENTAL RISK ANALYSIS FOR DIRECT COAL LIQUEFACTION

Authors

G. W. Suter II[1]
L. W. Barnthouse[1]
C. F. Baes III
S. M. Bartell
M. G. Cavendish
R. H. Gardner
R. V. O'Neill
A. E. Rosen

ORNL Project Manager

S. G. Hildebrand

Environmental Sciences Division
Publication No. 2294

---

[1]ORNL Principal Investigators.

Date of Issue - November 1984

EPA Project Officer
A. A. Moghissi

Prepared for
Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

Interagency Agreement No. DW 8993 0292-01-0
(DOE 40-740-78)

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-840R21400

DISCLAIMER

Although the research described in this report has been funded wholly or in part by the U.S. Environmental Protection Agency (EPA) through Interagency Agreement Number DW 8993 0292-01-0 to the U.S. Department of Energy, it has not been subjected to EPA review and therefore does not necessarily reflect the views of EPA and no official endorsement should be inferred.

CONTENTS

	Page
LIST OF FIGURES	v
LIST OF TABLES	vii
SUMMARY	xiii
ABSTRACT	xvii
1. INTRODUCTION	1
2. SOURCE TERMS AND EXPOSURE	4
2.1 Source Terms	4
2.2 Aquatic Exposure Assessment	5
2.3 Atmospheric Dispersion and Deposition	11
3. AQUATIC ENDPOINTS	26
3.1 Quotient Method	26
3.2 Analysis of Extrapolation Error	32
3.3 Ecosystem Uncertainty Analysis	45
4. TERRESTRIAL ENDPOINTS	57
4.1 Vegetation	57
4.2 Wildlife	63
5. EVALUATION OF RISKS	68
5.1 Evaluation of Risks to Fish	68
5.2 Evaluation of Risks of Algal Blooms	70
5.3 Evaluation of Risks to Vegetation and Wildlife	71
5.4 Validation Needs	71
6. ACKNOWLEDGMENTS	73
7. REFERENCES	74
APPENDIX A. Aquatic Toxicity Data	89
APPENDIX B. Terrestrial Toxicity Data	105
APPENDIX C. Common and Scientific Names of Animals and Plants	119
APPENDIX D. Species-Specific Results of the Analysis of Extrapolation Error	125
APPENDIX E. Detailed Methods and Assumptions for Ecosystem Uncertainty Analysis	143

LIST OF FIGURES

Figure		Page
3.3.1	Risk estimates for naphthalene (RAC 14) over a range of environmental concentrations	48
3.3.2	Risk estimates for phenol (RAC 21) and lead (RAC 35) over a range of environmental concentrations	49
3.3.3	Risk estimates for cadmium (RAC 34) and mercury (RAC 32) over a range of environmental concentrations . . .	50
3.3.4	Risk estimates for ammonia (RAC 5) over a range of environmental concentrations	51
3.3.5	Maximum risk estimates	54
3.3.6	Comparison of risks among technologies	56

LIST OF TABLES

Table		Page
1-1	Risk Analysis Categories (RACs)	2
2.1-1	Aqueous source terms for four direct coal liquefaction technologies, control option 1	6
2.1-2	Aqueous source terms for four direct coal liquefaction technologies, control option 2	7
2.2-1	Stream characteristics for the eastern reference site . . .	9
2.2-2	Contaminant characteristics	10
2.2-3	Estimated ambient contaminant concentrations, eastern reference stream, Exxon Donor Solvent process	12
2.2-4	Estimated ambient contaminant concentrations, eastern reference stream, SRC-I process	14
2.2-5	Estimated ambient contaminant concentrations, eastern reference stream, SRC-II process	16
2.2-6	Estimated ambient contaminant concentrations, eastern reference stream, H-Coal process	18
2.3-1	Maximum ambient atmospheric and soil concentrations for Exxon Donor Solvent process	22
2.3-2	Maximum ambient atmospheric and soil concentrations for SRC-I process	23
2.3-3	Maximum ambient atmospheric and soil concentrations for SRC-II process	24
2.3-4	Maximum ambient atmospheric and soil concentrations for H-Coal process	25
3.1-1	Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the Exxon Donor Solvent process	28
3.1-2	Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the SRC-I process	29
3.1-3	Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the SRC-II process	30

Table		Page
3.1-4	Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the H-Coal process	31
3.2-1	Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for Exxon Donor Solvent	35
3.2-2	Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for SRC-I	36
3.2-3	Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for SRC-II	37
3.2-4	Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for H-Coal	38
3.2-5	Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for Exxon Donor Solvent	40
3.2-6	Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for SRC-I	41
3.2-7	Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for SRC-II	42
3.2-8	Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for H-Coal	43
3.3-1	Values of LC_{50}/EC_{50} (mg/L) used to calculate E matrix for SWACOM	47
3.3-2	Deterministic results of ecosystem uncertainty analyses . .	52
4.1-1	Toxicity quotients for terrestrial plants for Exxon Donor Solvent process	58
4.1-2	Toxicity quotients for terrestrial plants for SRC-I process	59
4.1-3	Toxicity quotients for terrestrial plants for SRC-II process	

Table		Page
4.2-1	Toxicity quotients for terrestrial animals for Exxon Donor Solvent	64
4.2-2	Toxicity quotients for terrestrial animals for SRC-I process	65
4.2-3	Toxicity quotients for terrestrial animals for SRC-II process	66
5.1-1	RAC's determined to pose potentially significant risks to fish populations by one or more of three risk analysis methods	69
A-1	Acute toxicity of synfuels to aquatic animals	91
A-2	Chronic toxicity of synfuels chemicals to aquatic animals	100
A-3	Toxicity of synfuels chemicals to algae	102
B-1	Toxicity of chemicals in air to vascular plants	107
B-2	Toxicity of chemicals in soil or solution to vascular plants	110
B-3	Toxicity of chemicals in air to animals	114
D-1	Predicted geometric mean maximum allowable toxicant concentrations (PGMATCs) for each RAC and each species of fish	127
D-2	Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for Exxon Donor Solvent	128
D-3	Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for Exxon Donor Solvent	128
D-4	Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for Exxon Donor Solvent	129
D-5	Probabilities of chronic toxic effects on fish populations due to RAC 20 at annual median ambient concentrations for Exxon Donor Solvent	129

Table		Page
D-6	Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for Exxon Donor Solvent	130
D-7	Probabilities of chronic toxic effects on fish populations due to RAC 22 at annual median ambient concentrations for Exxon Donor Solvent	130
D-8	Probabilities of chronic toxic effects on fish populations due to RAC 28 at annual median ambient concentrations for Exxon Donor Solvent	131
D-9	Probabilities of chronic toxic effects on fish populations due to RAC 34 at annual median ambient concentrations for Exxon Donor Solvent	131
D-10	Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for SRC-I	132
D-11	Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for SRC-I	132
D-12	Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for SRC-I	133
D-13	Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for SRC-I	133
D-14	Probabilities of chronic toxic effects on fish populations due to RAC 35 at annual median ambient concentrations for SRC-I	134
D-15	Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for SRC-II	134
D-16	Probabilities of chronic toxic effects on fish populations due to RAC 8 at annual median ambient concentrations for SRC-II	135
D-17	Probabilities of chronic toxic effects on fish populations due to RAC 12 at annual median ambient concentrations for SRC-II	135

Table		Page
D-18	Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for SRC-II	136
D-19	Probabilities of chronic toxic effects on fish populations due to RAC 15 at annual median ambient concentrations for SRC-II	136
D-20	Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for SRC-II	137
D-21	Probabilities of chronic toxic effects on fish populations due to RAC 26 at annual median ambient concentrations for SRC-II	137
D-22	Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for H-Coal	138
D-23	Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for H-Coal	138
D-24	Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for H-Coal	139
D-25	Probabilities of chronic toxic effects on fish populations due to RAC 20 at annual median ambient concentrations for H-Coal	139
D-26	Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for H-Coal	140
D-27	Probabilities of chronic toxic effects on fish populations due to RAC 22 at annual median ambient concentrations for H-Coal	140
D-28	Probabilities of chronic toxic effects on fish populations due to RAC 28 at annual median ambient concentrations for H-Coal	141
D-29	Probabilities of chronic toxic effects on fish populations due to RAC 34 at annual median ambient concentrations for H-Coal	141

SUMMARY

The Environmental Sciences Division, Oak Ridge National Laboratory, is analyzing the potential environmental risks associated with commercial-scale synthetic liquid fuels (Synfuels) technologies. The overall objective of this environmental risk analysis project, which is funded by the Office of Research and Development, U.S. Environmental Protection Agency, is to guide research on environmental aspects of synfuel technologies by identifying the most hazardous synfuel-derived contaminants and the most important sources of scientific uncertainty concerning the fate and effects of these contaminants.

The general strategy adopted for the project involves (1) grouping the contaminants present in effluents and products of commercial-scale processes into 38 categories termed Risk Analysis Categories (RACs), (2) defining generalized reference environments with characteristics representative of regions in which synfuels plants may be sited, and (3) assessing risks of five distinct, adverse ecological effects: reductions in fish populations, development of algal blooms that detract from water use, reductions in timber yield or undesirable changes in forest composition, reductions in agricultural production, and reductions in wildlife populations.

This report presents results of a risk analysis of four direct coal liquefaction technologies: Exxon Donor Solvent (EDS), Solvent Refined Coal-I (SRC-I), Solvent Refined Coal-II (SRC-II), and H-Coal. All four technologies had equal capacites (2.72×10^4 Mg coal/d) and the same waste treatements. All were located in a reference environment resembling eastern Kentucky. Estimates of concentrations of released contaminants in the air, and surface water of the reference environment were obtained, using a simple Gaussian-plume atmospheric dispersion and deposition model and a steady-state surface water fate model. Concentrations in soil and soil solution were obtained from a terrestrial food chain model.

Risk to the five ecological end points were estimated using one or more of three methods: the quotient method, analysis of extrapolation error, and ecosystem uncertainty analysis. In the quotient method, estimated environmental concentrations were simply compared to toxicological benchmarks such as LC_{50}'s available for standard test organisms. In analysis of extrapolation error, statistical relationships between the sensitivities to contaminants of the various taxa of fish and between acute- and chronic-effects concentrations were used to estimate, with appropriate error bounds, chronic-effects thresholds for reference fish species characteristic of the reference environment. Taxonomic extrapolations were used to express the acute effects of RACs in terms of a common unit, the 96-h LC_{50} for largemouth bass. The extrapolated LC_{50}'s and the source-term estimates were then combined and used to assess the acute toxicities of the whole effluents from the four technologies. In ecosystem uncertainty analysis, an aquatic ecosystem model was used to compute risk estimates that explicitly incorporate biological phenomena such as competition and predation that can magnify or offset the direct effects of contaminants on organisms.

With respect to fish, nine RACs were determined to be significant for one or more technologies. RAC 5 (ammonia) was the only RAC found to be significant for all technologies, waste water treatment options and analysis methods. RAC 34 (cadmium) was significant for all technologies and water treatment options according to the quotient method and by all three methods for EDS and H-Coal. The whole effluent from the H-Coal technology with conventional water treatment appeared to be the most acutely toxic. For all technologies, conventional pollutants appear to be more hazardous to fish than the complex organic contaminents usually associated with synfuels.

Algal toxicity data were available for only 10 RACs. Because of the diversity of experimental designs and test end points used in algal bioassays, it was not possible to rank the RACs using the quotient method. However, most of the toxicity quotients calculated for algae were lower than the corresponding quotients for fish. Ecosystem uncertainty analysis suggested greater risks of effects on algae than

did the quotient method, primarily because reductions in grazing intensity related to effects of contaminants of zooplankton and fish. Both methods indicate that RAC 21 (phenols) and RAC 34 (cadmium) posed a significant risk to algal communities.

Conventional pollutants, especialy $SO_2$and NO_2, were found to have the greatest potential effects on terrestrial biota. Ground-level SO_2 concentrations for all technologies were within 1 to 2 orders of magnitude of phytotoxic levels, even excluding background concentrations. Gaseous pollutant levels were well below toxic concentrations for terrestrial mammals; however, it was not possible to assess risks to nonmammalian wildlife (e.g., birds). Of the materials deposited on soil, RACs 31 (arsenic), 33 (nickel), and 34 (cadmium) pose the greatest threat of toxicity. However, observable effects are unlikely unless these trace elements are deposited on soils with high background concentrations and chemical properties favoring the solution phase.

ABSTRACT

SUTER, G. W. II, L. W. BARNTHOUSE, C. F. BAES III, S. M. BARTELL, M. G. CANVENDISH, R. H. GARDNER, R. V. O'NEILL, and A. E. ROSEN. 1984. Environmental risk analysis for direct coal liquefaction. ORNL/TM-9074. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 166 pp.

This document presents an analysis of the risks to fish, water quality (due to noxious algal blooms), crops, forests, and wildlife of four technologies for the direct liquefaction of coal: Exxon Donor Solvent (EDS), Solvent Refined Coal-I (SRC-I), Solvent Refined Coal-II (SRC-II), and H-Coal. A variety of risk analysis techniques were used to make maximum use of the available data while considering effects of effluents on different levels of ecological organization. The primary objective of the analysis was to identify potentially significant effluent components. Ammonia, cadmium, and phenols were identified as presenting the highest risk to fish. An analysis of whole-effluent toxicity indicates that the H-Coal effluent poses the highest risk of the aqueous effluents examined. Six effluent components appear to pose risks of algal blooms, primarily because of their effects on higher trophic levels. The most important atmospheric emissions for crops, forests, and wildlife appear to be the conventional combustion products SO_2, NO_x, and respirable particles. Of the materials deposited on the soil, arsenic, cadmium, and nickel appear to be of greatest concern for phytotoxicity.

1. INTRODUCTION

Environmental risk analysis is defined as the process of identifying and quantifying probabilities of adverse changes in the environment resulting from human activities. This includes explicit incorporation and, to the extent possible, quantification of scientific uncertainties regarding the adverse effects being considered. The Environmental Sciences Division, Oak Ridge National Laboratory, has been developing and demonstrating methods for environmental risk analysis for the Office of Research and Development, U.S. Environmental Protection Agency. The methods employed in this project were described by Barnthouse et al. (1982a). Although the concept of risk is applicable to many types of environmental problems, this project is focusing on risks associated with toxic environmental contaminants derived from synthetic liquid fuels technologies. The overall objective of the project is to guide research on environmental aspects of synfuel technologies by identifying the most hazardous contaminants (or classes of contaminants) and the most important sources of scientific uncertainty concerning the fate and effects of contaminants. The analyses, results, and conclusions of this research are intended to be generic and are not estimates of actual impacts of specific plants at specific sites.

For purposes of risk analysis, the thousands of potentially significant contaminants in waste streams and products of synthetic liquid fuels technologies have been grouped into the 38 categories, termed Risk Analysis Categories (RACs) listed in Table 1-1. Five ecological endpoints are used: (1) reductions in fish populations, (2) development of algal communities that detract from water use, (3) reductions in timber yield due to reduced growth or changes in forest composition, (4) reductions in agricultural production, and (5) reductions in wildlife populations. Rather than descriptions of specific sites, we use reference environments, with characteristics representative of regions in which synfuels plants may be sited. Two reference environments are being used in the research for EPA: an eastern environment resembling eastern Kentucky or West Virginia, and a

Table 1-1. Risk Analysis Categories (RACs)

RAC Number	Name	Description
1	Carbon monoxide	CO
2	Sulfur oxides	SO_x
3	Nitrogen oxides	NO_x
4	Acid gases	H_2S, HCN
5	Alkaline gases	NH_3
6	Hydrocarbon gases	C_1-C_4 alkanes, alkynes, and cyclocompounds; bp < ∿20°C
7	Formaldehyde	HCHO
8	Volatile organochlorines	To bp ∿120°C; CH_2Cl_2, $CHCl_3$, CCl_4
9	Volatile carboxylic acids	To bp ∿120°C; formic and acetic acids only
10	Volatile O & S heterocyclics	To bp ∿120°C; furan, THF, thiophene
11	Volatile N heterocyclics	To bp ∿120°C; pyridine, piperidine, pyrrolidine, alkyl pyridines
12	Benzene	Benzene
13	Aliphatic/alicyclic hydrocarbons	C_5 (bp ∿40°C) and greater; paraffins, olefins, cyclocompounds, terpenoids, waxes, hydroaromatics
14	Mono- or diaromatic hydrocarbons (excluding benzene)	Toluene, xylenes, naphthalenes, biphenyls, alkyl derivatives
15	Polycyclic aromatic hydrocarbons	Three rings and greater; anthracene, BaA, BaP, alkyl derivatives
16	Aliphatic amines (excluding N heterocyclics)	Primary, secondary, and tertiary nonheterocyclic nitrogen, $MeNH_2$, diMeNH, triMeN
17	Aromatic amines (excluding N heterocyclics)	Anilines, napthylamines, amino pyrenes; nonheterocyclic nitrogen
18	Alkaline N heterocyclics ("azaarenes") (excluding "volatiles")	Quinolines, acridines, benzacridines (excluding pyridines)
19	Neutral N, O, S heterocyclics (excluding "volatiles")	Indoles, carbazoles, benzofurans, dibenzothiophenes
20	Carboxylic acids (excluding "volatiles")	Butyric, benzoic, phthalic, stearic
21	Phenols	Phenol, cresols, catechol, resorcinol
22	Aldehydes and ketones ("carbonyls") (excluding formaldehyde)	Acetaldehyde, acrolein, acetone, benzaldehyde
23	Nonheterocyclic organosulfur	Mercaptans, sulfides, disulfides, thiophenols, CS_2
24	Alcohols	Methanol, ethanol
25	Nitroaromatics	Nitrobenzenes, nitropyrenes
26	Esters	Acetates, phthalates, formates
27	Amides	Acetamide, formamide, benzamides
28	Nitriles	Acrylonitrile, acetonitrile
29	Tars	
30	Respirable particles	
31	Arsenic	As, all forms
32	Mercury	Hg, all forms
33	Nickel	Ni, all forms
34	Cadmium	Cd, all forms
35	Lead	Pb, all forms
36	Other trace elements	
37	Radioactive materials	^{226}Ra
38	Other remaining materials	

western environment resembling the western slope of the Rocky Mountains in north-western Colorado. Descriptions of the meteorology, hydrology, demography, land-use patterns, and biota of these two reference environments have been developed by Travis et al. (1983). The direct coal liquefaction plants are assumed to be located in the east.

This report analyzes risks associated with four direct coal liquefaction technologies: Exxon Donor Solvent, Solvent Refined Coal-I, Solvent Refined Coal-II, and H-Coal. We assumed commerical-scale facilities, with identical feed coal capacities and similar environmental control technologies, sited in the eastern reference environment. The objectives of the risk analyses were:

1. to identify the RACs of greatest concern for each technology,
2. to compare, as far as possible, the risks associated with different technologies,
3. to compare the risks of the direct coal liquefaction technology to the five ecological endpoints described above, and
4. to compare the magnitudes of uncertainty concerning risks of different RACs and different components of risk for each RAC.

2. SOURCE TERMS AND EXPOSURE

This section presents (a) estimates of aqueous and atmospheric source terms for four commercial-scale direct coal liquefaction plants, and (b) estimates of exposure concentrations for aquatic and terrestrial biota in the vicinity of a hypothetical plant site with environmental characteristics that roughly correspond to those of proposed sites for coal liquefaction facilities in eastern Kentucky and West Virginia.

2.1 SOURCE TERMS

Under a subcontract with Oak Ridge National Laboratory, TRW Inc. (TRW) described commerical-scale plant configurations for four direct coal liquefaction processes: Exxon Donor Solvent (EDS), Solvent Refined Coal-I (SRC-I), Solvent Refined Coal-II (SRC-II), and H-Coal (TRW 1983). The plant configurations evaluated by TRW were adapted from design information provided by the developers of the four technologies. The source term estimates developed by TRW were based largely on published process conceptual designs and test data obtained from bench-scale, pilot, or demonstration units. Control technology efficiencies were extrapolated from similar applications in other industries.

All four plant configurations reflect a feed coal capacity of 2.72×10^4 Mg (30,000 tons) per day. TRW estimated quantities and compositions of all uncontrolled and controlled waste streams, expressed in terms of Risk Analysis Units (RACs, Sect. 1). For aqueous waste streams, two alternative control options were considered:

1. Steam stripping/ammonia recovery, followed by phenol extraction and biological oxidation, and
2. Option 1, followed by carbon adsorption.

Because of the large number of atmospheric effluent sources associated with each technology, the atmopheric source terms are not presented in this report. They are in Tables 2-8, 3-8, 4-8, and 5-8 of TRW (1983).

The aqueous source terms are summarized in Tables 2.1-1 and 2.1-2. They include process-generated wastewaters, coal pile runoff, and cooling tower blowdown.

2.2 AQUATIC EXPOSURE ASSESSMENT

Estimates of contaminant concentrations in the surface waters of the eastern reference environment were computed based on the source terms described in the preceding section. The model used for this purpose is described by Travis et al. (1983). The model used for the synfuels risk analyses is similar in concept to the EXAMS model (Baughman and Lassiter 1978), but is simpler in process chemistry and environmental detail. A river is represented as a series of completely mixed reaches. Within each reach, steady-state contaminant concentrations are computed, based on dilution and on physical/chemical removal of contaminants from the water column. Ranges and variances can be placed on all of the environmental and chemical parameters in the model to compute frequency distribution of environmental concentrations. For this analysis, frequency distributions were computed for all RACs, based on observed variability in environmental parameters affecting contaminant transport and transformation.

2.2.1 Stream Characteristics

The environmental parameters used in the surface water exposure analysis were: stream flow (m^3/s), stream width (m), reach length (m), sediment load (mg/L), sediment density (g/m^3), depth of the biologically active sediment (cm), fraction of organic carbon in the sediment (unitless), stream temperature (K), current velocity (m/s), wind velocity (m/s), and radius of sediment particles (cm). Estimates of stream flow, temperature, and suspended solids for the eastern site were set within ranges observed by the U.S. Geological Survey for the Big Sandy River at Louisa, Kentucky, and the Monongahela River at Braddock, Pennsylvania (USGS 1977, 1979). Values for the other stream parameters were taken from Southworth (1979). Irradiance values (photons cm^2 s^{-1}) for estimating photolysis rates were obtained from Zepp and Cline (1977).

Table 2.1-1. Aqueous source terms (kg/h) for four direct coal liquefaction technologies, control option 1

RAC	Exxon Donor Solvent	Solvent Refined Coal-I	Solvent Refined Coal-II	H-Coal
4	0	0	0	0
5	5.5	9	5	5
6	0	0	0.002-0.017	0
7	0	0	0.79-1.8	4.8
8	0	0	0.017-0.96	0
9	0	0	0.15	0
10	0.41	0	0.0097	0.05
11	0.066	0	0.0047	0.0083
12	0.26	0	0.0016-0.8	0.033
13	35	35	0.0063-0.12	45
14	2.6	1.2	2.2-7.2	3.2
15	0.011	0.11	0.093-0.26	0.014
16	0	0	0	0
17	0.23	0	0.023	0.25
18	0	0	0	0
19	5.7	0.11	9.5-14	7.2
20	81	0	0	100
21	9	43	7.7-16	46
22	1.3	0	0	1.6
23	0.32	4.1	0.0077-0.09	0.4
24	0	0	0.011	0
25	0	0	0.12	0
26	0	0	0.08-0.72	0
27	0	0	0	0
28	5.4	0	0	0
31	0.0033-0.0042	0.0065	0.0045-0.0071	0.0083
32	0.00202	0.0115	0.000518-0.008018	0.0005
33	0.0308-0.035	0.0363	0.0076-0.0086	0.0132-0.0572
34	0.038	0.0033	0.0025-0.003	0.01062-0.01962
35	0.0382-0.0402	0.5607	0.0029-0.0039	0.01762-0.08762
36	3.52	1.226	0.46-7.79	0.353

Table 2.1-2. Aqueous source terms (kg/h) for four direct coal liquefaction technologies, control option 2

RAC	Exxon Donor Solvent	Solvent Refined Coal-I	Solvent Refined Coal-II	H-Coal
4	0	0	0	0
5	5.5	9	5	5
6	0	0	0.0002-0.0017	0
7	0	0	0.079-0.18	0.48
8	0	0	0.0017-0.096	0
9	0	0	0.015	0
10	0.041	0	0.00097	0.005
11	0.0066	0	0.00047	0.00083
12	0.026	0	0.00016-0.08	0.0033
13	3.5	3.5	0.00063-0.012	4.5
14	0.26	0.12	0.22-0.72	0.32
15	0.0011	0.011	0.0093-0.0256	0.0014
16	0	0	0	0
17	0.023	0	0.0023	0.028
18	0	0	0	10
19	0.57	0.011	0.95-1.4	0.72
20	8.1	0	0	10
21	0.9	4.3	0.77-1.6	4.6
22	0.13	0	0	0.16
23	0.032	0.41	0.00077-0.009	0.04
24	0	0	0.0011	0
25	0	0	0.012	0
26	0	0	0.008-0.072	0
27	0	0	0	0
28	0.54	0	0	0.68
31	0.0033-0.0042	0.0065	0.0045-0.0071	0.0083
32	0.00202	0.0115	0.000518-0.008018	0.0005
33	0.0308-0.035	0.0363	0.0076-0.0086	0.0132-0.0572
34	0.038	0.0033	0.0025-0.003	0.01062-0.01962
35	0.0382-0.0402	0.5607	0.0029-0.0039	0.01762-0.08762
36	3.52	1.226	0.46-7.79	0.353

Probability distributions for flow, temperature, and suspended solids were determined from the means, minima, and maxima of these parameters observed at the USGS stations. Normal distributions for particle radius, organic carbon fraction, current velocity, and wind velocity were derived from ranges used by Southworth (1979). Because current velocity and sediment load are influenced by stream flow, a correlation coefficient of 0.7 was specified between flow and velocity and between flow and suspended solids. All environmental parameters used in the exposure analysis are presented in Table 2.2-1.

2.2.2 Contaminant Characteristics

For organic contaminants, the chemical properties (Table 2.2-2) used were molecular weight (g/mol), aqueous solubility (g/L), octanol-water partition coefficient (unitless), quantum yield of direct photolysis (unitless), molar extinction coefficient (cm-L/mol) and vapor pressure (mmHg). Although microbial degradation rates can be accommodated in the model, none were used for this assessment. Molecular weights of organic compounds were obtained from Weast (1980); aqueous solubility data were obtained from Verschueren (1977); and octanol-water partition coefficients were obtained from Leo et al. (1971) and Briggs (1981). Equations relating vapor pressure to ambient temperature were generated from data points reported in Verschueren (1977). These equations are linear approximations that should provide adequate accuracy over the small temperature range (280-310 K) involved.

Derived characteristics of organic contaminants were calculated using functional relationships obtained from the literature. Henry's Law coefficients were approximated using the method of Dilling (1977). Mass transfer rates and dissolved fractions were calculated using the method of Southworth (1979), while particulate settling velocities were calculated from Stoke's Law (Weast 1980). Direct photolysis rate constants for anthracene were calculated using the method of Zepp and Cline (1977), and adsorption/desorption coefficients were approximated using the method of Karickhoff et al. (1979).

Table 2.2-1. Stream characteristics for the eastern reference site

Environmental parameter	Units	Mean value	Standard deviation	Minimum value	Maximum value
Stream flow	m^3/s	120	75	50	600
Reach length	m	1000	0	1000	1000
Stream width	m	40	0	40	40
Suspended solids	mg/L	25	20	1	250
Sediment depth	cm	1	0	1	1
Solids density	g/cm^3	1.02	0	1.02	1.02
Fraction organic carbon		0.1	0.1	0.05	0.25
Particle radius	cm	0.005	0.0025	0.001	0.01
Temperature	K	298	3	283	310
Current velocity	m/s	0.25	0.1	0.1	1.0
Wind velocity	m/s	1.5	0.1	0.25	4.0

Table 2.2-2. Contaminant characteristics

RAC	Representative contaminant	Molecular or atomic weight[a] (g/mol)	Aqueous solubility[b] (g/L)	Octanol-water partition coefficient (log P)	Quantum yield of photolysis (unitless)
4	Hydrogen sulfide	34.06			
5	Ammonia	17.03			
6	Butane	58.12	6.1 E-02		
7	Formaldehyde	30.03			
8	Methylene chloride	84.93	1.67 E+01		
9	Acetic acid	60.05	3.80 E-02	-0.17[c]	
10	Thiophene	84.14	4.43 E-01	1.81[c]	
11	Pyridine	79.10	3.00 E-02	0.650[c]	
12	Benzene	78.12	1.78 E+00	2.13[c]	
13	Cyclohexane	84.16	5.5 E-02	4.0[c]	
14	Toluene	92.15	5.15 E-01	2.69[c]	
15	Anthracene	178.24	7.50 E-05	4.45[c]	0.003[d]
17	Aniline	93.13	3.40 E+01	0.90[c]	
19	Dibenzofuran	168.21	3.00 E-03	4.12[c]	
20	Butanoic acid	88.1	5.62 E+01	0.79[c]	
21	Phenol	94.11	8.20 E+01	1.46[c]	
22	Acrolein	56.07	9.74 E-01	0.90[e]	
23	Methanethiol	48.11	4.00 E-05	-0.660[c]	
24	Methanol	32.04	2.7 E-01	-0.74[c]	
25	Nitrobenzene	123.11	1.9 E+00	2.31[e]	
26	Methyl phthalate	194.19	5.0 E+00		
28	Acrylonitrile	53.06	3.83 E-01	-0.92[c]	
31	Arsenic	74.92			
32	Mercury	200.59			
33	Nickel	58.71			
34	Cadmium	112.40			
35	Lead	207.19			
36	Fluorine	19.00			

[a] Weast (1980).
[b] Verschueren (1977).
[c] Leo et al. (1971).
[d] Zepp and Schlotzhauer (1979).
[e] Briggs (1981).

Because of their complex environmental chemistry, removal processes for trace elements were not directly modeled. Rates of removal by sedimentation were estimated, using an adsorption/desorption coefficient of 200. Schell and Sibley's (1982) study of K_d's for radionuclides suggests that this is probably a conservative estimate for most trace elments under most environmental conditions.

2.2.3 Results

Model runs were performed for the reference stream using the source rates presented in Tables 2.1-1 and 2.1-2. The means, medians, and upper 95% concentrations (i.e., the concentrations equaled or exceeded in 5% of the Monte Carlo simulations) in 1-km stream reaches immediately adjacent to the release sites are presented in Tables 2.2-3 through 2.2-6. For all practical purposes, the concentrations computed using contaminant-specific removal rates are identical to concentrations computed from pure dilution rates. Thus, at least in the immediate vicinity of contaminant sources located on rivers such as the eastern and western reference streams, the environmental removal processes modeled have very little influence on steady-state contaminant concentrations. It is possible, however, that some of the processes not modeled (e.g., hydrolysis, complexation, or microbial degradation) may occur more rapidly than do photolysis, sedimentation, and volatilization.

2.3 ATMOSPHERIC DISPERSION AND DEPOSITION

The short-range atmospheric dispersion code AIRDOS-EPA (Moore et al. 1979) was used in the environmental risk analysis to calculate ground-level atmospheric concentrations and deposition. This code is summarized by Travis et al. (1983), who also describe the method for calculating accumulation in soil. Soil concentrations are calculated for a 35-year accumulation period using site-specific values for soil bulk density, precipitation, evapotranspiration, and irrigation and taking into account removal by leaching, biological degradation, and chemical degradation.

Table 2.2-3. Estimated ambient contaminant concentrations, eastern reference stream, Exxon Donor Solvent process

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
4	Hydrogen sulfide	1	0	0	0
		2	0	0	0
5	Ammonia	1	1.3 E-05	1.1 E-05	2.5 E-05
		2	1.3 E-05	1.1 E-05	2.5 E-05
6	Butane	1	0	0	0
		2	0	0	0
7	Formaldehyde	1	0	0	0
		2	0	0	0
8	Methylene cnloride	1	0	0	0
		2	0	0	0
9	Acetic acid	1	0	0	0
		2	0	0	0
10	Thiophene	1	9.5 E-07	8.3 E-07	1.9 E-06
		2	9.5 E-08	8.3 E-08	1.9 E-07
11	Pyridine	1	1.5 E-07	1.3 E-07	3.0 E-07
		2	1.5 E-08	1.3 E-08	3.0 E-08
12	Benzene	1	6.0 E-07	5.3 E-07	1.2 E-06
		2	6.0 E-08	5.3 E-08	1.2 E-07
13	Cyclohexane	1	8.1 E-05	7.1 E-05	1.6 E-04
			8.1 E-06	7.1 E-06	1.6 E-05
14	Toluene	1	6.0 E-06	5.3 E-06	1.2 E-05
		2	6.0 E-07	5.3 E-07	1.2 E-06
15	Anthracene	1	2.2 E-08	2.1 E-08	3.8 E-08
		2	2.2 E-09	2.1 E-09	3.8 E-09
16	Methylamine	1	0	0	0
		2	0	0	0
17	Aniline	1	5.3 E-07	4.7 E-07	1.0 E-06
		2	5.3 E-08	4.7 E-08	1.0 E-07
18	Quinoline	1	0	0	0
		2	0	0	0

Table 2.2-3. (continued)

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
19	Dibenzofuran	1	1.3 E-05	1.2 E-05	2.6 E-05
		2	1.3 E-06	1.2 E-06	2.6 E-06
20	Butanoic acid	1	1.9 E-04	1.6 E-04	3.7 E-04
		2	1.9 E-05	1.6 E-05	3.7 E-05
21	Phenol	1	2.1 E-05	1.8 E-05	4.1 E-05
		2	2.1 E-06	1.8 E-06	4.1 E-06
22	Acrolein	1	3.0 E-06	2.6 E-06	5.9 E-06
		2	3.0 E-07	2.6 E-07	5.9 E-07
23	Methanethiol	1	7.4 E-07	6.5 E-07	1.5 E-06
		2	7.4 E-08	6.5 E-08	1.5 E-07
24	Methanol	1	0	0	0
		2	0	0	0
25	Nitrobenzene	1	0	0	0
		2	0	0	0
26	Methyl phthalate	1	0	0	0
		2	0	0	0
27	Acetamide	1	0	0	0
		2	0	0	0
28	Acrylonitrile	1	1.2 E-05	1.1 E-05	2.5 E-05
		2	1.2 E-06	1.1 E-06	2.5 E-06
31	Arsenic	1	9.7 E-09	8.5 E-09	1.9 E-08
		2	9.7 E-09	8.5 E-09	1.9 E-08
32	Mercury	1	4.7 E-09	4.1 E-09	9.2 E-09
		2	4.7 E-09	4.1 E-09	9.2 E-09
33	Nickel	1	8.1 E-08	7.1 E-08	1.6 E-07
		2	8.1 E-08	7.1 E-08	1.6 E-07
34	Cadmium	1	8.8 E-08	7.7 E-08	1.7 E-07
		2	8.8 E-08	7.7 E-08	1.7 E-07
35	Lead	1	9.3 E-08	8.2 E-08	1.8 E-07
		2	9.3 E-08	8.2 E-08	1.8 E-07
36	Fluorine	1	8.1 E-06	7.2 E-06	1.6 E-05
		2	8.1 E-06	7.2 E-06	1.6 E-05

Table 2.2-4. Estimated ambient contaminant concentrations, eastern reference stream, SRC-I process

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
4	Hydrogen sulfide	1	0	0	0
		2	0	0	0
5	Ammonia	1	2.1 E-05	1.8 E-05	4.1 E-05
		2	2.1 E-05	1.8 E-05	4.1 E-05
6	Butane	1	0	0	0
		2	0	0	0
7	Formaldehyde	1	0	0	0
		2	0	0	0
8	Methylene chloride	1	0	0	0
		2	0	0	0
9	Acetic acid	1	0	0	0
		2	0	0	0
10	Thiophene	1	0	0	0
		2	0	0	0
11	Pyridine	1	0	0	0
		2	0	0	0
12	Benzene	1	0	0	0
		2	0	0	0
13	Cyclohexane	1	8.1 E-05	7.1 E-05	1.6 E-04
			8.1 E-06	7.1 E-06	1.6 E-05
14	Toluene	1	2.8 E-06	2.4 E-06	5.5 E-06
		2	2.8 E-07	2.4 E-07	5.5 E-07
15	Anthracene	1	2.2 E-07	2.1 E-07	3.8 E-07
		2	2.2 E-08	2.1 E-08	3.8 E-08
16	Methylamine	1	0	0	0
		2	0	0	0
17	Aniline	1	0	0	0
		2	0	0	0
18	Quinoline	1	0	0	0
		2	0	0	0

Table 2.2-4. (continued)

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
19	Dibenzofuran	1	2.5 E-07	2.2 E-07	5.0 E-07
		2	2.5 E-08	2.2 E-08	5.0 E-08
20	Butanoic acid	1	0	0	0
		2	0	0	0
21	Phenol	1	9.9 E-05	8.7 E-05	2.0 E-04
		2	9.9 E-06	8.7 E-06	2.0 E-05
22	Acrolein	1	0	0	0
		2	0	0	0
23	Methanethiol	1	9.5 E-06	8.3 E-06	1.9 E-05
		2	9.5 E-07	8.3 E-07	1.9 E-06
24	Methanol	1	0	0	0
		2	0	0	0
25	Nitrobenzene	1	0	0	0
		2	0	0	0
26	Metnyl phthalate	1	0	0	0
		2	0	0	0
27	Acetamide	1	0	0	0
		2	0	0	0
28	Acrylonitrile	1	0	0	0
		2	0	0	0
31	Arsenic	1	1.5 E-08	1.3 E-08	3.0 E-08
		2	1.5 E-08	1.3 E-08	3.0 E-08
32	Mercury	1	2.7 E-08	2.3 E-08	5.2 E-08
		2	2.7 E-08	2.3 E-08	5.2 E-08
33	Nickel	1	8.4 E-08	7.4 E-08	1.7 E-07
		2	8.4 E-08	7.4 E-08	1.7 E-07
34	Cadmium	1	7.6 E-09	6.7 E-09	1.5 E-08
		2	7.6 E-09	6.7 E-09	1.5 E-08
35	Lead	1	1.3 E-06	1.1 E-06	2.6 E-06
		2	1.3 E-06	1.1 E-06	2.6 E-06
36	Fluorine	1	2.8 E-06	2.5 E-06	5.6 E-06
		2	2.8 E-06	2.5 E-06	5.6 E-06

Table 2.2-5. Estimated ambient contaminant concentrations, eastern reference stream, SRC-II process

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
4	Hydrogen sulfide	1	0	0	0
		2	0	0	0
5	Ammonia	1	1.2 E-05	1.0 E-05	2.3 E-05
		2	1.2 E-05	1.0 E-05	2.3 E-05
6	Butane	1	3.9 E-08	3.5 E-08	7.8 E-08
		2	3.9 E-09	3.5 E-09	7.8 E-09
7	Formaldehyde	1	4.2 E-06	3.7 E-06	8.2 E-06
		2	4.2 E-07	3.7 E-07	8.2 E-07
8	Methylene chloride	1	2.2 E-06	2.0 E-06	4.4 E-06
		2	2.2 E-07	2.0 E-07	4.4 E-07
9	Acetic acid	1	3.5 E-07	3.1 E-07	6.8 E-07
		2	3.5 E-08	3.1 E-08	6.8 E-08
10	Thiophene	1	2.2 E-08	2.0 E-08	4.4 E-08
		2	2.2 E-09	2.0 E-09	4.4 E-09
11	Pyridine	1	1.1 E-08	9.6 E-09	2.1 E-08
		2	1.1 E-09	9.6 E-10	2.1 E-09
12	Benzene	1	1.9 E-06	1.6 E-06	3.6 E-06
		2	1.9 E-07	1.6 E-07	3.6 E-07
13	Cyclohexane	1	2.8 E-07	2.4 E-07	5.5 E-07
			2.8 E-08	2.4 E-08	5.5 E-08
14	Toluene	1	1.7 E-05	1.5 E-05	3.3 E-05
		2	1.7 E-06	1.5 E-06	3.3 E-06
15	Anthracene	1	5.3 E-07	4.9 E-07	9.1 E-07
		2	5.3 E-08	4.9 E-08	9.1 E-08
16	Methylamine	1	0	0	0
		2	0	0	0
17	Aniline	1	5.3 E-08	4.7 E-08	1.1 E-07
		2	5.3 E-09	4.7 E-09	1.1 E-08
18	Quinoline	1	0	0	0
		2	0	0	0

Table 2.2-5. (continued)

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
19	Dibenzofuran	1	3.2 E-05	2.8 E-05	6.4 E-05
		2	3.2 E-06	2.8 E-06	6.4 E-06
20	Butanoic acid	1	0	0	0
		2	0	0	0
21	Phenol	1	3.7 E-05	3.3 E-05	7.3 E-05
		2	3.7 E-06	3.3 E-06	7.3 E-06
22	Acrolein	1	0	0	0
		2	0	0	0
23	Metnanethiol	1	2.1 E-07	1.8 E-07	4.1 E-07
		2	2.1 E-08	1.8 E-08	4.1 E-08
24	Methanol	1	2.5 E-08	2.2 E-08	5.0 E-08
		2	2.5 E-09	2.2 E-09	5.0 E-09
25	Nitrobenzene	1	2.8 E-07	2.4 E-07	5.5 E-07
		2	2.8 E-08	2.4 E-08	5.5 E-08
26	Metnyl phthalate	1	1.7 E-06	1.5 E-06	3.3 E-06
		2	1.7 E-07	1.5 E-07	3.3 E-07
27	Acetamide	1	0	0	0
		2	0	0	0
28	Acrylonitrile	1	0	0	0
		2	0	0	0
31	Arsenic	1	1.6 E-08	1.4 E-08	3.2 E-08
		2	1.6 E-08	1.4 E-08	3.2 E-08
32	Mercury	1	1.9 E-08	1.6 E-08	3.7 E-08
		2	1.9 E-08	1.6 E-08	3.7 E-08
33	Nickel	1	2.0 E-08	1.7 E-08	3.9 E-08
		2	2.0 E-08	1.7 E-08	3.9 E-08
34	Cadmium	1	6.9 E-09	6.1 E-09	1.4 E-08
		2	6.9 E-09	6.1 E-09	1.4 E-08
35	Lead	1	9.0 E-09	7.9 E-09	1.8 E-08
		2	9.0 E-09	7.9 E-09	1.8 E-08
36	Fluorine	1	1.8 E-05	1.6 E-05	3.6 E-05
		2	1.8 E-05	1.6 E-05	3.6 E-05

Table 2.2-6. Estimated ambient contaminant concentrations, eastern reference stream, H-Coal process.

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
4	Hydrogen sulfide	1	0	0	0
		2	0	0	0
5	Ammonia	1	1.2 E-05	1.0 E-05	2.3 E-05
		2	1.2 E-05	1.0 E-05	2.3 E-05
6	Butane	1	0	0	0
		2	0	0	0
7	Formaldehyde	1	1.1 E-05	9.8 E-06	2.2 E-05
		2	1.1 E-06	9.8 E-07	2.2 E-06
8	Methylene chloride	1	0	0	0
		2	0	0	0
9	Acetic acid	1	0	0	0
		2	0	0	0
10	Thiophene	1	1.2 E-07	1.0 E-07	2.3 E-07
		2	1.2 E-08	1.0 E-08	2.3 E-08
11	Pyridine	1	1.9 E-08	1.7 E-08	3.8 E-08
		2	1.9 E-09	1.7 E-09	3.8 E-09
12	Benzene	1	7.6 E-08	6.7 E-08	1.5 E-07
		2	7.6 E-09	6.7 E-09	1.5 E-08
13	Cyclohexane	1	1.0 E-04	9.1 E-05	2.0 E-04
			1.0 E-05	9.1 E-06	2.0 E-05
14	Toluene	1	7.4 E-06	6.5 E-06	1.5 E-05
		2	7.4 E-07	6.5 E-07	1.5 E-06
15	Anthracene	1	2.9 E-08	2.7 E-08	4.9 E-08
		2	2.9 E-09	2.7 E-09	4.9 E-09
16	Methylamine	1	0	0	0
		2	0	0	0
17	Aniline	1	6.5 E-07	5.7 E-07	1.3 E-06
		2	6.5 E-08	5.7 E-08	1.3 E-07
18	Quinoline	1	0	0	0
		2	0	0	0

Table 2.2-6. (continued)

RAC	Reference compound	Treatment option	Mean (g/L)	Median (g/L)	95% (g/L)
19	Dibenzofuran	1	1.7 E-05	1.5 E-05	3.3 E-05
		2	1.7 E-06	1.5 E-06	3.3 E-06
20	Butanoic acid	1	2.3 E-04	2.0 E-04	4.6 E-04
		2	2.3 E-05	2.0 E-05	4.6 E-05
21	Phenol	1	1.1 E-04	9.3 E-05	2.1 E-04
		2	1.1 E-05	9.3 E-06	2.1 E-05
22	Acrolein	1	3.7 E-06	3.3 E-06	7.3 E-06
		2	3.7 E-07	3.3 E-07	7.3 E-07
23	Methanethiol	1	9.3 E-07	8.1 E-07	1.8 E-06
		2	9.3 E-08	8.1 E-08	1.8 E-07
24	Methanol	1	0	0	0
		2	0	0	0
25	Nitrobenzene	1	0	0	0
		2	0	0	0
26	Methyl phthalate	1	0	0	0
		2	0	0	0
27	Acetamide	1	0	0	0
		2	0	0	0
28	Acrylonitrile	1	1.6 E-05	1.4 E-05	3.1 E-05
		2	1.6 E-06	1.4 E-06	3.1 E-06
31	Arsenic	1	1.9 E-08	1.7 E-08	3.8 E-08
		2	1.9 E-08	1.7 E-08	3.8 E-08
32	Mercury	1	1.2 E-09	1.0 E-09	2.3 E-09
		2	1.2 E-09	1.0 E-09	2.3 E-09
33	Nickel	1	1.3 E-07	1.2 E-07	2.6 E-07
		2	1.3 E-07	1.2 E-07	2.6 E-07
34	Cadmium	1	4.5 E-08	4.0 E-08	8.9 E-08
		2	4.5 E-08	4.0 E-08	8.9 E-08
35	Lead	1	2.0 E-07	1.8 E-07	4.0 E-07
		2	2.0 E-07	1.8 E-07	4.0 E-07
36	Fluorine	1	8.2 E-07	7.2 E-07	1.6 E-06
		2	8.2 E-07	7.2 E-07	1.6 E-06

Because most phytotoxicity studies are done in solution culture, we added a calculated concentration in soil solution that is not described in previous documents. For calculation of the soil solution concentration, the total accumulation in the soil compartment is first calculated as above. That is, the depositing material is summed over the lifetime of the facility and corrected for leaching, degradation, and other removal processes. The retained material is then partitioned between the solid and solution phases of the soil compartment assuming the relationship:

$$C_{iss} = \frac{C_{is}}{K_d} \quad , \tag{1}$$

where C_{iss} = the concentration of compound i in root zone soil solution (μg/L),

C_{is} = the concentration of compound i in root zone soil (μg/kg), and

K_d = the distribution coefficient (L/kg).

Because K_d is in the denominator of Eq. (1), the soil solution concentration, C_{iss} could take on extremely high values with small values of K_d. To bound the maximum value of C_{iss}, it is assumed that the upper bound concentration is represented by the total deposited and retained material divided by the quantity of water in the root zone defined by d or

$$C_{iss}^{max} = \frac{D_i[1 - \exp(-\lambda_{si}\ t_b)]}{10\ \rho\ \theta\ d\ \lambda_{si}} \quad , \tag{2}$$

where

D_i = the ground-level deposition rate of compound i ($\mu g\ m^{-2}\ s^{-1}$),

λ_{si} = the sum of all soil removal rate constants (L/s),

t_b = the period of long-term buildup in soil, equal to the length of time that the source term is in operation(s),

10 = a conversion factor from g/cm^2 to kg/m^2 [(10,000 cm^2/1 m^2) (1 kg/1000 g)],

ρ = soil bulk density (g/cm^3),
θ = volumetric water content (cm^3/cm^3),
d = the depth of the root zone (cm), and
r = soil volumetric water content (mL/cm^3).

If C_{iss} calculated using Eq. (1) exceeds C^{max} calculated using Eq. (2), then C_{iss} is set equal to C^{max}. The value of θ used in Eq. (2) is very important in providing a reasonable estimate of C^{max}. Since measured values of K_d are usually determined under saturated conditions, θ in Eq. (2) represents total soil porosity.

These calculations generate sector-average ground-level concentrations in air, soil, and soil solution in 16 directions at 500-m intervals from 1,500 m to 50,000 m from the source. The highest annual average concentrations in air and the highest soil and soil solution concentrations after 35 years of deposition are presented in Tables 2.3-1 through 2.3-4.

Table 2.3-1. Maximum ambient atmospheric and soil concentrations for Exxon Donor Solvent process.

RAC	RAC name	Annual average concentration in air ($\mu g/m^3$)	Concentration in soil ($\mu g/kg$)	Concentration in soil solution ($\mu g/L$)
1	Carbon monoxide	17.4	No accumulation in soil	
2	Sulfur oxides	6.61	No accumulation in soil	
3	Nitrogen oxides	7.57	No accumulation in soil	
4	Acid gases		No emissions	
5	Alkaline gases		No emissions	
6	Hydrocarbon gases	5.92	2.38	2.47
7	Formaldehyde		No emissions	
8	Volatile organochlorines		No emissions	
9	Volatile carboxylic acids		No emissions	
10	Volatile O & S heterocyclics	4.43 E-02	1.82 E-03	1.51 E-03
11	Volatile N heterocyclics		No emissions	
12	Benzene	2.47 E-02	1.03 E-02	7.91 E-03
13	Aliphatic/alicyclic hydrocarbons	1.37	35.4	2.53
14	Mono- or diaromatic hydrocarbons	3.19	1.85	0.37
15	Polycyclic aromatic hydrocarbons	0.415	37.3	0.573
16	Aliphatic amines		No emissions	
17	Aromatic amines	7.14 E-03	3.79 E-02	7.81 E-02
18	Alkaline N heterocyclics	0.261	2.39	0.919
19	Neutral N, O, S heterocyclics	1.09	4.14 E-02	1.09 E-02
20	Carboxylic acids		No emissions	
21	Phenols	0.52	133	196
22	Aldehydes and ketones	9.96 E-03	1.65 E-02	3.4 E-02
23	Nonheterocyclic organosulfur	9.38 E-06	1.12 E-05	5.1 E-06
24	Alcohols		No emissions	
25	Nitroaromatics		No emissions	
26	Esters		No emissions	
27	Amides		No emissions	
28	Nitriles		No emissions	
29	Tars		No emissions	
30	Respirable particles	45.4		
31	Arsenic	1.85 E-04	330	1.65
32	Mercury	1.54 E-05	2.46 E-03	2.46 E-04
33	Nickel	8.57 E-04	2460	16.4
34	Cadmium	1.32 E-04	49.1	7.56
35	Lead	1.32 E-03	981	1.09
36	Other trace elements	0.0287		
37	Radioactive materials	0.0226		

Table 2.3-2. Maximum ambient atmospheric and soil concentrations for SRC-I

RAC	RAC name	Annual average concentration in air ($\mu g/m^3$)	Concentration in soil ($\mu g/kg$)	Concentration in soil solution ($\mu g/L$)
1	Carbon monoxide	2.61	No accumulation in soil	
2	Sulfur oxides	5.40	No accumulation in soil	
3	Nitrogen oxides	7.86	No accumulation in soil	
4	Acid gases	1.79 E-02	No emissions	
5	Alkaline gases	3.11 E-01	No emissions	
6	Hydrocarbon gases	4.77	1.92	1.99
7	Formaldehyde		No emissions	
8	Volatile organochlorines		No emissions	
9	Volatile carboxylic acids		No emissions	
10	Volatile O & S heterocyclics		No emissions	
11	Volatile N heterocyclics		No emissions	
12	Benzene		No emissions	
13	Aliphatic/alicyclic hydrocarbons	1.29	33.4	2.38
14	Mono- or diaromatic hydrocarbons	2.96	1.72	3.44 E-01
15	Polycyclic aromatic hydrocarbons	1.48	133	2.05
16	Aliphatic amines		No emissions	
17	Aromatic amines	8.71 E-01	4.62	9.53
18	Alkaline N heterocyclics		No emissions	
19	Neutral N, O, S heterocyclics	8.32 E-01	3.16 E-02	8.31 E-03
20	Carboxylic acids		No emissions	
21	Phenols	1.82	466	686
22	Aldehydes and ketones		No emissions	
23	Nonheterocyclic organosulfur		No emissions	
24	Alcohols		No emissions	
25	Nitroaromatics		No emissions	
26	Esters		No emissions	
27	Amides		No emissions	
28	Nitriles		No emissions	
29	Tars		No emissions	
30	Respirable particles	96.7	No accumulation in soil	
31	Arsenic	1.23 E-03	2200	11.0
32	Mercury	1.44 E-05	2.30 E-03	2.30 E-04
33	Nickel	1.01	32000	213
34	Cadmium	1.99 E-05	4.74	7.29 E-01
35	Lead	1.01 E-03	766	8.51 E-01
36	Other trace elements	0.0287	No accumulation in soil	
37	Radioactive materials	0.0226	No accumulation in soil	

Table 2.3-3. Maximum ambient atmospheric and soil concentrations for SRC-II Process.

RAC	RAC name	Annual average concentration in air ($\mu g/m^3$)	Concentration in soil ($\mu g/kg$)	Concentration in soil solution ($\mu g/L$)
1	Carbon monoxide	1.67	No accumulation in soil	
2	Sulfur oxides	1.53	No accumulation in soil	
3	Nitrogen oxides	8.30	No accumulation in soil	
4	Acid gases		No emissions	
5	Alkaline gases		No emissions	
6	Hydrocarbon gases	3.72	1.50	1.55
7	Formaldehyde		No emissions	
8	Volatile organochlorines		No emissions	
9	Volatile carboxylic acids		No emissions	
10	Volatile O & S heterocyclics	0.0622	2.55 E-03	2.13 E-03
11	Volatile N heterocyclics	0.234	1.18	2.43
12	Benzene	0.12	0.0498	0.0383
13	Aliphatic/alicyclic hydrocarbons	2.10	54.3	3.88
14	Mono- or diaromatic hydrocarbons	2.07	1.20	0.241
15	Polycyclic aromatic hydrocarbons	0.463	41.6	0.640
16	Aliphatic amines		No emissions	
17	Aromatic amines	0.00386	0.0205	0.0422
18	Alkaline N heterocyclics	0.0564	0.516	0.198
19	Neutral N, O, S heterocyclics	0.235	0.00892	0.00235
20	Carboxylic acids		No emissions	
21	Phenols	0.784	201	295
22	Aldehydes and ketones		No emissions	
23	Nonheterocyclic organosulfur		No emissions	
24	Alcohols		No emissions	
25	Nitroaromatics		No emissions	
26	Esters		No emissions	
27	Amides		No emissions	
28	Nitriles		No emissions	
29	Tars		No emissions	
30	Respirable particles	63.3	No accumulation in soil	
31	Arsenic	4.84 E-04	14.5	7.24 E-02
32	Mercury	1.35 E-05	2.16 E-03	2.16 E-04
33	Nickel	3.57 E-04	10.4	6.93 E-02
34	Cadmium	1.68 E-05	8.41 E-02	1.29 E-02
35	Lead	2.27 E-04	1.92	2.13 E-03
36	Other trace elements	2.40 E-02	No accumulation in soil	
37	Radioactive materials		No emissions	

Table 2.3-4. Maximum ambient atmospheric and soil concentrations for H-Coal Process

RAC	RAC name	Annual average concentration in air ($\mu g/m^3$)	Concentration in soil ($\mu g/kg$)	Concentration in soil solution ($\mu g/L$)
1	Carbon monoxide	0.679	No accumulation in soil	
2	Sulfur oxides	2.50	No accumulation in soil	
3	Nitrogen oxides	3.18	No accumulation in soil	
4	Acid gases	7.65 E-03	No accumulation in soil	
5	Alkaline gases		No emissions	
6	Hydrocarbon gases	5.74	2.31	2.39
7	Formaldehyde		No emissions	
8	Volatile organochlorines		No emissions	
9	Volatile carboxylic acids		No emissions	
10	Volatile O & S heterocyclics		No emissions	
11	Volatile N heterocyclics	0.103	0.516	1.06
12	Benzene		No emissions	
13	Aliphatic/alicyclic hydrocarbons	0.946	24.4	1.75
14	Mono- or diaromatic hydrocarbons	4.63	2.69	0.537
15	Polycyclic aromatic hydrocarbons	0.0658	5.91	0.0909
16	Alipnatic amines		No emissions	
17	Aromatic amines	0.0285	0.152	0.313
18	Alkaline N heterocyclics	0.0960	0.877	0.337
19	Neutral N, O, S heterocyclics	0.175	0.00664	0.00175
20	Carboxylic acids	0.556	8.86	7.38
21	Phenols	0.959	245	361
22	Aldehydes and ketones		No emissions	
23	Nonheterocyclic organosulfur	0.0485	0.0581	0.0264
24	Alcohols		No emissions	
25	Nitroaromatics		No emissions	
26	Esters		No emissions	
27	Amides		No emissions	
28	Nitriles		No emissions	
29	Tars		No emissions	
30	Respirable particles	58.4	No accumulation in soil	
31	Arsenic	3.10 E-04	307	1.53
32	Mercury	1.77 E-05	2.83 E-03	2.83 E-04
33	Nickel	1.12 E-03	1130	7.51
34	Cadmium	1.84 E-04	23.2	3.57
35	Lead	1.89 E-03	776	0.863
36	Other trace elements	4.73 E-02	No accumulation in soil	
37	Radioactive materials	1.20 E-02	No accumulation in soil	

3. AQUATIC ENDPOINTS

3.1 QUOTIENT METHOD

Also known as the "Ratio Method," this approach to assessing the relative hazard of several constituents has been used in such fields as environmental health and epidemiology. The quotient is calculated from the ratio of the known or estimated concentration of a chemical in the environment to a concentration of that chemical proven or calculated (by extrapolation from experimental data) to be toxic to certain organisms at a particular test endpoint. The endpoint, known as a toxicological benchmark, may be one of several, among them the EPA water quality criteria (USEPA 1980a-p), EC_{20} (the effective concentration causing a designated effect on 20% of the test organisms), LOTC (lowest observed toxic concentration), TL_m (median tolerance limit), and LC_{50} (the concentration required to kill 50% of the test organisms).

Because this report compares potential toxic differences amoung groups of chemicals (RACs), benchmarks common to as many of the RACs as possible were preferred. The LC_{50} and TL_m (which are equivalent), were selected to represent acute toxicity (Table A-1). Chronic effects are presented as GMATCs (geometric mean maximum allowable toxicant concentrations, which is the geometric mean of the highest no observed effect concentration and the lowest-observed-effect concentration) (Table A-2). In contrast, benchmarks used in algal tests can vary between studies, and, therefore, a variety of test endpoints were selected for this report (Table A-3).

Appendix A does not include all extant data on the responses of freshwater organisms to the test chemicals. For example, with the heavy metals, several representative values are included for the sake of brevity.

As in the selection of benchmarks, the test species chosen for tabulation were those that appear most frequently in the literature. Invertebrates were usually represented by cladocerans (Daphnia species), with insect data presented when available. The fish species selected

are those usually used in toxicity testing, namely, fathead minnows (Pimephales promelas), bluegills (Lepomis macrochirus), and rainbow trout (Salmo gairdneri). Data for algal assays are sparse, so all species appearing in the literature, to our knowledge, were included in Table A-3.

Tables 3.1-1 to 3.1-4 present the highest quotients for each RAC and category of effect for the four direct liquefaction technologies. The acute toxicity quotients were calculated using the upper 95th percentile concentration (an estimate of the worst acute exposure, assuming stable plant operation). The chronic quotients were calculated using the annual median concentration, and the algal quotients were calculated for both concentrations because the distinction between acute and chronic effects is not clear for algae. The higher the value of these quotients the greater the risk of acute effects on organisms in the reference stream.

Quotients are interpreted according to the best judgment of the analyst (Barnthouse et al. 1982a). A value of 0.01 (1.0 E-02) or less indicates little apparent environmental significance; 0.01 to 10 (1.0 E+01) suggests possible or potential adverse effects; and greater than 10 describes a chemical of probable environmental concern. The utility of these screening criteria must be confirmed by further experience in risk analysis and by field studies.

Ammonia (alkaline gases-RAC 5) appears to be the most serious ichthyotoxin in the effluents of all four technologies, with quotients for fish acute toxicity of 0.23 to 0.60 for both effluent treatments. Cadmium (RAC 34) also appears to be a general problem with fish quotients greater than 0.01 for acute toxicity in all technologies. Quotients greater than 0.01 for acute or chronic toxicity appeared in three technologies for aliphatic/alicyclic hydrocarbons (RAC 13) and phenols (RAC 21); in two technologies for mono- or diaromatic hydrocarbons (RAC 14), aldehydes and ketones (RAC 22), and mercury (RAC 32); and in one technology for polycyclic aromatic hydrocarbons (RAC 15) and esters (RAC 26). SRC-II has the most RACs (8) that appear problematical for effects on fish.

Table 3.1-1. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the Exxon Donor Solvent process

RAC No.	RAC name	Treatment[b]	Highest quotient[a] Fish acute 95%	Fish chronic Median	Algae Median	Algae 95%
1	Carbon monoxide		No effluent			
2	Sulfur oxides		No effluent			
3	Nitrogen oxides		No effluent			
4	Acid gases		No effluent			
5	Alkaline gases	1	3.69 E-01	No toxicity data	No toxicity data	
		2	3.69 E-01			
6	Hydrocarbon gases		No effluent			
7	Formaldehyde		No effluent			
8	Volatile organochlorines		No effluent			
9	Volatile carboxylic acids		No effluent			
10	Volatile O & S heterocyclics		No toxicity data			
11	Volatile N-heterocyclics		No toxicity data			
12	Benzene	1	2.23 E-04	No toxicity data	1.01 E-06	2.25 E-06
		2	2.23 E-05		1.01 E-07	2.25 E-07
13	Aliphatic/alicyclic hydrocarbons	1	1.14 E-02	No toxicity data	No toxicity data	
		2	1.14 E-03			
14	Mono- or diaromatic hydrocarbons	1	5.15 E-03	8.52 E-03	1.60 E-04	3.59 E-04
		2	5.15 E-04	8.52 E-04	1.60 E-05	3.59 E-05
15	Polycyclic aromatic hydrocarbons	1	9.60 E-04	No toxicity data	3.84 E-07	7.06 E-07
		2	9.60 E-05		3.84 E-08	7.05 E-08
16	Aliphatic amines		No effuent			
17	Aromatic amines	1	No toxicity data	No toxicity dat.	4.67 E-02	1.05 E-01
		2			4.67 E-03	1.05 E-02
18	Alkaline N heterocyclics		No effluent			
19	Neutral N, O, S heterocyclics		No toxicity data			
20	Carboxylic acids	1	2.05 E-03	No toxicity data	No toxicity data	
		2	2.05 E-04			
21	Phenols	1	5.29 E-03	8.35 E-03	9.15 E-04	2.05 E-03
		2	5.29 E-04	8.35 E-04	9.15 E-05	2.05 E-04
22	Aldehydes and ketones	1	1.29 E-01	1.26 E-01	No toxicity data	
		2	1.20 E-02	1.25 E-02		
23	Nonheterocyclic organosulfur		No toxicity data			
24	Alcohols		No effluent			
25	Nitroaromatics		No effluent			
26	Esters		No effluent			
27	Amides		No effluent			
28	Nitriles	1	2.43 E-03	4.22 E-03	No toxicity data	
		2	2.43 E-04	4.22 E-04		
29	Tars		No effluent			
30	Respirable particles		No effluent			
31	Arsenic	1	1.43 E-06	1.71 E-06	3.68 E-06	8.25 E-06
		2	1.43 E-06	1.71 E-06	3.68 E-06	8.25 E-06
32	Mercury	1	3.84 E-04	1.79 E-02	5.13 E-05	1.15 E-04
		2	3.84 E-04	1.79 E-02	5.13 E-02	1.15 E-04
33	Nickel	1	3.47 E-05	6.53 E-04	7.12 E-04	1.60 E-03
		2	3.47 E-05	6.53 E-04	7.12 E-04	1.60 E-03
34	Cadmium	1	1.73 E-01	4.55 E-02	1.55 E-02	3.46 E-02
		2	1.73 E-01	4.55 E-02	1.55 E-02	3.46 E-02
35	Lead	1	3.05 E-04	4.30 E-03	1.63 E-04	3.66 E-04
		2	3.05 E-04	4.30 E-03	1.63 E-04	3.66 E-04
36	Other trace elements (fluorine)	1	6.97 E-03	6.33 E-05	No toxicity data	
		2	6.97 E-03	6.33 E-05		

[a]The quotients are calculated using the lowest acute LC_{50} or TL_m for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Tables 2.2-3 through 6).

[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.1-2. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the SRC-I process

RAC No.	RAC Name	Treatment[b]	Highest quotient[a] Fish acute 95%	Fish chronic Median	Algae Median	Algae 95%
1	Carbon monoxide		No effluent			
2	Sulfur oxides		No effluent			
3	Nitrogen oxides		No effluent			
4	Acid gases		No effluent			
5	Alkaline gases	1	6.03 E-01	No toxicity data	No toxicity data (nutrient)	
		2	6.03 E-01			
5	Hydrocarbon gases		No effluent			
7	Formaldehyde		No effluent			
8	Volatile organochlorines		No effluent			
9	Volatile carboxylic acids		No effluent			
10	Volatile O & S heterocyclics		No effluent			
11	Volatile N heterocyclics		No effluent			
12	Benzene		No effluent			
13	Alipnatic/alicyclic hydrocarbons	1	1.14 E-02	No toxicity data	No toxicity data	
		2	1.14 E-03			
14	Mono- or diaromatic hydrocarbons	1	2.38 E-03	3.93 E-03	7.39 E-05	1.66 E-04
		2	2.38 E-04	3.93 E-04	7.39 E-06	1.66 E-05
15	Polycyclic aromatic hydrocarbons	1	9.60 E-03	No toxicity data	3.84 E-06	7.06 E-06
		2	9.60 E-04		3.84 E-07	7.06 E-07
16	Alipnatic amines		No effluent			
17	Aromatic amines		No effluent			
18	Alkaline nitrogen heterocyclics		No effluent			
19	Neutral N, O, S heterocyclics		No toxicity data			
20	Carboxylic acids		No effluent			
21	Phenols	1	2.53 E-02	3.99 E-02	4.37 E-03	9.79 E-03
		2	2.53 E-03	3.99 E-03	4.37 E-04	9.79 E-04
22	Aldehydes and ketones		No effluent			
23	Nonheterocyclic organosulfur		No toxicity data			
24	Alcohols		No effluent			
25	Nitroaromatics		No effluent			
26	Esters		No effluent			
27	Amides		No effluent			
28	Nitriles		No effluent			
29	Tars		No effluent			
30	Respirable particles		No effluent			
31	Arsenic	1	2.22 E-06	2.64 E-06	5.70 E-06	1.28 E-05
		2	2.22 E-06	2.64 E-06	5.70 E-06	1.28 E-05
32	Mercury	1	2.18 E-03	1.02 E-01	2.92 E-04	6.55 E-04
		2	2.18 E-03	1.02 E-01	2.92 E-04	6.55 E-04
33	Nickel	1	3.60 E-05	6.77 E-04	7.38 E-04	1.65 E-03
		2	3.60 E-05	6.77 E-04	7.38 E-04	1.65 E-03
34	Cadmium	1	1.50 E-02	3.95 E-03	1.34 E-03	3.01 E-03
		2	1.50 E-02	3.95 E-03	1.34 E-03	3.01 E-03
35	Lead	1	4.26 E-03	6.00 E-02	2.28 E-03	5.11 E-03
		2	4.26 E-03	6.00 E-02	2.28 E-03	5.11 E-03
36	Other trace elements (fluorine)	1	2.43 E-03	2.21 E-05	No toxicity data	
		2	2.43 E-03	2.21 E-05		

[a]The quotients are calculated using the lowest acute LC_{50} or TL_m for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Table 2.2-4).

[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.1-3. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the SRC-II process

RAC No.	RAC name	Treatment[b]	Highest quotient[a] Fish acute 95%	Fish chronic Median	Algae Median	Algae 95%
1	Carbon monoxide		No effluent			
2	Sulfur oxides		No effluent			
3	Nitrogen oxides		No effluent			
4	Acid gases		No effluent			
5	Alkaline gases	1	3.35 E-01	No toxicity data	No toxicity data	
		2	3.35 E-01			
5	Hydrocarbon gases	1	1.57 E-08	No toxicity data	No toxicity data	
		2	1.57 E-09			
7	Formaldehyde	1	1.64 E-04	No toxicity data	No toxicity data	
		2	1.64 E-05			
8	Volatile organochlorines	1	1.60 E-04	1.63 E-03		
		2	1.60 E-05	1.63 E-04		
9	Volatile carboxylic acids	1	7.76 E-06	No toxicity data	No toxicity data	
		2	7.76 E-07			
10	Volatile O & S heterocyclics		No toxicity data			
11	Volatile N heterocyclics		No toxicity data			
12	Benzene	1	6.87 E-04	No toxicity data	3.10 E-06	6.93 E-06
		2	6.87 E-05		3.10 E-07	6.93 E-07
13	Aliphatic/alicyclic	1	3.90 E-05	No toxicity data	No toxicity data	
		2	3.90 E-06			
14	Mono- or diaromatic hydrocarbons	1	1.43 E-02	2.36 E-02	4.43 E-04	9.94 E-04
		2	1.43 E-03	2.36 E-03	4.43 E-05	9.94 E-05
15	Polycyclic aromatic hydrocarbons	1	2.27 E-02	No toxicity data	9.07 E-06	1.67 E-05
		2	2.27 E-03		9.07 E-07	1.67 E-06
16	Aliphatic amines		No toxicity data			
17	Aromatic amines		No toxicity data			
18	Alkaline N heterocyclics		No effluent			
19	Neutral N, O, S heterocyclics		No toxicity data			
20	Carboxylic acids		No effluent			
21	Phenols	1	9.40 E-03	1.48 E-02	1.63 E-03	3.64 E-03
		2	9.40 E-04	1.48 E-03	1.63 E-04	3.64 E-04
22	Aldehydes and ketones		No effluent			
23	Nonheterocyclic organosulfur		No toxicity data			
24	Alcohols		No toxicity data			
25	Nitroaromatics		No toxicity data			
26	Esters	1	4.49 E-03	1.83 E-01	1.33 E-02	2.98 E-02
		2	4.49 E-04	1.83 E-02	1.33 E-03	2.98 E-03
27	Amides		No effluent			
28	Nitriles		No effluent			
29	Tars		No effluent			
30	Respirable particles		No effluent			
31	Arsenic	1	2.43 E-06	2.89 E-06	6.22 E-06	1.39 E-05
		2	2.43 E-06	2.89 E-06	6.22 E-06	1.39 E-05
32	Mercury	1	1.58 E-03	7.09 E-02	2.04 E-04	4.57 E-04
		2	1.58 E-03	7.00 E-02	2.04 E-04	4.57 E-04
33	Nickel	1	8.52 E-06	1.60 E-04	1.75 E-04	3.92 E-04
		2	8.52 E-06	1.60 E-04	1.75 E-04	3.92 E-04
34	Cadmium	1	1.37 E-02	3.59 E-03	1.22 E-03	2.73 E-03
		2	1.37 E-02	3.59 E-03	1.22 E-03	2.73 E-03
35	Lead	1	2.96 E-05	4.17 E-04	1.59 E-05	3.55 E-05
		2	2.96 E-05	4.17 E-04	1.59 E-05	3.55 E-05
36	Other trace elements (fluorine)	1	1.54 E-02	1.40 E-04	No toxicity data	
		2	1.54 E-02	1.40 E-04		

[a]The quotients are calculated using the lowest acute LC_{50} or TL_m for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Table 2.2-5).

[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.1-4. Toxicity quotients for toxicity to fish and algae (ambient contaminant concentration/toxic benchmark concentration) for the H-Coal process

RAC No.	RAC name	Treatment[b]	Highest quotient[a] Fish acute 95%	Fish chronic Median	Algae Median	Algae 95%
1	Carbon monoxide		No effluent			
2	Sulfur oxides		No effluent			
3	Nitrogen oxides		No effluent			
4	Acid gases		No effluent			
5	Alkaline gases	1	3.35 E-01	No toxicity data	No toxicity data	
		2	3.35 E-01			
5	Hydrocarbon gases		No effluent			
7	Formaldehyde	1	4.37 E-04	No toxicity data	No toxicity data	
		2	4.37 E-05			
8	Volatile organochlorines		No effluent			
9	Volatile carboxylic acids		No effluent			
10	Volatile O & S heterocyclics		No toxicity data			
11	Volatile N heterocyclics		No toxicity data			
12	Benzene	1	2.83 E-05	No toxicity data	1.28 E-07	2.86 E-07
		2	2.83 E-06		1.28 E-08	2.86 E-08
13	Aliphatic/alicyclic hydrocarbons	1	1.46 E-02	No toxicity data	No toxicity data	
		2	1.46 E-03			
14	Mono-or diaromatic hydrocarbons	1	6.33 E-03	1.05 E-02	1.97 E-04	4.42 E-04
		2	6.33 E-04	1.05 E-03	1.97 E-05	4.42 E-05
15	Polycyclic aromatic hydrocarbons	1	1.22 E-03	No toxicity data	4.88 E-07	8.99 E-07
		2	1.22 E-04		4.88 E-08	8.99 E-08
16	Aliphatic amines		No effluent			
17	Aromatic amines	1	No toxicity data	No toxicity data	5.69 E-02	1.28 E-01
		2			5.69 E-03	1.28 E-02
18	Alkaline N heterocyclics		No effluent			
19	Neutral N, O, S heterocyclics		No toxicity data			
20	Carboxylic acids	1	2.53 E-03	No toxicity data	No toxicity data	
		2	2.53 E-04			
21	Phenols	1	2.70 E-02	4.27 E-02	4.67 E-03	1.05 E-02
		2	2.70 E-03	4.27 E-03	4.67 E-04	1.05 E-03
22	Aldehydes and ketones	1	1.58 E-01	1.55 E-01	No toxicity data	
		2	1.58 E-02	1.55 E-02		
23	Nonheterocyclic organosulfur		No toxicity data			
24	Alcohols		No effluent			
25	Nitroaromatics		No effluent			
26	Esters		No effluent			
27	Amides		No effluent			
28	Nitriles	1	3.05 E-03	5.31 E-03	No toxicity data	
		2	3.05 E-04	5.31 E-04		
29	Tars		No effluent			
30	Respirable particles		No effluent			
31	Arsenic	1	2.84 E-06	3.38 E-06	7.28 E-06	1.63 E-05
		2	2.84 E-06	3.38 E-06	7.28 E-06	1.63 E-05
32	Mercury	1	9.49 E-05	4.42 E-03	1.27 E-05	2.85 E-05
		2	9.49 E-05	4.42 E-03	1.27 E-05	2.85 E-05
33	Nickel	1	5.67 E-05	1.07 E-03	1.16 E-03	2.61 E-03
		2	5.67 E-05	1.07 E-03	1.16 E-03	2.61 E-03
34	Cadmium	1	8.94 E-02	2.35 E-02	7.98 E-03	1.79 E-02
		2	8.94 E-02	2.35 E-02	7.98 E-03	2.79 E-02
35	Lead	1	6.66 E-04	9.38 E-03	3.56 E-04	7.99 E-04
		2	6.66 E-04	9.38 E-03	3.56 E-04	7.99 E-04
36	Other trace elements (fluorine)	1	7.00 E-04	6.35 E-06	No toxicity data	
		2	7.00 E-04	6.35 E-06		

[a]The quotients are calculated using the lowest acute LC_{50} or TL_m for fish in each RAC (Table A-1), the lowest chronic response by a fish (Table A-2), and the lowest algal response (Table A-3) with either the median or upper 95th percentile of the predicted ambient contaminant concentration (Table 2.2-6).

[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Fewer RACs appear to be important for algal toxicity due to both the shortage of algal toxicity data and the relative insensitivity of algae to several tested RACs. Aromatic amines (RAC 17) may be toxic in EDS and H-Coal effluents, with quotients greater than 0.1 for acute exposures and 0.01 for chronic exposures. Cadmium may also be toxic in EDS and H-Coal effluents, and phenols (RAC 21) and esters (RAC 26) may be toxic in effluents from H-Coal and SRC-II, respectively.

Barnthouse et al. (1982a) discussed the uncertainties involved in applying the quotient method to environmental data. One of the major inherent problems is that of comparing results from dissimilar tests. Although an attempt was made in this analysis to avoid such pitfalls by comparing, when possible, the same test species and benchmarks, uncontrolled variables inevitably remain. For example, in tests with certain metals (RACs 33, 34, and 35), water hardness is important in determining the concentrations of these metals required to elicit a toxic response (Table 3.1-1), a fact reflected in the EPA criteria for each. Usually the data are insufficient to compare quotients from tests using the same organisms in both "soft" and "hard" water. Also, in some instances, the analyst must compare quotients derived from tests using water of unspecified or inconsistent quality.

This exercise with the quotient method, in addition to suggesting which of the assigned RACs pose the greatest potential environmental threat, emphasizes the lack of toxicological research on algae as important components of the ecosystem and on synfuels-related organic compounds in general. Despite obvious weaknesses, the method does provide a useful means of screening data from a variety of sources.

3.2 ANALYSIS OF EXTRAPOLATION ERROR

This method of risk analysis is based on the fact that application of the results of laboratory toxicity tests to field exposures requires a series of extrapolations, each of which is made with some error (Barnthouse et al. 1982a; Suter et al. 1983). The products of the extrapolation are estimates of the centroid and distribution of the ambient concentration of a chemical at which a particular response will occur. The risk of occurrence of the prescribed response is equal to

the probability that the response concentration is less than the ambient concentration, given the probability distribution of each. In this section, we extrapolate from acute toxic concentrations for test species of fish to chronic responses of the reference commercial and game species characteristic of the eastern and western reference sites (Travis et al. 1983). The acute toxicity criterion is the 96-h LC_{50}. The chronic toxicity criterion is the life-cycle maximum allowable toxicant concentration (MATC), an interval bounded by the highest no-observed-effects concentration and the lowest concentration causing a statistically significant effect on growth, survival, or reproduction in a life-cycle toxicity test (Mount and Stephan 1969). The geometric mean of the bounds (GMATC) is used as a point estimate of the MATC, as was done in calculating the national water quality criteria (USEPA 1980a-p).

3.2.1 Methods

A detailed description of the computational methods used for the analysis of extrapolation error (AEE) is contained in Suter et al. (1983). Acute toxicity data from the Columbia National Fisheries Research Laboratory (Johnson and Finley 1980) are used for the extrapolation between species. Life-cycle toxicity data (Suter et al., 1983) were used to develop a regression relationship between acute and chronic toxicity data. Variances associated with extrapolating acute toxicity between taxa and acute to chronic toxicity are accumulated to provide an estimate of the variability associated with the estimate of chronic toxicity and used in obtaining estimates of risk, given estimates of the distribution of the ambient contaminant concentrations.

All of the emitted RACs for which 96-h LC_{50}'s could be found (Table A-1) have been analyzed by the extrapolation error method. The quotient of the ratio of the ambient concentration of an RAC to its predicted GMATC (PGMATC) is presented as an estimate of the hazard of chronic toxicity. Risk, which is defined as the probability that the ambient contaminant concentration exceeds the GMATC, is also presented. Both the hazard and risk estimates are based on the annual average ambient concentrations (Tables 2.2-3 through 6).

In general, the extrapolation between species was done using the regression relationship between the tested and assessed fish at the same taxonomic level and having in common the next higher level. For example, if the fish are in the same family but different genera, the extrapolation would be made between genera. There were three instances when our hierarchical approach failed because of the limitation in the acute toxicity data for the contaminant. The only acute toxicity datum available for hydrogen sulfide (RAC 4) and for fluoranthene (RAC 15) was for bluegill sunfish (Lepomis macrochirus); and the only acute toxicity datum available for indan (RAC 13) and for quinoline (RAC 18) was for fathead minnow (Pimephales promelas). Difficulties also arose with RAC 15 for estimating the acute toxicity of white bass (Morone chrysops) and with RAC 13 for estimating the acute toxicity of bigmouth and smallmouth buffalo (Ictiobus cyprinellus and I. bubalus). The problem arose because no fish in the family Percichthyidaea or in the genus Ictiobus were tested at the Columbia National Fisheries Research Laboratory. The genus Ictiobus is in the family Catostomidae, members of which were tested at the Columbia National Fisheries Research Laboratory, but the Cyprinidae-Catostomidae relationship had insufficient sample size (n = 1). Hence, further statistical relationships were developed comparing bluegill sunfish with all Perciformes other than bluegills (R^2 = 0.91) and fathead minnow with all Cypriniformes other than fathead minnow (R^2 = 0.92).

3.2.2 Results

The species-specific values of the predicted GMATCs, quotients, and the risks of exceeding the GMATC for the annual median ambient contaminant concentrations are presented in Appendix D. These species-specific values are only presented for those RACs with a hazard greater than or equal to 0.01. They are summarized in Tables 3.2-1 through 3.2-4 for the four technologies. Ammonia (RAC 5) appears to present the most consistent threat of chronic toxicity to fish, with quotients and risks greater than 0.1 for all species, technologies, and water treatments. For SRC-I, the predicted GMATC for ammonia slightly exceeds the ambient median concentration for five out of nine fish

Table 3.2-1. Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for Exxon Donor Solvent[a]

RAC	Ambient concentration/PGMATC		Probability of exceeding the PGMATC	
	treatment1[b]	treatment2	treatment1	treatment2
1	No effluent			
2	No effluent			
3	No effluent			
4	No effluent			
5	0.2572-0.6205	0.2572-0.6205	0.2616-0.4039	0.2616-0.4039
6	No effluent			
7	No effluent			
8	No effluent			
9	No effluent			
10	No fish toxicity data			
11	No fish toxicity data			
12	0.0013-0.0046	0.0001-0.0005	0.0003-0.0072	0.0000-0.0003
13	0.2786-1.0832	0.0279-0.1083	0.2530-0.5145	0.0312-0.1557
14	0.0362-0.0813	0.0036-0.0081	0.0497-0.1063	0.0021-0.0121
15	0.0001-0.0010	0.0000-0.0001	0.0000-0.0008	0.0000-0.0000
16	No effluent			
17	No fish toxicity data			
18	No effluent			
19	No fish toxicity data			
20	0.0034-0.1147	0.0003-0.0115	0.0047-0.3107	0.0001-0.1540
21	0.0396-0.3539	0.0040-0.0354	0.0478-0.3230	0.0020-0.0698
22	0.2082-1.1049	0.0208-0.1105	0.2241-0.5182	0.0225-0.1561
23	No fish toxicity data			
24	No effluent			
25	No effluent			
26	No effluent			
27	No effluent			
28	0.0282-0.2706	0.0028-0.0271	0.0449-0.2805	0.0013-0.0542
29	No effluent			
30	No effluent			
31	0 0000-0.0001	0.0000-0.0001	0.0000-0.0000	0.0000-0.0000
32	0.0001-0.0003	0.0001-0.0003	0.0000-0.0001	0.0000-0.0001
32A	0.0004-0.0009	0.0004-0.0009	0.0001-0.0003	0.0001-0.0003
33	0.0001-0.0027	0.0001-0.0027	0.0000-0.0040	0.0000-0.0040
34	0.0010-0.1468	0.0010-0.1468	0.0000-0.1692	0.0000-0.1692
35	0.0002-0.0015	0.0002-0.0015	0.0000-0.0017	0.0000-0.0017

[a]Species-specific values are provided in Appendix D.
[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-2. Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for SRC-I[a]

RAC	Ambient concentration/PGMATC		Probability of exceeding the PGMATC	
	treatment1[b]	treatment2	treatment1	treatment2
1	No effluent			
2	No effluent			
3	No effluent			
4	No effluent			
5	0.420-1.02	0.420-1.02	0.342-0.5031	0.342-0.5031
6	No effluent			
7	No effluent			
8	No effluent			
9	No effluent			
10	No effluent			
11	No effluent			
12	No effluent			
13	0.2786-1.0832	0.0279-0.1083	0.2530-0.5145	0.0312-0.1557
14	0.0167-0.0375	0.0017-0.0038	0.0199-0.0565	0.0005-0.0048
15	0.0011-0.0095	0.0001-0.0010	0.0002-0.0171	0.0000-0.0008
16	No effluent			
17	No effluent			
18	No effluent			
19	No fish toxicity data			
20	No effluent			
21	0.1890-1.6908	0.0189-0.1691	0.1951-0.5918	0.0203-0.2150
22	No effluent			
23	No fish toxicity data			
24	No effluent			
25	No effluent			
26	No effluent			
27	No effluent			
28	No effluent			
29	No effluent			
30	No effluent			
31	0.0000-0.0002	0.0000-0.0002	0.0000-0.0001	0.0000-0.0001
32	0.0007-0.0017	0.0007-0.0017	0.0003-0.0010	0.0003-0.0010
32A	0.0020-0.0052	0.0020-0.0052	0.0017-0.0038	0.0017-0.0038
33	0.0001-0.0028	0.0001-0.0028	0.0000-0.0042	0.0000-0.0042
34	0.0001-0.0128	0.0001-0.0128	0.0000-0.0147	0.0000-0.0147
35	0.0028-0.0212	0.0028-0.0212	0.0005-0.0380	0.0005-0.0380

[a]Species-specific values are provided in Appendix D.
[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-3. Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for SRC-II[a]

RAC	Ambient concentration/PGMATC		Probability of exceeding the PGMATC	
	treatment1[b]	treatment2	treatment1	treatment2
1	No effluent			
2	No effluent			
3	No effluent			
4	No effluent			
5	0.2334-0.5639	0.2334-0.5639	0.2472-0.3851	0.2472-0.3851
6	0.0000-0.0000	0.0000-0.0000	0.0000-0.0073	0.0000-0.0020
7	No fish toxicity data			
8	0.0016-0.0177	0.0002-0.0018	0.0004-0.0402	0.0000-0.0030
9	0.0000-0.0003	0.0000-0.00000	0.0000-0.0000	0.0000-0.0000
10	No fish toxicity data			
11	No fish toxicity data			
12	0.0039-0.0140	0.0004-0.0014	0.003-0.0251	0.0000-0.0015
13	0.0010-0.0037	0.0001-0.0004	0.0001-0.0054	0.0000-0.0002
14	0.1002-0.2251	0.0100-0.0225	0.1335-0.2242	0.0100-0.0353
15	0.0026-0.0225	0.0003-0.0022	0.0011-0.0421	0.0000-0.0028
16	No effluent			
17	No fish toxicity data			
18	No effluent			
19	No fish toxicity data			
20	No effluent			
21	0.0704-0.6293	0.0070-0.0629	0.0856-0.4189	0.0053-0.1107
22	No effluent			
23	No fish toxicity data			
24	No fish toxicity data			
25	No fish toxicity data			
26	0.0051-0.1813	0.0005-0.0181	0.0070-0.2178	0.0002-0.0336
27	No effluent			
28	No effluent			
29	No effluent			
30	No effluent			
31	0.0000-0.0002	0.0000-0.0002	0.0000-0.0001	0.0000-0.0001
32	0.0005-0.0012	0.0005-0.0012	0.0002-0.0006	0.0002-0.0006
32A	0.0014-0.0036	0.0014-0.0036	0.0010-0.0022	0.0010-0.0022
33	0.0000-0.0007	0.0000-0.0007	0.0000-0.0005	0.0000-0.0005
34	0.0001-0.0116	0.0001-0.0116	0.0000-0.0131	0.0000-0.0131
35	0.0000-0.0001	0.0000-0.0001	0.0000-0.0000	0.0000-0.0000

[a]Species-specific values are provided in Appendix D.
[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-4. Ranges of ratios of ambient concentrations to PGMATCs and probabilities of exceeding the PGMATC for H-Coal[a]

RAC	Ambient concentration/PGMATC		Probability of exceeding the PGMATC	
	treatment1[b]	treatment2	treatment1	treatment2
1	No effluent			
2	No effluent			
3	No effluent			
4	No effluent			
5	0.2338-0.05639	0.2338-0.5639	0.2472-0.3851	0.2472-0.3851
6	No effluent			
7	No fish toxicity data			
8	No effluent			
9	No effluent			
10	No fish toxicity data			
11	No fish toxicity data			
12	0.0002-0.0006	0.0000-0.0001	0.0000-0.0004	0.0000-0.0000
13	0.3582-1.3927	0.0358-0.1393	0.2966-0.5599	0.0416-0.1847
14	0.0445-0.1001	0.0045-0.0100	0.0620-0.1239	0.0030-0.0152
15	0.0001-0.0012	0.0000-0.0001	0.0000-0.0011	0.0000-0.0000
16	No effluent			
17	No fish toxicity data			
18	No effluent			
19	No fish toxicity data			
20	0.0042-0.1416	0.0004-0.0142	0.0063-0.3278	0.0002-0.1657
21	0.2022-1.8089	0.0202-0.1809	0.2048-0.6034	0.0221-0.2248
22	0.2563-1.3601	0.0256-0.1360	0.2592-0.5561	0.0292-0.1800
23	No fish toxicity data			
24	No effluent			
25	No effluent			
26	No effluent			
27	No effluent			
28	0.0355-0.3407	0.0036-0.0341	0.0586-0.3160	0.0021-0.0664
29	No effluent			
30	No effluent			
31	0.0000-0.0003	0.0000-0.0003	0.0000-0.0001	0.0000-0.0001
32	0.0000-0.0001	0.0000-0.0001	0.0000-0.0000	0.0000-0.0000
32A	0.0001-0.0002	0.0001-0.0002	0.0000-0.0000	0.0000-0.0000
33	0.0001-0.0044	0.0001-0.0044	0.0000-0.0075	0.0000-0.0075
34	0.0005-0.0758	0.0005-0.0758	0.0000-0.0990	0.0000-0.0990
35	0.0004-0.0033	0.0004-0.0033	0.0000-0.0048	0.0000-0.0048

[a]Species-specific values are provided in Appendix D.
[b]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

species so the risk is greater than 0.5. Four organic RACs, aliphatic/alicyclic hydrocarbons (RAC 13), mono- or diaromatic hydrocarbons (RAC 14), phenols (RAC 21), and aldehydes and ketones (RAC 22), have high quotients and risks for treatment 1 for at least 2 of the technologies. However, use of treatment 2 reduces the concentration of all of these RACs by an order of magnitude so that only RACs 13, 21, and 22 have hazards exceeding 0.1 and none exceed 1. The only other RAC with hazard or risk values exceeding 0.1 for both treatments is cadmium (RAC 34) for EDS. The only other RACs with hazard or risk values greater than 0.1 for any combination of species, technology, and treatment are carboxylic acids (RAC 20) for EDS and H-Coal, esters (RAC 26) for SRC-II, and nitriles (RAC 28) for EDS and H-Coal.

The differences in the relative rankings between species is attributable to variation in three factors: (1) the magnitudes of the LC_{50}'s of different species tested for a particular chemical, (2) differences in sensitivity of the site species expressed as biases in the extrapolation between the test species and site species, and (3) the variance associated with the extrapolation.

3.2.3 Toxicity of the Whole Effluent

Tables 3.2-5 to 3.2-8 present a consideration of the acute toxicity of the whole effluent. Only acute toxicity is considered because there is no accepted theory for modeling addition of effects expressed as toxic thresholds such as GMATCs. The acute effects are expressed in a common unit, the 96-h LC_{50} to largemouth bass, which is generated by taxonomic extrapolation from LC_{50} data for a variety of species (Appendix A) using the method of Suter et al. (1983).

The possible modes of joint action of chemicals are synergism, concentration addition, independent action (response addition), and antagonism (Muska and Weber 1977). Concentration addition is generally accepted to be the best general model for combined effects of mixed chemicals on fish (Alabaster and Lloyd 1982; EIFAC 1980; SGOMSEC, in press). In a recent review, Lloyd (in press) stated "There is no evidence for synergism (i.e., more-than-additive action) between the

Table 3.2-5. Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for Exxon Donor Solvent

RAC	LC_{50} (µg/L)	Concentration/LC_{50}	
		Treatment 1[a]	Treatment 2
1	No toxicity data		
2	No toxicity data		
3	No toxicity data		
4	36.3	No effluent	
5	444	5.64 E-02	5.64 E-02
6	5,716,048	No effluent	
7	No toxicity data		
8	52,048	No effluent	
9	10,511	No effluent	
10	No toxicity data		
11	No toxicity data		
12	4,815	2.46 E-04	2.46 E-05
13	2,324	6.85 E-02	6.85 E-03
14	2,296	5.16 E-03	5.16 E-04
15	3,310	1.16 E-05	1.16 E-06
16	No toxicity data		
17	No toxicity data		
18	6,171	No effluent	
19	No toxicity data		
20	184,876	1.99 E-03	1.99 E-04
21	14,282	2.87 E-03	2.87 E-04
22	160	3.70 E-02	3.70 E-03
23	No toxicity data		
24	No toxicity data		
25	No toxicity data		
26	601	No effluent	
27	No toxicity data		
28	9,437	2.60 E-03	2.60 E-04
29	No toxicity data		
30	No toxicity data		
31	22,236	8.61 E-07	8.61 E-07
32	321	2.87 E-05	2.87 E-05
32A	74.6	1.23 E-04	1.23 E-04
33	4,496	3.55 E-05	3.55 E-05
34	1,696	1.02 E-04	1.02 E-04
35	20,865	8.78 E-06	8.78 E-06
Total		1.75 E-01	6.85 E-02

[a]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-6. Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for SRC-I

RAC	LC_{50} (µg/L)	Concentration/LC_{50}	
		Treatment 1[a]	Treatment 2
1	No toxicity data		
2	No toxicity data		
3	No toxicity data		
4	36.3	No effluent	
5	444	9.23 E-02	9.23 E-02
6	5,716,048	No effluent	
7	No toxicity data		
8	52,048	No effluent	
9	10,511	No effluent	
10	No toxicity data		
11	No toxicity data		
12	4,815	No effluent	
13	2,324	6.85 E-02	6.85 E-03
14	2,296	2.38 E-03	2.38 E-04
15	3,310	1.16 E-04	1.16 E-05
16	No toxicity data		
17	No toxicity data		
18	6,171	No effluent	
19	No toxicity data		
20	184,876	No effluent	
21	14,282	1.37 E-02	1.37 E-03
22	160	No effluent	
23	No toxicity data		
24	No toxicity data		
25	No toxicity data		
26	601	No effluent	
27	No toxicity data		
28	9,437	No effluent	
29	No toxicity data		
30	No toxicity data		
31	22,236	1.33 E-06	1.33 E-06
32	321	1.63 E-04	1.63 E-04
32A	74.6	7.02 E-04	7.02 E-04
33	4,496	3.68 E-05	3.68 E-05
34	1,696	8.87 E-06	8.87 E-06
35	20,865	1.22 E-04	1.22 E-04
Total		1.78 E-01	1.02 E-01

[a]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-7. Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for SRC-II

RAC	LC_{50} (μg/L)	Concentration/LC_{50}	
		Treatment 1[a]	Treatment 2
1	No toxicity data		
2	No toxicity data		
3	No toxicity data		
4	36.3	No effluent	
5	444	5.13 E-02	5.13 E-02
6	5,716,048	1.36 E-08	1.36 E-09
7	No toxicity data		
8	52,048	8.40 E-05	8.40 E-06
9	10,511	6.50 E-05	6.50 E-06
10	No toxicity data		
11	No toxicity data		
12	4,815	7.56 E-04	7.56 E-05
13	2,324	2.35 E-04	2.35 E-05
14	2,296	1.43 E-02	1.43 E-03
15	3,310	2.74 E-04	2.74 E-05
16	No toxicity data		
17	No toxicity data		
18	6,171	No effluent	
19	No toxicity data		
20	184,876	No effluent	
21	14,282	5.10 E-03	5.10 E-04
22	160	No effluent	
23	No toxicity data		
24	No toxicity data		
25	No toxicity data		
26	601	5.45 E-03	5.45 E-04
27	No toxicity data		
28	9,437	No effluent	
29	No toxicity data		
30	No toxicity data		
31	22,236	1.45 E-06	1.45 E-06
32	321	1.14 E-04	1.14 E-04
32A	74.6	4.90 E-04	4.90 E-04
33	4,496	8.72 E-06	8.72 E-06
34	1,696	8.06 E-06	8.06 E-06
35	20,865	8.52 E-07	8.52 E-07
Total		7.82 E-02	5.45 E-02

[a]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

Table 3.2-8. Estimated acute LC_{50} for largemouth bass and ratio of upper 95th percentile of the ambient concentration to the LC_{50} for H-Coal

RAC	LC_{50} (µg/L)	Concentration/LC_{50}	
		Treatment 1[a]	Treatment 2
1	No toxicity data		
2	No toxicity data		
3	No toxicity data		
4	36.3	No effluent	
5	444	5.13 E-02	5.13 E-02
6	5,716,048	No effluent	
7	No toxicity data		
8	52,048	No effluent	
9	10,511	No effluent	
10	No toxicity data		
11	No toxicity data		
12	4,815	3.12 E-05	3.12 E-06
13	2,324	8.81 E-02	8.81 E-03
14	2,296	6.35 E-03	6.35 E-04
15	3,310	1.48 E-05	1.48 E-06
16	No toxicity data		
17	No toxicity data		
18	6,171	No effluent	
19	No toxicity data		
20	184,876	2.46 E-03	2.46 E-04
21	14,282	1.47 E-02	1.47 E-03
22	160	4.55 E-02	4.55 E-03
23	No toxicity data		
24	No toxicity data		
25	No toxicity data		
26	601	No effluent	
27	No toxicity data		
28	9,437	3.28 E-03	3.28 E-04
29	No toxicity data		
30	No toxicity data		
31	22,236	1.70 E-06	1.70 E-06
32	321	7.10 E-06	7.10 E-06
32A	74.6	3.05 E-05	3.05 E-05
33	4,496	5.80 E-05	5.80 E-05
34	1,696	5.27 E-05	5.27 E-05
35	20,865	1.91 E-05	1.91 E-05
Total		2.12 E-01	6.75 E-02

[a]The alternate effluent treatments are: (1) steam stripping/ammonia recovery, phenol extraction, and biological oxidation; and (2) treatment 1 plus carbon adsorption.

common pollutants; at toxic concentrations the joint action is additive and at concentrations below those considered 'safe' there is circumstantial evidence for less-than-additive joint action." Furthermore, Parkhurst et al. (1981) found that when ammonia speciation was accounted for, the toxicity of the major components of synfuels effluents was concentration additive. Therefore, we use the concentration addition model to examine the potential toxicity of the combined RACs.

The analysis was performed by calculating the total toxic units (ΣTU) of the effluent, where a toxic unit is the concentration of a toxiciant divided by the threshold LC_{50} (Sprague and Ramsey 1965). We used the upper 95th percentile of the predicted ambient concentration since the concern in this case is with acute lethality, and we use the 96-h LC_{50} as a reasonable approximation of the threshold LC_{50} (Ruesink and Smith 1975). The ΣTU values for the eight combinations of liquefaction technologies and effluent treatment ranged from 0.0545 to 0.212. The highest value is for treatment 1 of H-Coal effluent and is primarily due to the summation of RACs 5, 13, 21, and 22 (alkaline gases, aliphatic/alicyclic hydrocarbons, phenols, and aldehydes and ketones). While these values do not suggest that acute lethality of post-larval fish would be caused by these effluents, they indicate that the toxicity of the total effluent could be considerably higher than that of any one RAC and suggest that sublethal effects or mortality of sensitive life stages due to direct liquefaction effluents may be a problem.

These results can be compared with results of tests for Daphnia acute lethality in diluted SRC and H-Coal effluent treated in bench-scale facilities (Bostick et al. 1982). The Daphnia magna 48-h LC_{50} for steam-stripped and bio-oxidized SRC effluent (equivalent to treatment 1 but without phenol extraction) was 2.4% effluent and for effluent additionally ozonated and carbon filtered (treatment 2 only adds carbon filtration) was 4.7% effluent. The D. magna LC_{50} for steam-stripped and solvent-extracted H-Coal effluent (only roughly equivalent to treatment 1) was 4.4% effluent and with additional ozonation and carbon filtration was 3.2% effluent (ozonation increased

the toxicity). For comparison, our model generates an exposure in the first river reach equivalent to 0.4% effluent. Thus our predicted exposure is approximately an order of magnitude lower than the acute toxic concentration to Daphnia of bench-treated effluent. This result is consistent with the ΣTU values shown in Tables 3.2-5 to 3.2-8 which are approximately one-tenth of those for a largemouth bass LC_{50}.

3.3 ECOSYSTEM UNCERTAINTY ANALYSIS

3.3.1 Explanation of Method

Ecosystem Uncertainty Analysis (EUA) estimates the risk associated with both direct and indirect effects of toxicants. It considers data on a variety of test organisms rather than emphasizing a single taxonomic group. By integrating effects across trophic levels, EUA considers components of environmental risk not included in other methods.

The method uses the Standard Water Column Model, SWACOM (O'Neill and Giddings 1979; O'Neill et al. 1982). SWACOM is an adaptation of an earlier model, CLEAN (Park et al. 1974), and considers 10 phytoplankton, 5 zooplankton, 3 forage fish, and a game fish population. The model simulates the annual cycle of a lake and incorporates temperature, light, and nutrient responses. Changes can be made to tailor SWACOM for toxicological assessments in a variety of aquatic ecosystems. The model is designed to simulate a generalized water column and sacrifices site specificity to emphasize complex interactions and indirect effects.

Available toxicity data are primarily in the form of mortalities. Therefore, assumptions about the mode of action of the toxicant are required to determine appropriate changes in model parameters. We assumed that organisms respond to all chemicals according to a general stress syndrome (GSS). That is, they increase respiration rates, decrease photosynthetic and grazing rates, become more susceptible to predation, etc. This assumption permits us to define percent changes in model parameters that cause the same mortality as that measured in the laboratory. This extrapolation of laboratory data involves considerable uncertainty. In our analysis, the uncertainties are

preserved by associating each parameter change with a probability distribution. In calculating risk, parameter values are selected from the distributions and a simulation is performed with SWACOM. The process is repeated 500 times. The risk associated with an undesirable effect, such as a significant reduction in game fish, is estimated by the frequency of simulations that showed this effect. Further details of the method are given in Appendix E and in O'Neill et al. (1982).

The data used for the EUA are shown in Table 3.3-1. Estimates of risk can be made for nine RAC. These RACs were the only chemical groups for which adequate data exist.

3.3.2 Results of Ecosystem Uncertainty Analysis

Results of the risk analysis for the direct liquefaction technologies are shown in Fig. 3.3-1 to 3.3-4 and determininstic results are shown in Table 3.3-2. None of the technologies produces measureable amounts of quinoline (RAC 18), and this risk assessment unit will not be considered in the analysis. Environmental concentrations of benzene (RAC 12), arsenic (RAC 31), and nickel (RAC 33) were very low and did not result in significant risks. Therefore, results for these three chemicals are not shown on the graphs.

Two endpoints were considered: a quadrupling of the peak biomass of noxious blue-green algae and a 25% decrease in game fish biomass. These endpoints were chosen as indicative of minimal effects that could be noticed in the field. Risk values were calculated for these endpoints across a range of environmental concentrations that encompass the 5th to 95th percentile exposures. The range of exposures for each technology is shown at the bottom of the figures.

The lines on the graph do not pass through the origin because there is a risk of an increase in algae (0.086) or a decrease in fish biomass (0.038), even as the environmental concentrations of the toxicants approach zero. This reflects residual uncertainty in simulating ecosystem effects. For example, there is always some probability of a small decrease in fish biomass due to natural variability.

Results for naphthalene, phenol, mercury, and lead show a similar pattern. In all of these cases, there is an upturn in the risk curves,

Table 3.3-1. Values[a] of LC_{50}/EC_{50} (mg/L) used to calculate E matrix for SWACOM

Trophic Level	Model species	Ammonia	Benzene	Naphthalene	Quinoline	Phenol	Arsenic	Nickel	Cadmium	Lead	Mercury
Algae	1-3	420.0	525.0	33.0	25.0	258.0	2.32	0.50	0.16	0.50	0.01
	4-7	420.0	525.0	33.0	25.0	20.0	2.32	0.50	0.06	0.50	0.01
	8-10	420.0	525.0	33.0	117.0	95.0	2.32	0.50	0.06	0.50	0.01
Zooplankton	11	8.0	450.0	8.6	57.2	300.0	4.47	9.67	0.5	40.8	0.78
	12	8.0	380.0	8.6	28.5	36.4	5.28	0.85	0.0099	0.45	0.005
	13	8.0	300.0	6.5	48.2	58.1	1.35	1.93	0.14	27.4	0.53
	14	8.0	233.8	4.5	39.3	157.0	2.49	4.91	0.25	14.0	0.27
	15	8.0	17.6	2.5	30.3	14.0	0.51	0.15	0.0035	0.67	0.01
Forage fish	16	1.1	33.0	6.6	1.5	36.0	15.6	4.87	0.63	4.61	0.15
	17	8.2	22.0	78.3	1.5	16.4	41.8	5.27	1.94	23.8	0.24
	18	23.7	34.0	150.0	1.5	34.9	26.0	4.45	1.63	31.5	0.50
Game fish	19	0.41	5.3	2.3	11.0	9.0	13.3	0.05	0.002	1.17	0.25

[a]Values taken from following documents: ammonia - Hohreiter (1980); benzene - USEPA (1980c); naphthalene - USEPA (1980e); quinoline - O'Neill et al. (1982); phenol - USEPA (1980g); arsenic - USEPA (1980l); nickel - USEPA (1980n); cadmium - USEPA (1980o); lead - USEPA (1980p); and mercury - USEPA (1980m).

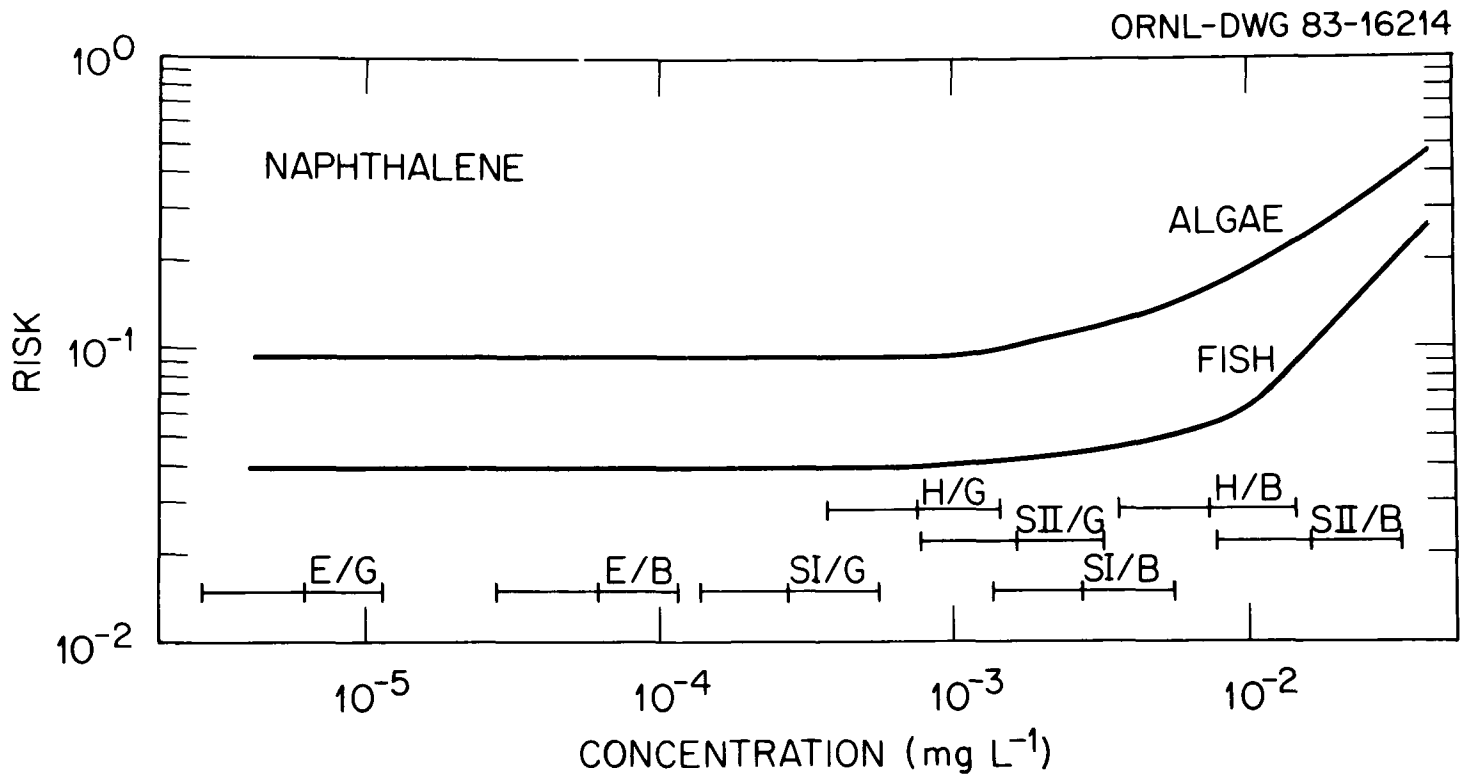


Fig. 3.3-1. Risk estimates for naphthalene (RAC 14) over a range of environmental concentrations. The 5th percentile, mean, and 95th percentile concentrations associated with the Exxon (E), H-Coal (H), SRC-I (SI), and SRC-II (SII) technologies are shown at the bottom of the graph. The notation /B and /G refer to the biologic and GAC methods (treatment options 1 and 2) for each technology. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

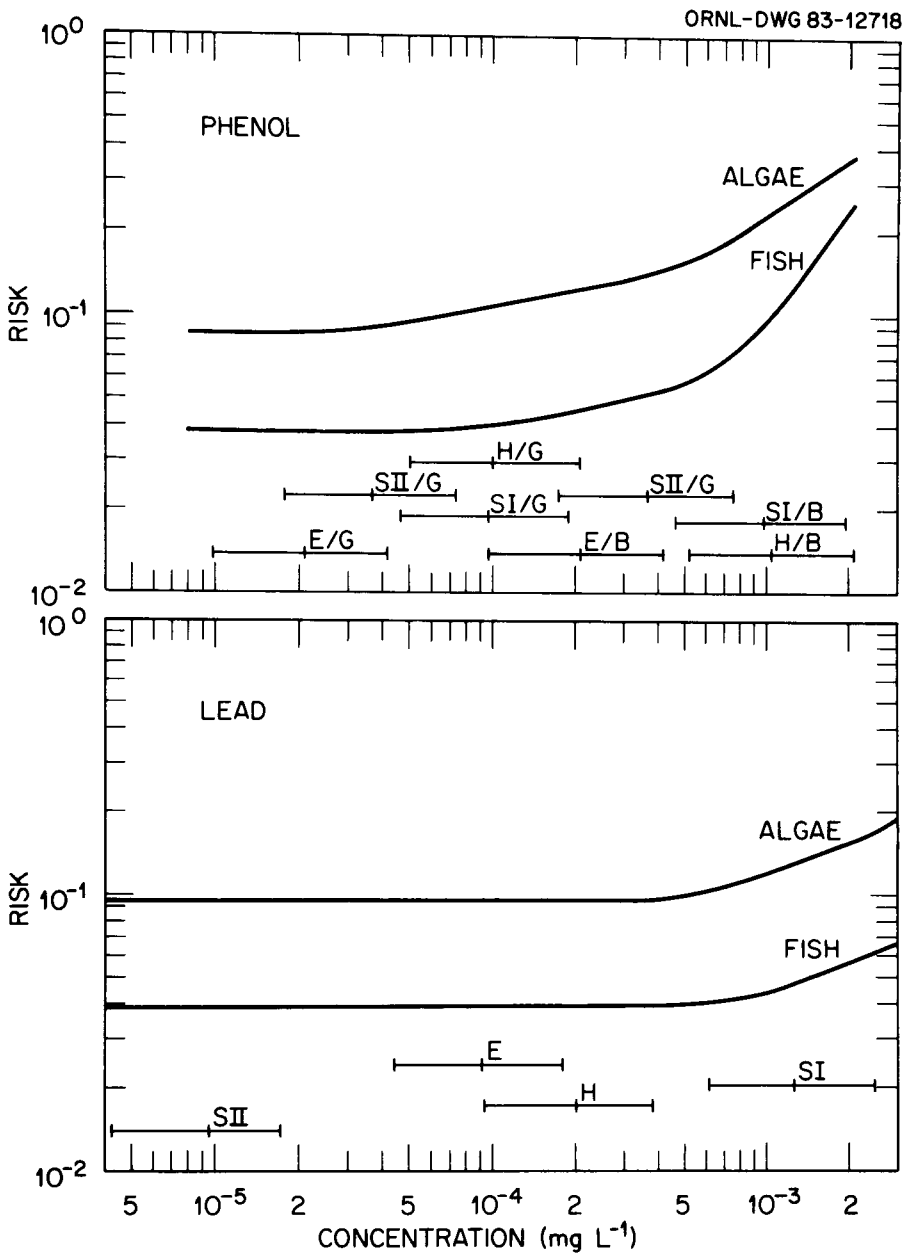


Fig. 3.3-2. Risk estimates for phenol (RAC 21) and lead (RAC 35) over a range of environmental concentrations. The 5th percentile, mean, and 95th percentile concentrations associated with the Exxon (E), H-Coal (H), SRC-I (SI), and SRC-II (SII) technologies are shown at the bottom of the graph. The notation /B and /G refer to the biologic and GAC methods (treatment options 1 and 2) for each technology. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

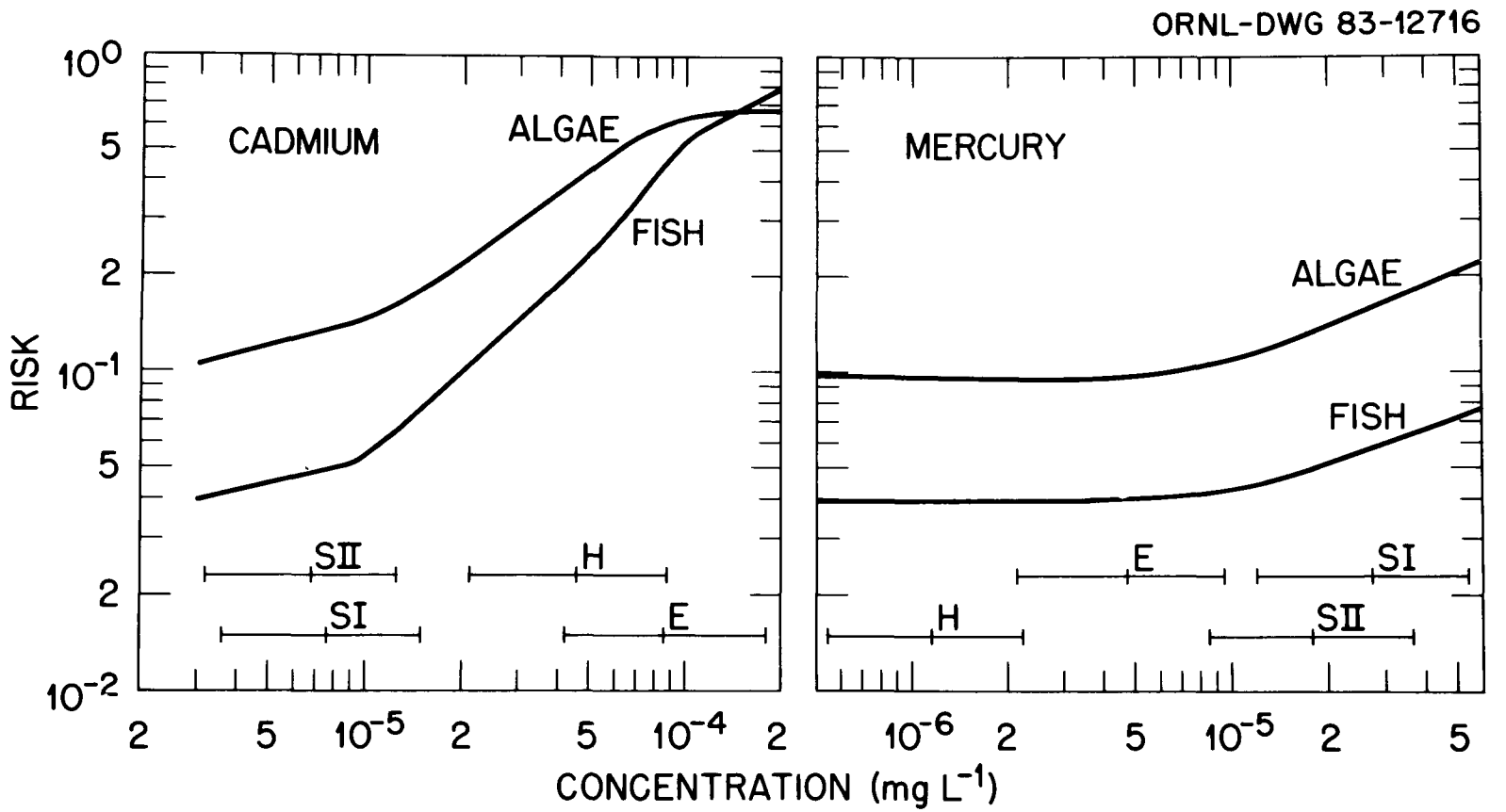


Fig. 3.3-3. Risk estimates for cadmium (RAC 34) and mercury (RAC 32) over a range of environmental concentrations. The 5th percentile, mean, and 95th percentile concentrations associated with the Exxon (E), H-Coal (H), SRC-I (SI), and SRC-II (SII) technologies are shown at the bottom of the graph. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

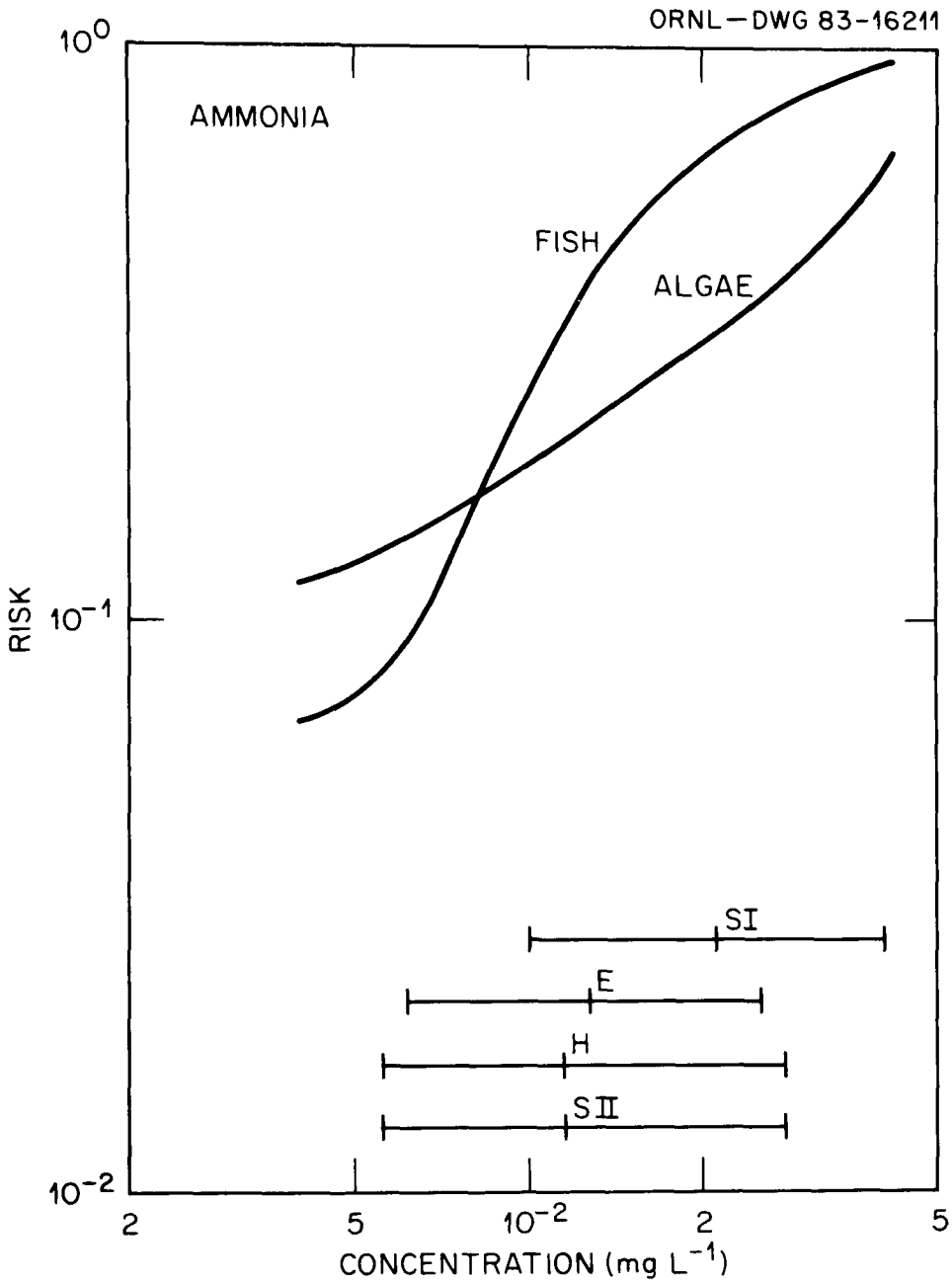


Fig. 3.3-4. Risk estimates for ammonia (RAC 5) over a range of environmental concentrations. The 5th percentile, mean, and 95th percentile concentrations associated with the Exxon (E), H-Coal (H), SRC-I (SI), and SRC-II (SII) technologies are shown at the bottom of the graph. The plotted values are the probability of a quadrupling of the blue-green algal bloom and a 25% reduction in game fish biomass.

Table 3.3-2. Deterministic results of ecosystem uncertainty analyses. Values are percent increases in maximum algal bloom and percent decrease in game fish biomass at the mean environmental concentration for each of the direct liquefaction technologies. When two values are given, the first is for treatment 1 and the second value (in parentheses) is treatment 2.

	Algae	EXXON	H-Coal	SRC-I	SRC-II
Ammonia	Algae	80	66	176	66
	Fish	17	14	32	14
Benzene	Algae	a (a)	a (a)	b	1 (a)
	Fish	a (a)	a (a)	b	a (a)
Naphthalene	Algae	42 (2)	53 (3)	17 (a)	124 (9)
	Fish	2 (a)	3 (a)	1 (a)	6 (a)
Phenol	Algae	14 (a)	87 (6)	77 (6)	25 (2)
	Fish	2 (a)	8 (a)	8 (a)	3 (a)
Arsenic	Algae	a	a	a	a
	Fish	a	a	a	a
Mercury	Algae	4	a	26	17
	Fish	a	a	2	1
Nickel	Algae	4	5	4	1
	Fish	a	a	a	a
Cadmium	Algae	351	250	22	20
	Fish	20	13	3	2
Lead	Algae	1	3	18	a
	Fish	a	a	2	a

[a]Percent change is less than 1.

[b]SRC-I has no effluent for this chemical.

showing significant risks at the higher concentrations reached by at least one of the technologies. The increased risk of an effect to game fish populations seems intuitively reasonable. However, the increasing risk of a blue-green algal bloom with increasing concentration is counterintuitive. This is an example of the indirect effects which EUA is capable of showing. Even though each of the chemicals is toxic to the algae, the reduction in sensitive grazing organisms more than compensates for the direct effect on phytoplankton.

Results for ammonia and cadmium show both higher risk values and more complex response curves. Because of the wide range of environmental concentrations, cadmium tends to be more important for some technologies than for others. Environmental concentrations for ammonia overlap broadly so that this chemical takes on major importance for all of the technologies. The results indicate that these two risk assessment units should be of primary concern in evaluating the environmental hazards of direct coal liquefaction.

All of the graphs illustrate the complexity of the ecosystem responses simulated by EUA. The relationship between concentration of toxicant and risk is not simply linear or exponential. The complexity of these responses results from the nonlinear interactions considered in the analysis.

3.3.3 Comparison of Risks across RACs

The importance of cadmium and ammonia is further emphasized in Figure 3.3-5. The graph shows the maximum risk associated with each of the nine RACs. The maximum risk is defined as the risk associated (1) with the upper 95th percentile concentration for whichever technology showed the highest concentrations and (2) with either algal blooms or a reduction in game fish biomass, whichever showed the higher risk. Thus, the maximum risk attempts to separate RACs that never show a significant risk from those that are significant in at least one of the relevant calculations.

The figure shows that there is a very reasonable probability that cadmium and ammonia could cause significant effects in the aquatic ecosystem. In addition, the graph indicates that mercury (RAC 32)

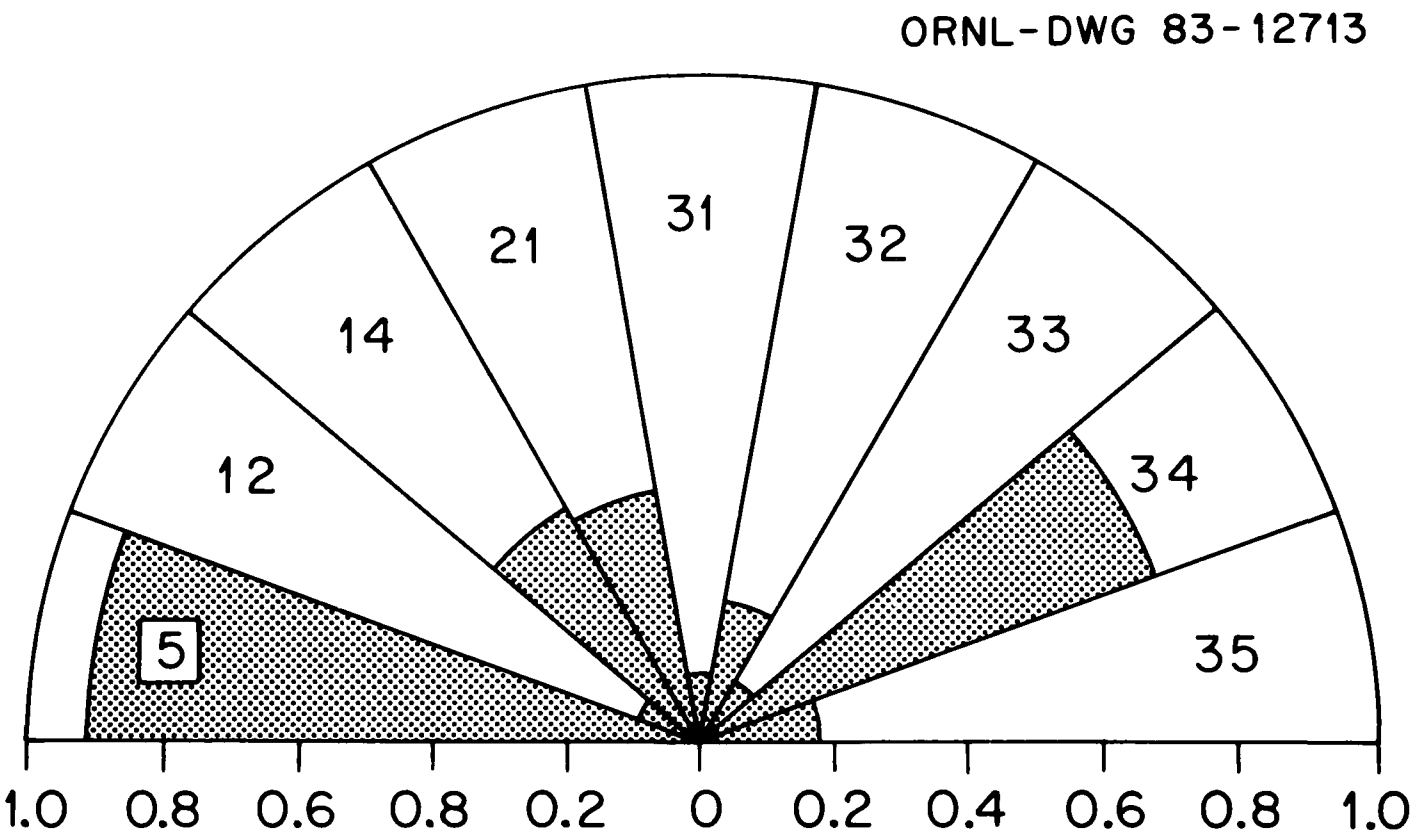


Fig. 3.3-5. Maximum risk estimates. The numbers represent each of the nine RACs. The risk values are associated with either algal blooms or reductions in fish biomass, whichever is larger, at the 95th percentile concentration of the technology with the highest concentration.

could also cause problems, though only in the SRC processes. Naphthalene (RAC 14) and phenol (RAC 21) show significant maximum risks, but this appears only in treatment option 1.

3.3.4 Comparison of Risks between Technologies

Figure 3.3-6 compares risks across the nine RACs for the four technologies. The risk values are those associated with the upper 95th percentile concentrations. For each RAC, moving in a clockwise direction, results are given first for the risk of algal blooms and then for the risk of a reduction in game fish.

Application of treatment option 2 would largely eliminate the risks associated with naphthalene (RAC 14) and phenol (RAC 21). This would seem to be particularly important for H-Coal and SRC processes.

The Exxon and H-Coal methods show high risks for emissions of cadmium (RAC 34). The SRC processes show much lower risks associated with cadmium, with smaller significant risks for the other heavy metals (RACs 31-35). However, all four technologies have high risks for ammonia (RAC 5). The risk of reduction in game fish populations is particularly high.

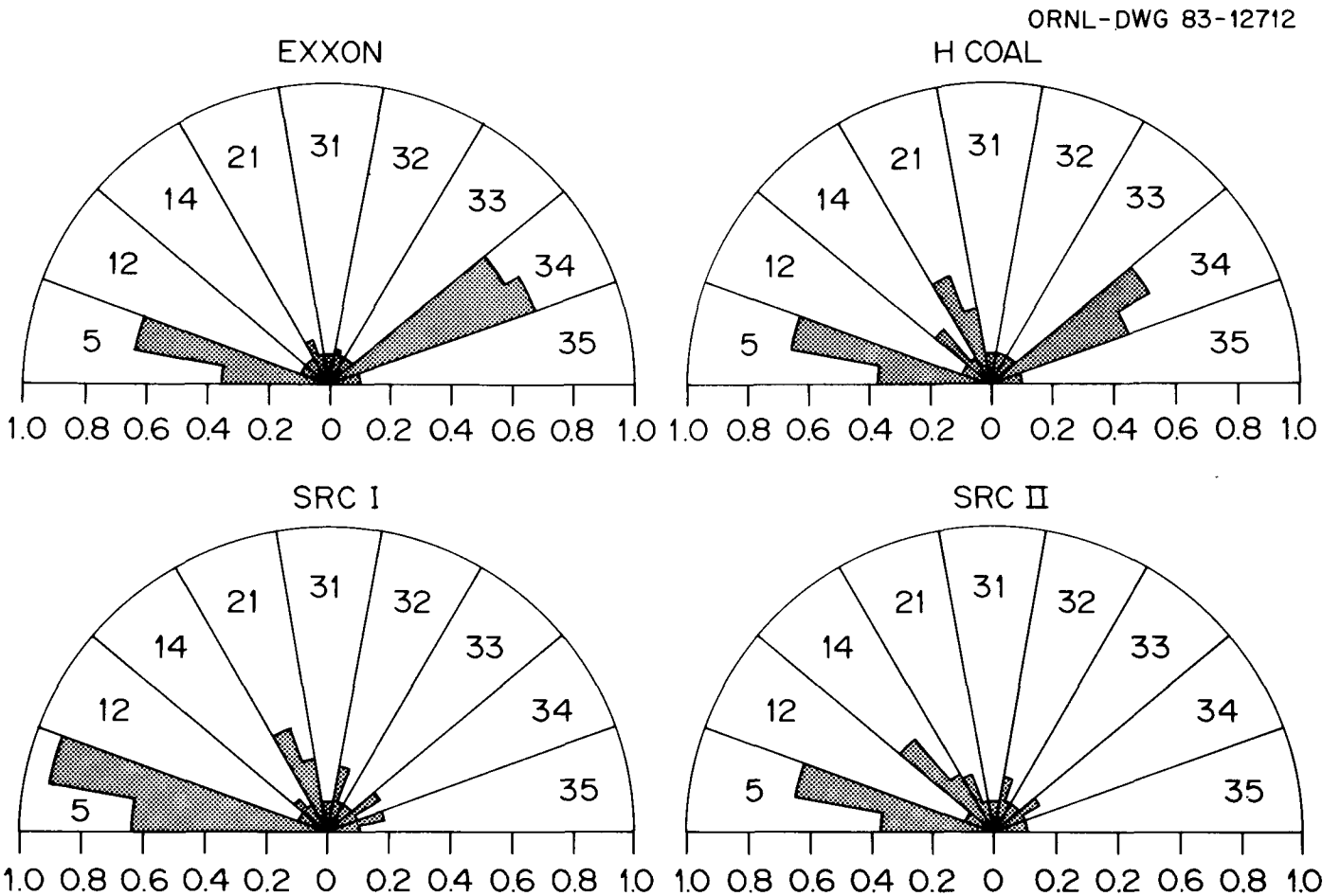


Fig. 3.3-6. Comparison of risks among technologies. Risks at the 95th percentile concentration are shown first for the algae and then for game fish, for each of the nine RACs (indicated by numbers).

4. TERRESTRIAL ENDPOINTS

The quotient method, as discussed in Sect. 3.1, consists of dividing the ambient concentrations of toxicants by the concentration at which some toxic effect is induced. It is used in this section to provide an indication of the likelihood of effects due to emissions of the individual RACs. The other risk analysis methods are not readily applicable to terrestrial organisms because of the limited data for most terrestrial taxa, the lack of standard tests and toxicological benchmarks in the data base, and the lack of agreed-upon standard responses for terrestrial biota.

4.1 VEGETATION

The phototoxicity data for the gaseous and volatile RACs are presented in Table B-1, the concentrations in ambient ground-level air are in Tables 2.3-1 through 4, and the quotients of the ratios of these values are in Table 4.1-1 through 4.1-3. The ambient concentrations are the increment of the entire RAC to the background concentration at the point of maximum ground-level concentration (Sect. 2.3). It is assumed that the RAC is composed entirely of the representative chemical and that the background concentration is zero. Quotients are calculated from two classes of data: (1) the lowest toxic concentration found in the literature for any flowering plant species as an indication of maximum toxic potential of the RAC, and (2) the range across studies of the lowest concentrations causing effects on growth or yield of the whole plant or some plant part. The latter set of responses is relatively consistent and closely related to crop and forest yield.

The worst atmospheric toxicant in the emissions of all technologies is hydrocarbon gases (RAC 6). This rank is misleading because the worst-case representative chemical (ethylene) is a plant hormone whereas most members of this RAC are essentially inert (NRC 1976). However, because atmospheric ethylene has caused significant damage to crops near urban areas and in the vicinity of petrochemical plants (NRC 1976), the emission rate of this gas should be specifically considered in the future. The most serious phytotoxicants in air

Table 4.1-1. Toxicity quotients for terrestrial plants for Exxon Donor Solvent Process. Ambient concentrations in air (annual, median, ground-level) and soil (soil solution or whole dry soil basis) are divided by concentrations causing reductions in growth, yield, or other toxic responses[a]

RAC	RAC name	Air concentration/ lowest toxic concentration	Range of air concentration/ growth effects concentration	Soil concentration/ lowest toxic concentration	Range of soil concentration/ growth effects concentration
1	Carbon monoxide	9.67 E-03	1.58 E-06	No accumulation in soil	
2	Sulfur oxides	1.02 E-01	1.69 E-02 - 5.08 E-02	No accumulation in soil	
3	Nitrogen oxides	3.60 E-02	1.89 E-03 - 3.60 E-02	No accumulation in soil	
4	Acid gases	No emissions			
5	Alkaline gases	No emissions			
6	Hydrocarbon gases	5.15	2.48 E-03 - 8.64 E-03		
7	Formaldehyde	No emissions			
8	Volatile organochlorines	No emissions			
9	Volatile carboxylic acids	No emissions			
10	Volatile O&S heterocyclics	No phytotoxicity data			
11	Volatile N-heterocyclics	No emissions			
12	Benzene	8.23 E-07			
13	Aliphatic/alicyclic hydrocarbons	1.22 E-12		1.00 E-04	
14	Mono- or diaromatic hydrocarbons	1.70 E-05		3.7 E-06	3.7 E-06
15	Polycyclic aromatic hydrocarbons			3.73	1.15-3.73[b]
16	Aliphatic amines	No emissions			
17	Aromatic amines	2.64 E-05			
18	Alkaline nitrogen heterocyclics	No phytotoxicity data			
19	Neutral N, O, S heterocyclics			1.09 E-06	1.09 E-07 - 1.09 E-06
20	Carboxylic acids	No emissions			
21	Phenols			9.8 E-05	
22	Aldehydes and ketones	3.98 E-05		3.4 E-07	3.4 E-07
23	Nonheterocyclic organosulfur	3.47 E-09	1.91 E-08	2.67 E-11[b]	
24	Alcohols	No emissions			
25	Nitroaromatics	No emissions			
26	Esters	No emissions			
27	Amides	No emissions			
28	Nitriles	No emissions			
29	Tars	No emissions			
30	Respirable particles	No phytotoxicity data			
31	Arsenic			1.1 E-01[b]	5.16 E-03[b] - 1.1 E-01[b]
32	Mercury	1.54 E-06		2.46 E-07	2.26 E-09 - 2.46 E-07
33	Nickel			4.92 E-02[b]	5.34 E-05 - 4.92 E-02[b]
34	Cadmium			3.78 E-02	8.4 E-04 - 3.78 E-02
35	Lead			1.96 E-03[b]	1.76 E-05 - 1.96 E-03[b]

[a]Ambient air concentrations and soil and soil solution concentrations are presented in Table 2.3-1. Toxic concentrations are presented in Appendix B.
[b]Quotients calculated from concentrations in soil and results of tests performed in soil. Quotients without superscript were calculated from concentrations in soil solution and results of tests performed in nutrient solution.

Table 4.1-2. Toxicity quotients for terrestrial plants for SRC-I Process. Ambient concentrations in air (annual, median, ground-level) and soil (soil solution or whole dry soil basis) are divided by concentrations causing reductions in growth, yield, or other toxic responses[a]

RAC	RAC Name	Phytotoxicity in air		Phytotoxicity in air	
		Air concentration/ lowest toxic concentration	Range of air concentration/ growth effects concentration	Soil concentration/ lowest toxic concentration	Range of soil concentration/ growth effects concentration
1	Carbon monoxide	1.45 E-03	2.37 E-07	No accumulation in soil	
2	Sulfur oxides	8.31 E-02	1.38 E-02 - 4.15 E-02	No accumulation in soil	
3	Nitrogen oxides	3.74 E-02	1.97 E-03 - 3.74 E-02	No accumulation in soil	
4	Acid gases	6.39 E-05	6.39 E-05	No accumulation in soil	
5	Alkaline gases	1.48 E-04		No accumulation in soil	
6	Hydrocarbon gases	4.15	2.0 E-03 - 6.96 E-03		
7	Formaldehyde	No emissions			
8	Volatile organochlorines	No emissions			
9	Volatile carboxylic acids	No emissions			
10	Volatile O & S heterocyclics	No emissions			
11	Volatile N heterocyclics	No emissions			
12	Benzene	No emissions			
13	Alipnatic/alicyclic hydrocarbons	1.15 E-12		9.44 E-05	
14	Mono- or diaromatic hydrocarbons	1.57 E-05		3.44 E-06	3.44 E-06
15	Polycyclic aromatic hydrocarbons			13.3[b]	4.1-13.3[b]
16	Aliphatic amines	No emissions			
17	Aromatic amines	3.23 E-03			
18	Alkaline N heterocyclics	No emissions			
19	Neutral N, O, S heterocyclics			8.31 E-07	8.31 E-08 - 8.31 E-07
20	Carboxylic acids	No emissions			
21	Phenols			3.43 E-04	
22	Aldehydes and ketones	No emissions			
23	Nonheterocyclic organosulfur	No emissions			
24	Alcohols	No emissions			
25	Nitroaromatics	No emissions			
26	Esters	No emissions			
27	Amides	No emissions			
28	Nitriles	No emissions			
29	Tars	No emissions			
30	Respirable particles			No accumulation in soil	
31	Arsenic			7.33 E-01[b]	3.44 E-02[b] - 7.33 E-01[b]
32	Mercury	2.3 E-05		2.3 E-07	2.11 E-09 - 2.3 E-07
33	Nickel			6.4 E-01[b]	7.58 E-04 - 6.4 E-01[b]
34	Cadmium			3.65 E-03	8.1 E-05 - 3.65 E-03
35	Lead			1.53 E-03[b]	1.37 E-05 - 1.53 E-03[b]

[a]Air, soil and soil solution concentrations are presented in Table 2.3-2. Toxic concentrations are presented in Appendix B.
[b]Quotients calculated from concentrations in soil and results of tests performed in soil. Quotients without superscript were calculated from concentrations in soil solution and results of tests performed in nutrient solution.

Table 4.1-3. Toxicity quotients for terrestrial plants for SRC-II Process. Ambient concentrations in air (annual, median, ground-level) and soil (soil solution or whole dry soil basis) are divided by concentrations causing reductions in growth, yield, or other toxic responses[a]

RAC	RAC Name	Air concentration/ lowest toxic concentration	Range of air concentration/ growth effects concentration	Soil concentration/ lowest toxic concentration	Range of soil concentration/ growth effects concentration
1	Carbon monoxide	9.28 E-04	1.52 E-07	No accumulation in soil	
2	Sulfur oxides	2.35 E-02	3.92 E-03 - 1.18 E-02	No accumulation in soil	
3	Nitrogen oxides	3.95 E-02	2.08 E-03 - 3.95 E-02	No accumulation in soil	
4	Acid gases	No emissions			
5	Alkaline gases	No emissions			
6	Hydrocarbon gases	3.23 E+00	1.56 E-03 - 5.43 E-03		
7	Formaldehyde	No emissions			
8	Volatile organochlorines	No emissions			
9	Volatile carboxylic acids	No emissions			
10	Volatile O & S heterocyclics	No phytotoxicity data			
11	Volatile N heterocyclics			2.61 E-05	2.61 E-05
12	Benzene	4.0 E-06			
13	Aliphatic/alicyclic hydrocarbons	1.88 E-12		1.54 E-04	
14	Mono- or diaromatic hydrocarbons	1.10 E-05		2.41 E-06	2.41 E-06
15	Polycyclic aromatic hydrocarbons			4.16[b]	1.28-4.16[b]
16	Aliphatic amines	No emissions			
17	Aromatic amines	1.43 E-05			
18	Alkaline N heterocyclics	No phytotoxicity data			
19	Neutral N, O, S heterocyclics			2.35 E-07	2.35 E-08 - 2.35 E-07
20	Carboxylic acids	No emissions			
21	Phenols			1.48 E-04	
22	Aldehydes and ketones	No emissions			
23	Nonheterocyclic organosulfur	No emissions			
24	Alcohols	No emissions			
25	Nitroaromatics	No emissions			
26	Esters	No emissions			
27	Amides	No emissions			
28	Nitriles	No emissions			
29	Tars	No emissions			
30	Respirable particles			No accumulation in soil	
31	Arsenic			4.83 E-03[b]	2.27 E-04[b] - 4.83 E-03[b]
32	Mercury	1.35 E-06		2.16 E-07	1.98 E-09 - 2.16 E-07
33	Nickel			2.08 E-04[b]	2.47 E-07 - 2.08 E-04[b]
34	Cadmium			6.45 E-05	1.43 E-06 - 6.45 E-05
35	Lead			3.84 E-06[b]	3.44 E-08 - 3.84 E-06[b]
36	Other trace elements			No accumulation in soil	
37	Radioactive materials	No emissions			

[a]Air, soil and soil solution concentrations are presented in Table 2.3-3. Toxic concentrations are presented in Appendix B.
[b]Quotients calculated from concentrations in soil and results of tests performed in soil. Quotients without superscript were calculated from concentrations in soil solution and results of tests performed in nutrient solution.

(ignoring ethylene) are SO_x and NO_x. The maximum annual average concentrations predicted for SO_2 (RAC 2) from EDS emissions are within a tenth of those that cause visible injury to needles of sensitive white pines, and, for both SO_2 and NO_x (RAC 3) emissions from all technologies, those concentrations are greater than a hundredth of those that reduce growth or yield of several plant species.

Because of its ubiquity and importance as a phytotoxicant, sulfur dioxide (RAC 2) has been relatively well studied for its effects on crop yield and can be analyzed in greater detail than other RACs. McLaughlin and Taylor (in press) have put forward the following dose-response relationship for yield reduction of beans as a function of SO_2 exposure:

$$\% \text{ yield reduction} = -17.4 + 29.2 \text{ (log dose-ppmh)}.$$

This empirical relationship is based on a regression of 20 points from five field experiments on soybeans and snap beans. Eighty percent of the variation in yield reduction was associated with variation in dosage, and the equation was significant at $\alpha = 0.0001$.

Because SO_2 appears to be the most serious phytotoxic air pollutant, we used this relationship to examine the potential effects of full growing-season exposure to SO_2 on crop yield. If we assume a 200-d growing season for soybeans on the eastern site and a 12 h exposure day, the SO_2 dose from EDS at 6.61 $\mu g/m^3$ SO_2 is 5.95 ppmh. Sulfur dioxide concentrations from EDS are 1.2 times those from SRC-I, 2.6 times those from H-Coal, and 4.3 times those from SRC-II. That dose results in a 5.6% reduction in yield using McLaughlin and Taylor's formula.

This predicted effect is remarkable in that it results from an SO_2 concentration that is more than 10 times lower than the lowest concentration reported to affect yield. This anomaly is due to the great length of a growing season relative to the length of experiments. The longest fumigation available to McLaughlin and Taylor was 337 h. Thus, use of their formula for a full growing season requires an extrapolation of almost a factor of 10 in the duration

component of the dose. Because the experimental field fumigations are typically carried out in the most sensitive stage (assumed to be the pod-fill in the case of beans), use of the formula for the full growing season probably overestimates effects.

We might place a lower bound on the level of effect by assuming that effects only occur during pod-fill. If that stage is assumed to last 30 d, the dose is 0.89 ppmh. This is less than a quarter of the threshold dose for effects on yield (3.92 ppmh).

For a real synfuels plant, this SO_2 emission would be added to a background SO_2 concentration that may reach 80 $\mu g/m^3$ under the current annual average ambient air quality standard. The SO_2 would also interact with ozone, which reaches phytotoxic levels in many areas of the United States. This analytical exercise emphasizes the need for the full season field experiments on effects of SO_2 and $SO_2 + O_3$ originally planned for the EPA's National Crop Loss Assessment Network.

The phytotoxicity of materials deposited on the landscape is a more complex phenomenon than that of gases and vapors. Because the atmospheric transport model AIRDOS-EPA has a deposition velocity of zero for inorganic gases and does not model the formation of aerosols, RACs 1 through 5 are assumed to not accumulate in the soil. This assumption is likely to be acceptable except in the case of SO_4 deposition in forests with acid soils. The effects of SO_4 deposition in forests result from regional-scale emissions and atmospheric processes, and therefore are well beyond the scope of this report. Deposited nongaseous RACs were assumed to accumulate in the soil over the 35-year life of the liquefaction plant. Losses due to decomposition and leaching from the root zone were calculated by the terrestrial food chain model (Sect. 2.3). The toxicity data (Table B-3) were primarily derived from exposure of plants or plant parts to solutions of the chemicals rather than contaminated soil because few data are available on toxicity in soil. Whereas the results of tests conducted in soil can be directly compared with concentrations in the whole soil, results of tests conducted in solution must be compared with a calculated concentration in soil solution. Because the concentration in soil solution is more difficult

to model than concentration in whole soil and requires more simplifying assumptions, solution concentrations are less reliable. In addition, as with the gases and vapors, the toxicity data concern a wide variety of tests and measured responses that are not equivalent. Finally, for most of the RACs, only one or two chemicals have been tested. We cannot determine whether the chemicals used are representative of the entire RAC.

For all four technologies, the most phytotoxic RAC deposited in soil was polycyclic aromatic hydrocarbons (RAC 15). The high rank of RAC 15 is suspect because benzo(a)pyrene and some other PAHs appear to act as plant hormones and can stimulate growth at very low concentrations. While PAHs can modify plant growth at concentrations as low as 0.5 ng/g soil and alteration of growth patterns can affect survival, there is no evidence that they reduce plant growth or cause injury, even at relativity high experimental concentrations (Edwards, 1983). Phytotoxic concentrations are more than 10 times those in soil or soil solution for all other RACs from all technologies, except arsenic (31) and nickel (33) for SRC-I. They are within a factor of 100 for arsenic (31), nickel (33), and cadmium (34) from EDS; phenols (21) from SRC II; and phenols, arsenic, and cadmium from H-Coal. The results for phenols are highly uncertain since only one test result has been found, inhibition of wheat seed germination. More data on the phytotoxicity of nonhalogenated phenols would be desirable. While the trace elements arsenic, nickel, and cadmium do not appear to be serious problems on the basis of this simple analysis, their concentrations are high enough to warrant greater attention in future research and risk analysis methods development.

4.2 WILDLIFE

Table 4.2-1 through 4 present the lowest quotients for the two technologies for toxicity to terrestrial animals. The quotients are calculated from the lowest lethal concentration for any species and from the lowest concentration producing any toxic effect (Table B-3) divided by the highest annual average ground-level concentration in

Table 4.2-1. Toxicity quotients for terrestrial animals for Exxon Donor Solvent. Concentrations in air (annual, median, ground-level) are divided by lethal concentrations and the lowest toxic concentrations[a]

RAC	RAC name	Lowest lethal concentration	Lowest toxic concentration
1	Carbon monoxide	1.89 E-08	4.05 E-04
2	Sulfur oxides	3.67 E-04	6.61 E-02
3	Nitrogen oxides	3.29 E-04	8.05 E-03
4	Acid gases	No emissions	
5	Alkaline gases	No emissions	
6	Hydrocarbon gases		1.6 E-08
7	Formaldehyde	No emissions	
8	Volatile organochlorines	No emissions	
9	Volatile carboxylic acids	No emissions	
10	Volatile O & S heterocyclics	1.48 E-09	1.48 E-09
11	Volatile N heterocyclics	No emissions	
12	Benzene	1.3 E-07	1.3 E-07
13	Aliphatic/alicyclic hydrocarbons	1.49 E-08	9.79 E-07
14	Mono- or diaromatic hydrocarbons	2.13 E-06	4.04 E-05
15	Polycyclic aromatic hydrocarbons	No data on respiratory toxicity	
16	Aliphatic amines	No emissions	
17	Aromatic amines	9.65 E-09	9.65 E-09
18	Alkaline N heterocyclics	No data on respiratory toxicity	
19	Neutral N, O, S heterocyclics	No data on respiratory toxicity	
20	Carboxylic acids	No data on respiratory toxicity	
21	Phenols	No data on respiratory toxicity	
22	Aldehydes and ketones	5.53 E-07	1.95 E-05
23	Nonheterocyclic organosulfur	6.25 E-11	9.38 E-10
24	Alcohols	No emissions	
25	Nitroaromatics	No emissions	
26	Esters	No emissions	
27	Amides	No emissions	
28	Nitriles	No emissions	
29	Tars	No emissions	
30	Respirable particles		9.87 E-02
31	Arsenic		7.4 E-06
32	Mercury		9.06 E-08
33	Nickel	3.57 E-09	3.57 E-09
34	Cadmium	2.64 E-08	1.32 E-05
35	Lead		2.64 E-06

[a]Ambient air concentrations are presented in Table 2.3-1. Toxic concentrations are presented in Appendix B.

Table 4.2-2. Toxicity quotients for terrestrial animals for SRC-I Process. Concentrations in air (annual, median, ground-level) are divided by lethal concentrations and the lowest toxic concentrations[a]

RAC	RAC name	Lowest lethal concentration	Lowest toxic concentration
1	Carbon monoxide	2.84 E-09	6.07 E-05
2	Sulfur oxides	3.0 E-04	5.4 E-02
3	Nitrogen oxides	3.42 E-04	8.36 E-03
4	Acid gases	8.52 E-08	2.56 E-07
5	Alkaline gases	4.44 E-07	2.39 E-05
6	Hydrocarbon gases	---	1.29 E-08
7	Formaldehyde	No emissions	
8	Volatile organochlorines	No emissions	
9	Volatile carboxylic acids	No emissions	
10	Volatile O & S heterocyclics	No emissions	
11	Volatile N heterocyclics	No emissions	
12	Benzene	No emissions	
13	Aliphatic/alicyclic hydrocarbons	1.40 E-08	9.21 E-07
14	Mono- or diaromatic hydrocarbons	1.97 E-06	3.75 E-05
15	Polycyclic aromatic hydrocarbons		
16	Aliphatic amines	No emissions	
17	Aromatic amines	1.18 E-06	1.18 E-06
18	Alkaline N heterocyclics	No emissions	
19	Neutral N, O, S heterocyclics		
20	Carboxylic acids	No emissions	
21	Phenols		
22	Aldehydes and ketones	No emissions	
23	Nonheterocyclic organosulfur	No emissions	
24	Alcohols	No emissions	
25	Nitroaromatics	No emissions	
26	Esters	No emissions	
27	Amides	No emissions	
28	Nitriles	No emissions	
29	Tars	No emissions	
30	Respirable particles		2.10 E-01
31	Arsenic		4.92 E-05
32	Mercury		8.47 E-08
33	Nickel	4.21 E-06	4.21 E-06
34	Cadmium	3.98 E-09	1.99 E-06
35	Lead		2.02 E-06

[a]Ambient air concentrations are presented in Table 2.3-2. Toxic concentrations are presented in Appendix B.

Table 4.2-3. Toxicity quotients for terrestrial animals for SRC-II Process. Concentrations in air (annual, median, ground-level) are divided by lethal concentrations and the lowest toxic concentrations[a]

RAC	RAC name	Lowest lethal concentration	Lowest toxic concentration
1	Carbon monoxide	1.82 E-09	3.88 E-05
2	Sulfur oxides	8.5 E-05	1.53 E-02
3	Nitrogen oxides	3.61 E-04	8.83 E-03
4	Acid gases	No emissions	
5	Alkaline gases	No emissions	
6	Hydrocarbon gases		1.01 E-08
7	Formaldehyde	No emissions	
8	Volatile organochlorines	No emissions	
9	Volatile carboxylic acids	No emissions	
10	Volatile O & S heterocyclics	2.07 E-09	2.07 E-09
11	Volatile N heterocyclics	1.8 E-08	1.8 E-08
12	Benzene	6.32 E-07	6.32 E-07
13	Aliphatic/alicyclic hydrocarbons	2.28 E-08	1.5 E-06
14	Mono- or diaromatic hydrocarbons	1.38 E-06	2.62 E-05
15	Polycyclic aromatic hydrocarbons		
16	Aliphatic amines	No emissions	
17	Aromatic amines	5.22 E-09	5.22 E-09
18	Alkaline N heterocyclics		
19	Neutral N, O, S heterocyclics		
20	Carboxylic acids	No emissions	
21	Phenols		
22	Aldehydes and ketones	No emissions	
23	Nonheterocyclic organosulfur	No emissions	
24	Alcohols	No emissions	
25	Nitroaromatics	No emissions	
26	Esters	No emissions	
27	Amides	No emissions	
28	Nitriles	No emissions	
29	Tars	No emissions	
30	Respirable particles		1.38 E-01
31	Arsenic		1.94 E-05
32	Mercury		7.94 E-08
33	Nickel	1.49 E-09	1.49 E-09
34	Cadmium	3.36 E-09	1.68 E-06
35	Lead		4.54 E-07

[a]Ambient air concentrations are presented in Table 2.3-3. Toxic concentrations are presented in Appendix B.

air. Data from all species are lumped because there were not enough data on the nonmammalian taxa for separate treatment. Carcinogenesis and other genotoxic effects were not included.

Lethality is considered because it is a consistent and frequently determined response that has clear population implications, but all predicted concentrations were well below lethal levels. The lowest toxic concentrations include a diversity of endpoints, most of which cannot be readily related to effects on wildlife populations but which occur at concentrations that are as low as one ten-thousandth of lethal concentrations. These responses range from increased airway resistance in one-hour exposures of guinea pigs to impaired lung and liver function in human occupational exposures. The most toxic RACs for all technologies by this sublethal criterion are the conventional combustion products: sulfur oxides (2) and respirable particulates (30). Whereas these concentrations may constitute a locally significant increment to the background concentration of these major pollutants, the significance of ambient air pollution to wildlife is largely unknown. While the predicted sulfur oxide and respirable particle concentrations are below the annual primary ambient air quality standards for SO_2 (1.5-6.6 $\mu g/m^3$ vs 80 $\mu g/m^3$) and total particulates (45.4-63.3 $\mu g/m^3$ vs 75 $\mu g/m^3$), there is little scientific basis for the assumption that protection of human health will automatically protect wildlife.

5. EVALUATION OF RISKS

5.1 EVALUATION OF RISKS TO FISH

Table 5.1-1 lists, for each technology and wastewater treatment option, the RACs determined to be potentially ecologically significant by one or more of the three methods employed in this report. The significance criterion for the quotient method is an acute effects quotient greater than 0.01 (i.e., a lowest observed LC_{50} or TLM_{96} less than a hundred times the estimated environmental concentration). For analysis of extrapolation error, RACs are considered to be significant if the risk that the environmental concentration may exceed the PGMATC of one or more of the reference fish species is greater than 0.1. For ecosystem uncertainty analysis, RACs are considered to be significant if the risk of a 25% reduction in game fish biomass is greater than 0.1.

A total of nine RACs were determined to be significant for one or more technologies. RAC 5 (ammonia) was the only RAC found to be significant for all technologies, all treatment options, and all risk analysis methods. RAC 34 (cadmium) was significant for all technologies and treatment options according to the quotient method; RAC 21 (phenols) was significant for all technologies according to analysis of extrapolation error (AEE). AEE ranked five RACs as significant for at least one combination of technology and waste treatment that was not picked by the other two methods, and AEE found cadmium (RAC 34) to be significant less often than the other methods. These differences can be largely accounted for by the fact that while the other methods use the responses of the species that are tested, AEE predicts the responses of a specific fish fauna. Several members of this fauna are significantly more sensitive to most chemicals than are the species used to test those five RACs. However, in the case of cadmium, data are available for the other methods on rainbow trout, which is more sensitive to this metal than are the warm-water species used in AEE. Thus, differences in sensitivity among fish taxa appear to account for most of the variation between methods in the lists of significant RACs.

Table 5.1-1. RACs determined to pose potentially significant risks to fish populations by one or more of three risk analysis methods

Exxon Donor Solvent		SRC-I		SRC-II		H-Coal	
1[a]	2[b]	1	2	1	2	1	2
5 (QM, AEE, EUA)[c]	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)	5 (QM, AEE, EUA)
13 (QM, AEE)	13 (AEE)	13 (QM, AEE)	13 (AEE)	14 (QM, AEE, EUA)	21 (AEE)	13 (QM, AEE)	13 (QM, AEE)
14 (AEE)	20 (AEE)	21 (QM, AEE, EUA)	21 (AEE)	21 (AEE)	34 (QM)	14 (QM, AEE)	20 (AEE)
20 (AEE)	22 (QM, AEE)	34 (QM)	34 (QM)	26 (AEE)		20 (AEE)	21 (AEE)
21 (AEE)	34 (QM, AEE, EUA)			34 (QM)		21 (QM, AEE, EUA)	22 (QM, AEE)
22 (QM, AEE)						22 (QM, AEE)	34 (QM, EUA)
28 (AEE)						28 (AEE)	
34 (QM, AEE, EUA)						34 (QM, EUA)	

[a]Wastewater treatment option 1.

[b]Wastewater treatment option 2.

[c]QM = quotient method; AEE = analysis of extrapolation error, EUA = ecosystem uncertainty analysis.

The exposure analyses, the significance criteria, and the methods themselves are conservative, and therefore it would be premature to conclude that adverse consequences would result from the contaminant releases assessed in this report. These nine RACs should, however, be foci for future refinements of the risk analyses and for future toxicological and ecological research. In addition to the RACs listed in Table 5.1-1, there are eight RACs for which no applicable toxicity data were available. These are RACs 10 (volatile O & S heterocyclics), 11 (volatile N heterocyclics), 16 (aliphatic amines), 17 (aromatic amines), 23 (nonheterocyclic organosulfur compounds), 24 (alcohols), 25 (nitroaromatics), and 27 (amides).

There are two ways to compare the four technologies for ecological risk. It was shown using the toxic units approach (Sect. 3.2-3) that, for treatment option 1, the H-Coal effluent has the greatest potential for acute toxicity to fish; for option 2, the Exxon Donor Solvent effluent appears to be the most acutely toxic. SRC-I's total toxicity is almost entirely due to ammonia while H-Coal also has large emissions of organics and cadmium. By the other criterion, number of potentialy significant RACs in the effluent (Table 5.1-1), H-Coal and EDS appear to pose the greatest risk to fish.

5.2 EVALUATION OF RISKS OF ALGAL BLOOMS

Algal toxicity data were available for only 10 RACs. Moreover, because of the diversity of experimental designs and test endpoints used in algal bioassays, it is not meaningful to rank the RACs using the quotient method. Finally, as noted in Sect. 3.1, there is no clear distinction between acute effects and chronic effects in algal bioassays.

It does appear, however, that most of the quotients that can be calculated are lower for algae than for fish; only RACs 17, 21, 26, and 34 would be judged significant for any technology using the quotient method. For treatment option 2, only RAC 34 is significant.

Ecosystem uncertainty analysis suggests greater risks of effects on algae than does the quotient method. Risks of 10% or more of a fourfold increase in algal biomass, for one or more technologies and

for treatment options, were estimated for six of the nine RACs examined: 5, 14, 21, 32, 34, and 35. It is important to note that the effects pathway postulated in ecosystem uncertainty analysis is indirect rather than direct. All of the RACs are toxic to algae. The increases in algal biomass are caused by reductions in grazing intensity resulting from effects of contaminants on zooplankton and fish.

5.3 EVALUATION OF RISKS TO VEGETATION AND WILDLIFE

Gases and vapors emitted by direct coal liquefaction processes appear to pose a minor threat to terrestrial plants and animals. The most serious problems appear to arise from conventional products of combustion: sulfur oxides, nitrogen oxides, and respirable particles that may already be present in high concentrations at synfuels plant sites. Of the materials deposited on the soil, the trace elements arsenic, cadmium, and nickel cause the greatest concern. However, they are unlikely to be a problem except when deposited on acid soils with preexisting high concentrations of heavy metals.

5.4 VALIDATION NEEDS

There are no uniquely correct methods of quantifying ecological risks. There are several plausible ways to combine uncertainties concerning differential sensitivities of fish taxa and acute-chronic relationships. Similarly, there are many aquatic ecosystem models. Different models produce different estimates of uncertainty and risk. Validation studies of the methods used in these risk analyses would greatly increase the credibility of the results.

There are two ways in which these synfuels risk analyses can be validated. A specific validation would involve building a synfuels industry and monitoring the resulting environmental effects. A generic validation would involve checking the assumptions and models used in the risk analyses against the results of field and laboratory studies. Given the current state of the synfuels industry, a generic validation seems more practical.

Generic validation of the environmental risk analysis methods would begin by examining the ability of existing published evidence to support or refute the models or their component assumptions. To a certain extent this has been done by us as a part of our methods development (e.g., Suter et al. 1983, Suter and Vaughan, 1984), and by others for generally used models such as the Gaussian plume atmospheric dispersion model. However, there has been no systematic consideration of such major assumptions as the validity of hydroponic phytotoxicity studies nor of the risk analysis methodology as a whole. The results of validation studies would not only indicate the level of confidence that can be placed in environmental risk analyses but also would indicate what research is necessary for further development and validation of risk analysis methods.

6. ACKNOWLEDGMENTS

The authors thank G. A. Holton and F. R. O'Donnell for performing the atmospheric dispersion and deposition calculations used in this report. We also than R. E. Millemann, J. W. Webb, and the members of the Environmental Protection Agency's Peer Review Panel for their thorough review of this report. Finally, we thank A. A. Moghissi and S. G. Hildebrand for their support and encouragement during this project.

7. REFERENCES CITED IN TEXT AND APPENDIXES

Adelman, I. R., and L. L. Smith, Jr. 1970. Effects of hydrogen sulfide on northern pike eggs and sac fry. Trans. Am. Fish. Soc. 99:501-509.

Agarwala, S. C., S. S. Bisht, and C. P. Sharma. 1977. Relative effectiveness of certain heavy metals in producing toxicity and symptoms of iron deficiency in barley. Can. J. Bot. 55:1299-1307.

Alabaster, J. S., J. H. N. Garland, I. C. Hart, and J. F. De L. G. Solbe. 1972. An approach to the problem of pollution and fisheries. Symp. Zool. Soc. London 29:87-114.

Alabaster, J. S., and R. Lloyd. 1982. Water Quality Criteria for Freshwater Fish, 2nd ed. Butterworths, London.

Albert, W. B., and C. H. Arndt. 1932. The Concentration of Soluble Arsenic as an Index of Arsenic Toxicity to Plants. S. C. Agric. Exp. Stn. Annu. Rep. No. 44. [As cited in Deuel and Swoboda (1972)].

Allen, W. R., W. L. Askew, and K. Schreiber. 1961. Effect of insecticide-fertilizer mixtures and seed treatments on emergence of sugar beet seedlings. J. Econ. Entomol. 54:181-187.

Anderson, B. G. 1946. The toxicity thresholds of various sodium salts determined by the use of Daphnia magna. Sewage Works J. 18:82-87.

Ashendon, T. W., and T. A. Mansfield. 1978. Extreme pollution sensitivity of grasses when SO_2 and NO_2 are present in the atmosphere together. Nature 273:142-143.

Angelovic, J. W., W. F. Sigler, and J. M. Newhold. 1961. Temperature and fluorosis in rainbow trout. J. Water Pollut. Control Fed. 33:371-381.

Badilescu, T., S. Botis-Simon, and Z. Simon. 1967. Response of some seeds of different ploidies towards alkylating agents and some common phytotoxica. Rev. Roum. Biochim. 4:279-285.

Barnthouse, L. W., D. L. DeAngelis, R. H. Gardner, R. V. O'Neill, C. D. Powers, G. W. Suter II, and D. S. Vaughan. 1982a. Methodology for environmental risk analysis. ORNL/TM-8167. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barnthouse, L. W., S. M. Bartell, D. L. DeAngelis, R. H. Gardner, R. V. O'Neill, C. D. Powers, G. W. Suter II, G. P. Thompson, and D. S. Vaughan. 1982b. Preliminary environmental risk analysis for indirect coal liquefaction. Report to the Office of Research and Development. U.S. Environmental Protection Agency, Washington, D.C.

Batterton, J., K. Winters, and C. Van Baalen. 1978. Anilines: Selective toxicity to blue-green algae. Science 199:1068-1070.

Baughman, G. L., and R. R. Lassiter. 1978. Prediction of environmental pollution concentration. pp. 35-54. IN J. Cairns, K. L. Dickson, and A. W. Maki (eds.), Estimating the Hazard of Chemical Substances to Aquatic Life. ASTM STP 657. American Society for Testing and Materials, Philadelphia, Pennsylvania.

Bazzaz, F. A., G. L. Rolfe, and P. W. Windle. 1974. Differing sensitivity of corn and soybean photosynthesis and transpiration to lead contamination. J. Environ. Qual. 3:156-157.

Biesinger, K. E., and G. M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. J. Fish. Res. Board Can. 29:1691-1700.

Birge, W. J., and J. A. Black. 1981. Aquatic toxicity tests on organic contaminants originating from coal conversion. University of Kentucky report to the Advanced Fossil Energy Program, Environmental Sciences Division, Oak Ridge National Laboratory. University of Kentucky, Lexington.

Bostick, W. D., R. L. Jolley, J. D. Hewitt, and J. B. Overton. 1982. Bench-scale treatment of Coal Liquefaction Process Wastewaters, ORNL/TM-8408. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Brenniman, G., R. Hartung, and W. J. Weber, Jr. 1976. A continuous flow bioassay method to evaluate the effects of outboard motor exhausts and selected aromatic toxicants on fish. Water Res. 10:165-169.

Briggs, G. G. 1981. Theoretical and experimental relationships between soil adsorption, octanol-water partition coefficients, water solubilities, bioconcentration factors, and the parachor. J. Agric. Food Chem. 29:1050-1059.

Canton, J. H., and D. M. M. Adema. 1978. Reproducibility of short-term and reproduction toxicity experiments with Daphnia magna and comparison of the sensitivity of Daphnia magna with D. pulex and D. cucullata in short-term experiments. Hydrobiologia 59:135-140.

Cardwell, R. D., D. G. Foreman, J. R. Payne, and D. J. Wilker. 1976. Acute toxicity of selected toxicants to six species of fish. EPA-600/3-76-008. U.S. Environmental Protection Agency, Duluth, Minnesota.

Carlson, R. W., F. A. Bazzaz, and G. L. Rolfe. 1975. The effects of heavy metals on plants. Part II, Net photosynthesis and transpiration of whole corn and sunflower plants treated with Pb, Cd, Ni, and Tl. Environ. Res. 10:113-120.

Carlson, R. L., and F. A. Bazzaz. 1977. Growth reduction in American sycamore (Platanus occidentalis L.) caused by Pb-Cd interaction. Environ. Pollut. 12:243-253.

Cassidy, D. R., and A. Furr. 1978. Toxicity of inorganic and organic mercury compounds in animals. pp. 303-330. IN F. W. Oehme (ed.), Toxicity of Heavy Metals in the Environment. Marcel Dekker, Inc., New York.

Cheeseman, J. M., and T. O. Perry. 1977. Suspect identification through biological assay (The Wake County, N.C., pine kill). Plant Physiol. 59:123.

Chen, S.-C., and R. M. Olofson. 1978. Phytotoxicity of organic and inorganic iodines to Avena fatua. J. Agric. Food Chem. 26:287-289.

Chou, C.-H., and Z. A. Patrick. 1976. Identification and phytotoxic activity of compounds produced during decomposition of corn and rye residues in soil. Phytopathology 58:41-45.

Clubb, R. W., A. R. Gaufir, and J. L. Lords. 1975. Acute cadmium toxicity studies upon nine species of aquatic insects. Environ. Res. 9:332-341.

Cleland, J. G., and G. L. Kingsbury. 1977. Multimedia Environmental Goals for Environmental Assessment, Vol. II. EPA-600/7-77-136b. U.S. Environmental Protection Agency, Washington, D.C.

Cushman, R. M., S. G. Hildebrand, R. H. Strand, and R. M. Anderson. 1977. The toxicity of 35 trace elements in coal to freshwater biota: A data base with automated retrieval capabilities. ORNL/TM-5793. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 46 pp.

Davies, W., G. A. Atkins, and P. C. B. Hudson. 1937. The effect of ascorbic acid and certain indole derivatives on the regeneration and germination of plants. Ann. Bot. 1:329-351.

Davies, P. H., J. P. Goetth, J. R. Sinley, and N. F. Smith. 1976. Acute and chronic toxicity of lead to rainbow trout (Salmo gairdneri) in hard and soft water. Water Res. 10:199-206.

DeGraeve, D. M., R. G. Elder, D. C. Woods, and H. L. Bergman. 1982. Effects of naphthalene and benzene on fathead minnows and rainbow trout. Arch. Environ. Toxicol. 11:487-490.

Deubert, K. H., R. M. Devlin, R. M. Kisiel, and M. J. Koslusiak. 1979. The influence of benzo(a)pyrene on the growth of wheat and corn. Environ. Int. 1:91-93.

Deuel, L. E., and A. R. Swoboda. 1972. Arsenic toxicity to cotton and soybeans. J. Environ. Qual. 1:317-320.

Dilling, W. L. 1977. Interphase transfer processes II. Evaporation rates of chloromethanes, ethanes, ethylenes, propanes, and propylenes from dilute aqueous solution. Comparison with theoretical predictions. Environ. Sci. Technol. 11(4):405-409.

Dowden, B. F., and H. J. Bennett. 1965. Toxicity of selected chemicals to certain animals. J. Water Pollut. Control Fed. 37:1308-1316.

Dutta, T. R., J. Prasad, and R. P. Singh. 1972. Evaluation of herbicides for submerged weeds in Chambal and Bhakra-Nangal canal systems. Indian J. Agric. Sci. 42:70-75.

Edwards, N. T. 1983. Polycyclic aromatic hydrocarbons (PAHs) in the terrestrial environment: A review. J. Environ. Qual. 12:427-441.

European Inland Fisheries Advisory Commision (EIFAC). 1970. Water Quality Criteria for European Freshwater Fish. Report on Ammonia and Inland Fisheries. EIFAC Tech. Paper II. Food and Agriculture Organisation, Rome. 12 pp.

European Inland Fisheries Advisory Commision (EIFAC). 1980. Working Party on Water Quality Criteria. Report on Combined Effects on Freshwater Fish and Other Aquatic Life of Mixtures of Toxicants in Water. EIFAC Tech. Pap. 37. Food and Agriculture Organisation, Rome.

Gaur, A. C., and R. P. Pareek. 1976. A study on the effect of certain phenolic acids and fumaric acid in soil on the development of paddy seedlings and nitrogen-fixing bacteria. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. abt. 2. 131:148-156.

Giddings, J. M., A. J. Stewart, R. V. O'Neill, and R. H. Gardner. An efficient algal bioassay based on short-term photosynthetic response. American Society of Testing and Materials (in press).

Gledhill, W. E., R. G. Kaley, W. J. Adams, O. Hicks, P. R. Michael, and V. W. Saeger. 1980. An environmental safety assessment of butyl benzyl phthalate. Environ. Sci. Technol. 14:301-305.

Gräf, W., and W. Nowak. 1966. Promotion of growth in lower and higher plants by carcinogenic polycyclic aromatics. Arch. Hyg. Bakteriol. 150:513-528.

Haghiri, F. 1973. Cadmium uptake by plants. J. Environ. Qual. 2:93-95.

Hale, J. G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17:66-73.

Halstead, R. L., B. J. Finn, and A. J. MacLean. 1969. Extractability of nickel added to soils and its concentration in plants. Can. J. Soil Sci. 49:335-342.

Hammons, A. S., J. E. Huff, H. M. Braunstein, J. S. Drury, C. R. Shiner, E. B. Lewis, B. L. Whitfield, and L. E. Torvill. 1978. Reviews of the Environmental Effects of Pollutants: IV. Cadmium. ORNL/EIS-106. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Heck, W. W., and D. T. Tingey. 1979. Nitrogen dioxide: Time-concentration model to predict acute foliar injury. EPA 600/3/-79-057. U.S. Environmental Protection Agency, Corvallis, Oregon.

Heck, W. W., and E. G. Pires. 1962. Growth of Plants Fumigated with Saturated and Unsaturated Hydrocarbon Gases and Their Derivatives. MP-603. The Agricultural and Mechanical Experiment Station, College Station, Texas.

Herbert, D. W. M., and D. S. Shurben. 1963. A preliminary study of the effect of physical activity on the resistance of rainbow trout (Salmo gairdnerii Richardson) to two poisons. Ann. Appl. Biol. 52:321-326.

Hilton, H. W., and N. Nomura. 1964. Phytotoxicity of herbicides as measured by root absorption. Weed Res. 4:216-222.

Hohreiter, D. W. 1980. Toxicities of Selected Substances to Freshwater Biota. ANL/ES-94. Argonne National Laboratory, Argonne, Illinois.

Huange, C. Y., F. A. Bazzaz, and L. N. Vanderhoef. 1974. The inhibition of soybean metabolism by cadmium and lead. Plant Physiol. 54:122-124.

Ivens, G. W. 1952. The phytotoxicity of mineral oils and hydrocarbons. Ann. Biol. 39:418-422.

John, M. K., and C. J. VanLaerhaven. 1972. Lead uptake by lettuce and oats as affected by lime, nitrogen, and sources of lead. J. Environ. Qual. 1:169-171.

Johnson, S. C. 1967. Hierarchical clustering schemes. Psychometrika 32:241-254.

Johnson, W. W., and M. T. Finley. 1980. Handbook of acute toxicity of chemicals to fish and aquatic invertebrates. U.S. Fish and Wildlife Service Resource Publication 137. U.S. Department of the Interior, Washington, D.C. 98 pp.

Karickhoff, S. W., D. S. Brown, and T. A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res. 13:241-248.

Kingsbury, G. L., R. S. Sims, and J. B. White. 1979. Multimedia Environmental Goals for Environmental Assessment. Vol. IV. EPA-600/7-79-176. U.S. Environmental Protection Agency, Washington, D.C.

Leo, A. C., C. Hansch, and D. Elkins. 1971. Partition coefficients and their uses. Chem. Rev. 71(6):525-616.

Lloyd, R. The toxicity of mixtures of chemicals to fish. IN Hazard Assessment of Complex Effluents, Proceedings of the 5th Pellston Workshop. Pergamon Press, New York (in press).

Lloyd, R., and L. D. Orr. 1969. The diuretic response by rainbow trout to sublethal concentrations of ammonia. Water Res. 3:335-349.

Lynch, J. M. 1977. Phytotoxicity of acetic acid produced in the anaerobic decomposition of wheat straw. J. Appl. Bacteriol. 42:81-87.

Mattson, V. R., J. W. Arthur, and C. T. Walbridge. 1976. Acute Toxicity of Selected Organic Compounds to Fathead Minnows. EPA-600/3-76-097. Environmental Research Laboratory, U.S. Environmental Protection Agency, Duluth, Minnesota.

Mayer, F. L., and H. O. Sanders. 1973. Toxicology of phthalic acid esters in aquatic organisms. Environ. Health Perspect. 3:153-157.

McKee, J. E., and H. W. Wolf (eds.). 1963. Water Quality Criteria 2nd ed. Publ. No. 3-A. California State Water Quality Control Board, Sacramento

McKim, J. M., G. F. Olson, G. W. Holcombe, and E. P. Hunt. 1976. Long-term effects of methylmercuric chloride on three generations of brook trout (Salvelinus fontinalis): Toxicity, accumulation, distribution, and elimination. J. Fish. Res. Board Can. 33:2726-2739.

McLaughlin, S. B., Jr., and G. E. Taylor, Jr. Effects of SO_2 on dicot crops: Some issues, mechanisms and indicators. IN W. E. Winner, H. A. Mooney, and R. A. Goldstein (eds.), The effects of SO_2 on plant productivity. Stanford Univ. Press (in press).

Meyer, H., and A. M. Mayer. 1971. Permeation of dry seeds with chemicals: Use of dichloromethane. Science 171:583-584.

Millemann, R. E., W. J. Birge, J. A. Black, R. M. Cushman, K. L. Daniels, P. J. Franco, J. M. Giddings, J. F. McCarthy, and A. J. Stewart. 1984. Comparative acute toxicity to aquatic organisms of components of coal-derived synthetic fuels. Trans. Am. Fish. Soc. 113:74-85.

Moore, R. E., C. F. Baes III, L. M. McDowell-Boyer, A. P. Watson, F. O. Hoffman, J. C. Pleasant, and C. W. Miller. 1979. AIRDOS-EPA: A computerized methodology for estimating environmental concentrations and dose to man from airborne releases of radionuclides. ORNL/TM-5532. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Mount, D. I., and C. E. Stephan. 1969. Chronic toxicity of copper to the fathead minnow (Pimephales promelas) in soft water. J. Fish. Res. Board Can. 26:2449.

Mukhiya, Y. K., KV. C. Gupta, N. Shrotriya, J. K. Joshi, and V. P. Singh. 1983. Comparative responses of the action of different mercury compounds on barley. Int. J. Environ. Stud. 20:323-327.

Muska, C. F., and L. J. Weber. 1977. An approach for studying the effects of mixtures of environmental toxicants on whole organism performances. pp. 71-87. IN R. A. Tubb (ed.), Recent Advances in Fish Toxicology. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon.

Nag, P., A. K. Paul, and S. Mukherji. 1980. Effects of mercury, copper, and zinc on the growth, cell division, GA-induced α-amylase synthesis and membrane permeability of plant tissues. Indian J. Exp. Biol. 18:822-827.

Naik, M. N., R. B. Jackson, J. Stokes, and R. J. Swaby. 1972. Microbial degradation and phytotoxicity of Picloram and other substituted pyridines. Soil Biol. Biochem. 4:313-323.

National Air Pollution Control Administration (NAPCA). 1970. Air Quality Criteria for Hydrocarbons. AP-64. U.S. Government Printing Office, Washington, D.C.

National Research Council (NRC). 1972. Lead. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1975. Nickel. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1976. Vapor-Phase Organic Pollutants. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1977a. Carbon Monoxide. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1977b. Nitrogen Oxides. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1977c. Arsenic. National Academy of Sciences, Washington, D.C.

National Research Council (NRC). 1979a. Hydrogen Sulfide. University Park Press, Baltimore, Maryland.

National Research Council (NRC). 1979b. Ammonia. University Park Press, Baltimore, Maryland.

National Research Council (NRC). 1979c. Airborne Particles. University Park Press, Baltimore, Maryland.

National Research Council (NRC). 1981. Formaldehyde and Other Aldehydes. National Academy Press, Washington, D.C.

O'Neill, R. V., and J. M. Giddings. 1979. Population interactions and ecosystem function. pp. 103-123. IN G. S. Innis and R. V. O'Neill (eds.), Systems Analysis of Ecosystems. International Cooperative Publishing House, Fairland, Maryland.

O'Neill, R. V., R. H. Gardner, L. W. Barnthouse, G. W. Suter, S. G. Hildebrand, and C. W. Gehrs. 1982. Ecosystem risk analysis: A new methodology. Environ. Toxicol. Chem. 1:167-177.

Oseid, D. M., and L. L. Smith, Jr. 1974. Chronic toxicity of hydrogen sulfide to Gammarus pseudolimnaeus. Trans. Am. Fish. Soc. 103:819-822.

Page, A. L., F. T. Bingham, and C. Nelson. 1972. Cadmium absorption and growth of various plant species as influenced by solution cadmium concentration. J. Environ. Qual. 1:288-291.

Park, R. A., R. V. O'Neill, J. A. Bloomfield, H. H. Shugart, R. S. Booth, R. A. Goldstein, J. B. Mankin, J. F. Koonce, D. Scavia, M. S. Adams, L. S. Clesceri, E. M. Colon, E. H. Dettmann, J. Hoopes, D. D. Huff, S. Katz, J. F. Kitchell, R. C. Kohberger, E. J. LaRow, D. C. McNaught, J. Petersen, J. Titus, P. R. Weiler, J. W. Wilkinson, and C. S. Zahorcak. 1974. A generalized model for simulating lake ecosystems. Simulation 23:33-50.

Parkhurst, B. R. 1981. Unpublished data on acute toxicity of coal organics to Daphnia magna. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Parkhurst, B. R., J. S. Meyer, G. M. DeGraeve, and H. L. Bergman. 1981. A reevaluation of the toxicity of coal conversion process waters. Bull. Environ. Contam. Toxicol. 26:9-15.

Pickering, Q. H., and C. Henderson. 1966a. Acute toxicity of some important petrochemicals to fish. J. Water Pollut. Control. Fed. 38(9):1419-1429.

Pickering, Q. H., and C. Henderson. 1966b. The acute toxicity of some heavy metals to different species of warm water fishes. Air Water Pollut. 10:453-463.

Pickering, Q. H. 1974. Chronic toxicity of nickel to the fathead minnow. J. Water Pollut. Control Fed. 37:1308-1316.

Pizey, J. S., and R. L. Wain. 1959. Pre-emergent herbicidal activity of some substituted amides and related compounds. J. Sci. Food Agric. 10:577-584.

Rehwoldt, R., L. Lasko, C. Shaw, and E. Wirhouski. 1973. The acute toxicity of some heavy metal ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10:291-294.

Rice, S. D., and R. M. Stokes. 1975. Acute toxicity of ammonia to several developmental stages of rainbow trout, Salmo gairdneri. Fish. Bull. U.S. Natl. Mar. Fish. Serv. 73:207-211.

Ruesink, R. G., and L. L. Smith, Jr. 1975. The relationship of the 96-hour LC_{50} to the lethal threshold concentration of hexavalent chromium, phenol, and sodium pentachlorophenate for fathead minnows (Pimephales promelas Rafinesque). Trans. Am. Fish. Soc. 3:567-570.

Sanders, H. O., and O. B. Cope. 1966. Toxicities of several pesticides to two species of cladocerans. Trans. Am. Fish. Soc. 95:165-169.

Sanders, H. O., and O. B. Cope. 1968. The relative toxicities of several pesticides to naiads of three species of stoneflies. Limnol. Oceanogr. 13:112-117.

Schell, W. R., and T. H. Sibley. 1982. Distribution coefficients for radionuclides in aquatic environments. NUREG/CR-1869. U.S. Government Printing Office, Washington, D.C.

Schlesinger, A. H., and D. T. Mowry. 1951. Benzothiophenes and their 1-dioxides. J. Am. Chem. Soc. 73:2614-2616.

Schultz, T. W., M. Cajina-Quezada, and J. N. Dumont. 1980. Structure-toxicity relationships of selected nitrogenous heterocyclic compounds. Arch. Environ. Contam. Toxicol. 9:591-598.

Shukla, S. P. 1972. The effects of some chemicals on the germination of a weed, Psoralea corylifolia L. Weed Res. 12:293-300.

Scientific Group on Methods for the Safety Evaluation of Chemicals (SGOMSEC). Joint Report of the Workshop on Methods for Assessing the Effects of Mixtures of Chemicals. John Wiley & Sons, Ltd., Chichester, England (in press).

Siegel, B. Z., and S. M. Siegel. 1979. Biological indicators of atmospheric mercury. pp. 131-159. In J. O. Nriagu, (ed.), The Biogeochemistry of Mercury in the Environment. Elsevier/North-Holland Biomedical Press, New York.

Smith, L. L., D. M. Oseid, G. L. Kimball, and S. M. Elkandelgy. 1976. Toxicity of hydrogen sulfide to various life history stages of bluegill (Lepomis macrochirus). Trans. Am. Fish. Soc. 105:442-449.

Southworth, G. R. 1979. Transport and transformation of anthracene in natural waters. pp. 359-380. IN L. L. Marking and R. A. Kimmerle (eds.), Aquatic Toxicology. ASTM STP 667. American Society for Testing and Materials, Philadilphia, Pennsylvania..

Sprague, J. B., and B. A. Ramsay. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. J. Fish. Res. Board Can. 22:213-234.

Stahl, Q. R. 1969. Air Pollution Aspects of Mercury and its Compounds. Litton Systems, Inc., Bethesda, Maryland.

Suter, G. W. II, and D. S. Vaughan. 1984. Extrapolation of ecotoxicity data: Choosing tests to suit the assessment. pp. 387-399. IN K. E. Cowser and C. R. Richmond (eds.), Synthetic Fossil Fuel Technologies: Results of Health and Environmental Studies. Butterworth Publishers, Boston, Massachusetts.

Suter, G. W. II, D. S. Vaughan, and R. H. Gardner. 1983. Risk assessment by analysis of extrapolation error: A demonstration for effects of pollutants on fish. Environ. Toxicol. Chem. 2:369-378.

Taylor, G. E., Jr. The significance of the developing energy technologies of coal conversion to plant productivity. J. Am. Soc. Hort. Sci. (in press).

Thompson, C. R., and G. Kats. 1978. Effects of continuous H_2S fumigation on crop and forest plants. Environ. Sci. Technol. 12:550-553.

Travis, C. C., C. F. Baes III, L. W. Barnthouse, E. L. Etnier, G. A., Holton, B. D. Murphy, G. P. Thompson, G. W. Suter II, and A. P. Watson. 1983. Exposure assessment methodology and reference environments for synfuel risk analysis. ORNL/TM-8672. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

TRW. 1983. Source term estimates for synthetic fuels technologies: Direct coal liquefaction technologies. TRW Energy Technology Division, Redondo Beach, California.

Underhill, G. W., and J. A. Cox. 1940. Carbon disulphide and dichloroethyl ether as soil fumigants for the woolly aphid, Eroisoma lanigerum Hausm. V. Fruit 28:20-26.

U.S. Environmental Protection Agency (USEPA). 1980a. Ambient Water Quality Criteria for Carbon Tetrachloride. EPA 440/5-80-026. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980b. Ambient Water Quality Criteria for Chloroform. EPA 440/5-80-033. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980c. Ambient Water Quality Criteria for Benzene. EPA 440/5-80-018. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980d. Ambient Water Quality Criteria for Toluene. EPA 440/5-80-075. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980e. Ambient Water Quality Criteria for Napthalene. EPA 440/5-80-059. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980f. Ambient Water Quality Criteria for Fluoranthene. EPA 440/5-80-049. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980g. Ambient Water Quality Criteria for Phenol. EPA 440/5-80-066. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980h. Ambient Water Quality Criteria for 2,4 Dimethylphenol. EPA 440/5-80-044. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980i. Ambient Water Quality Criteria for Acrolein. EPA 440/5-80-016. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980j. Ambient Water Quality Criteria for Phthalate Esters. EPA 440/5-80-067. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980k. Ambient Water Quality Criteria for Acrylonitrile. EPA 440/5-80-017. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980l. Ambient Water Quality Criteria for Arsenic. EPA 440/5-80-021. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980m. Ambient Water Quality Criteria for Mercury. EPA 440/5-80-058. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980n. Ambient Water Quality Criteria for Nickel. EPA 440/5-80-060. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980o. Ambient Water Quality Criteria for Cadmium. EPA 440/5-80-025. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980p. Ambient Water Quality Criteria for Lead. EPA 440/5-80-057. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1982. Air quality criteria for particulate matter and sulfur oxides. EPA-600/8-82-029c. Environmental Criteria and Assessment Office, Research Triangle, Park, N.C.

U.S. Geological Survey (USGS). 1977. Water Resources Data for Kentucky WY-1976. USGS Water Data Report KY 76-1.

U.S. Geological Survey (USGS). 1979. Water Resources Data for Pennsylvania WY-1978. Vol. 3. Ohio River and St. Lawrence River basins. USGS Water-Data Report PA-78-3.

Vergnano, O., and J. G. Hunter. 1953. Nickel and cobalt toxicities in oat plants. Ann. Bot. 17:317-328.

Verschueren, K. 1977. Handbook of Environmental Data on Organic Chemicals. Van Nostrand Reinhold Co., New York.

Wakabayashi, M., B. G. Bang, and F. B. Bang. 1977. Mucociliary transport in chickens infected with newcastle disease virus and exposed to sulfur dioxide. Arch. Environ. Health 32:101-108.

Waldron, L. J., and N. Terry. 1975. Effect of mercury vapor on sugar beets. J. Environ. Qual. 4:58-60.

Wallen, I. E., W. C. Greer, and R. Lasater. 1957. Toxicity to Gambusia affinis of certain pure chemicals in turbid waters. Sewage Ind. Wastes 29:695-711.

Warnick, S. L., and H. L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. J. Water Pollut. Control Fed. 41:280-284.

Weast, R. C. (ed.). 1980. Handbook of Chemistry and Physics. CRC Press, Cleveland, Ohio.

Woolson, E. A., J. H. Axley, and P. C. Kearny. 1971. Correlation between available soil arsenic, estimated by six methods, and response of corn (Zea mays L.). Soil Sci. Soc. Am. Proc. 35:101-105.

Zahn, R. 1975. Begasungsuerusche mit NO_2 in Kleingewächshäuserun. Staub Reinhalt. Luft 35:194-196.

Zepp, R. G., and P. M. Cline. 1977. Rates of direct photolysis in aquatic environment. Environ. Sci. Technol. 11:359-366.

Zepp, R. G., and P. F. Schlotzhauer. 1979. Photoreactivity of selected aromatic hydrocarbons in water. IN P. W. Jones and P. Leber (eds.), Polynuclear Aromatic Hydrocarbons. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

APPENDIX A

Aquatic Toxicity Data

Table A-1. Acute toxicity of synfuels chemicals to aquatic animals

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
1	Carbon monoxide					No toxicity data	
2	Sulfur oxides					Aquatic problems associated with pH, not direct toxicity	
3	Nitrogen oxides					Aquatic problems associated with pH, not direct toxicity	
4	H_2S	Scud (*Gammarus pseudolimnaeus*)	LC_{50}	96	0.022		Oseid and Smith 1974
		Bluegill					
		(adults)	TL_m	96	0.0448	Flow-through test	Smith et al. 1976
		(juveniles)	TL_m	96	0.0478	Flow-through test	Smith et al. 1976
		(fry, 35-d-old)	TL_m	96	0.0131	Flow-through test	Smith et al. 1976
		(eggs)	TL_m	72	0.0190	Flow-through test	Smith et al. 1976
		Northern pike					
		(eggs)	TL_m	96	0.034-0.037	DO = 2-6 ppm	Adelman and Smith 1970
		(fry)	TL_m	96	0.009-0.026	DO = 2-6 ppm	Adelman and Smith 1970
5	Ammonia	Rainbow trout					
		(fry, 85-d-old)	TL_m	24	0.068		Rice and Stokes 1975
		(adults)	TL_m	24	0.097		Rice and Stokes 1975
		Rainbow trout	LC_{50}	24	0.50		Herbert and Shurben 1963
		Rainbow trout	LC_{50}	24	0.47		Lloyd and Orr 1969
		Rainbow trout (fry)	LC_{50}	24	0.2		EIFAC 1970
		(fingerlings)	LC_{50}	24	0.2		EIFAC 1970
6	Heptane	Mosquitofish	TL_m	96	4924		Wallen et al. 1957
7	Formaldehyde	Several fish species	LC_{50}	24	50-120		National Research Council 1981

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
8	Carbon tetrachloride	Daphnia magna	LC_{50}	48	35.2		US EPA 1980a
		Fathead minnow	LC_{50}	96	43.1	Flow-through test	US EPA 1980a
		Bluegill	LC_{50}	96	27.3		US EPA 1980a
		Bluegill	LC_{50}	96	125.0		US EPA 1980a
	Chloroform	D. magna	LC_{50}	48	28.9		US EPA 1980b
		Bluegill	LC_{50}	96	100.0		US EPA 1980b
		Bluegill	LC_{50}	96	115.0		US EPA 1980b
		Rainbow trout	LC_{50}	96	43.8		US EPA 1980b
9	Acetic acid	Fathead minnow	LC_{50}	96	88.0		Mattson et al. 1976
		Mosquitofish	TL_m	96	251.0		Wallam et al. 1957
10	Volatile O- and S-heterocyclics					No toxicity data	
11	Pyridine	Ciliate (Tetrahymena pyriforma)	LC_{50}	72	1211.8	50% growth inhibition	Schultz et al. 1980
		D. magna	LC_{50}	48	1165		Canton and Adema 1978
		D. magna	LC_{50}	48	1755		Canton and Adema 1978
12	Benzene	D. magna	LC_{50}	48	203.0-620.0		US EPA 1980c
		D. magna	LC_{50}	48	426.0		Canton and Adema 1978
		Fathead minnow	LC_{50}	96	32.0		US EPA 1980c
		Fathead minnow	LC_{30}	96	15.1	Flow-through test	DeGraeve et al. 1982
		Mosquitofish	LC_{50}	96	1300.0		Wallam et al. 1957
		Rainbow trout	LC_{50}	96	5.3	Flow-through test	US EPA 1980c
13	Cyclohexane	Fathead minnow	LC_{50}	96	93.0		Mattson et al. 1976
		Fathead minnow	TL_m	96	30.0		Pickering and Henderson 1966a
		Fathead minnow	TL_m	96	32.0		Pickering and Henderson 1966a
		Bluegill	TL_m	96	31.0		Pickering and Henderson 1966a
	Indan	Fathead minnow	LC_{50}	96	14.0		Mattson et al. 1976

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
14	Toluene	D. magna	LC_{50}	48	39.22		Millemann, et al. 1984
		Fathead minnow	TL_m	96	44.0		Pickering and Henderson 1966a
		Fathead minnow	TL_m	96	45.0		Pickering and Henderson 1966a
		Bluegill	TL_m	96	24.0		Pickering and Henderson, 1966a
		Bluegill	LC_{50}	96	12.7		US EPA 1980d
	Naphthalene	D. magna	LC_{50}	48	2.16		Millemann et al. 1984
		D. magna	LC_{50}	48	8.57		US EPA 1980e
		Fathead minnow	LC_{50}	48	3.14		Millemann et al. 1984
		Fathead minnow	LC_{50}	96	4.90-8.90	2 tests	US EPA 1980e
		Rainbow trout	LC_{50}	96	2.30		US EPA 1980e
	Xylene	Fathead minnow	TL_m	96	42.0		Mattson et al. 1976
		Goldfish	TL_m	96	17.0		Brenniman et al. 1976
15	Antnracene					Not toxic to fish, even in super-saturated solutions	McKee and Wolf 1963
	Phenanthrene	D. magna	LC_{50}	48	0.75		Millemann et al. 1984
		D. magna	LC_{50}	48	1.10		Parkhurst 1981
		Rainbow trout (embryo-larva)	LC_{50}	96	0.04		Birge and Black 1981
	Fluorantnene	D. magna	LC_{50}	48	325.0		US EPA 1980f
		Bluegill	LC_{50}	96	3.9		US EPA 1980f
16	Aliphatic amines					No toxicity data	
17	Aniline	D. magna	LC_{50}	48	0.65		Canton and Adema 1978
		Daphnia cucullata	LC_{50}	48	0.68		Canton and Adema 1978
		D. magna	LC_{50}	48	0.58		Millemann et al. 1984
	3,5-Dimethylaniline	D. magna	LC_{50}	48	1.29		Millemann et al. 1984

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
18	Quinoline	Ciliate (*T. pyriforma*)	LC_{50}	72	125.7	50% growth inhibition	Schultz et al. 1980
		D. magna	LC_{50}	48	30.28		Millemann et al. 1984
		Fathead minnow	LC_{50}	48	1.50		Millemann et al. 1984
		Fathead minnow	LC_{50}	96	46.0		Mattson et al. 1976
	2-Methylquinoline	Ciliate (*T. pyriforma*)	EC_{50}	72	48.7	50% growth inhibition	Schultz et al. 1980
	2,6-Dimethylquinoline	Ciliate (*T. pyriforma*)	EC_{50}	72	33.0	50% growth inhibition	Schultz et al. 1980
19	Neutral N-,O-,S-heterocyclics					No toxicity data	
20	Benzoic acid	Mosquitofish	TL_m	96	180		Wallam et al. 1957
21	Phenol	*D. magna*	LC_{50}	48	19.79		Millemann et al. 1984
		D. magna	LC_{50}		9.6		US EPA 1980g
		D. magna (Young)	TL_m	50	7.0		Dowden and Bennett 1965
		Copepod (*Mesocyclops leukarti*)	LC_{50}		108.0		US EPA 1980g
		Fathead minnow	LC_{50}	48	25.6		Millemann et al. 1984
		Fathead minnow	LC_{50}	96	24.0-67.5	4 tests	US EPA 1980g
		Bluegill	LC_{50}		11.5-23.9	6 tests	US EPA 1980g
		Rainbow trout	LC_{50}		8.9-11.6	2 flow-through tests	US EPA 1980g
	2-Methyphenol	*D. magna*	LC_{50}	48	9.2		US EPA 1980g
		D. magna	LC_{50}	48	23.5		US EPA 1980g
		Fathead minnow	TL_m	96	12.55	Soft water	Pickering and Henderson 1966a
		Fathead minnow	TL_m	96	13.42	Hard water	Pickering and Henderson 1966a
		Bluegill	TL_m	96	20.78	Soft water	Pickering and Henderson 1966a
	4-Methylphenol	Fathead minnow	TL_m	96	19.0		Mattson et al. 1976

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
	Mixed cresol isomers	Aquatic life	TL_m	96	1.0-10.0		Kingsbury et al. 1979
	2,4-Dimethylphenol	D. magna	LC_{50}	48	2.12		US EPA 1980h
		Fathead minnow (juvenile)	LC_{50}	96	16.75	Flow-through test	US EPA 1980h
		Bluegill	LC_{50}	96	7.75		US EPA 1980h
	3,4-Dimethylphenol	Fathead minnow	LC_{50}	96	14.0		Mattson et al. 1976
	2,5-Dimethylphenol	D. magna	LC_{50}	48	0.96		Millemann et al. 1984
22	Acrolein	D. magna	LC_{50}	48	0.057		US EPA 1980i
		D. magna	LC_{50}	48	0.080		US EPA 1980i
		Mosquitofish	LC_{50}	48	0.061		National Research Council 1981
		Bluegill	LC_{50}	96	0.100		US EPA 1980i
		Bluegill	LC_{50}	96	0.090		US EPA 1980i
		Brown trout	LC_{50}	24	0.046		National Research Council 1981
		Rainbow trout	LC_{50}	24	0.065		National Research Council 1981
		Largemouth bass	LC_{50}	96	0.160		US EPA 1980i
	Acetaldehyde	Bluegill	LC_{50}	96	53.0		National Research Council 1981
	Acetone	D. magna	LC_{50}	48	12,600		Canton and Adema 1978
23	Nonheterocylic organosulfur					No toxicity data	
24	Alcohols					No toxicity data	
25	Nitroaromatics					No toxicity data	
26	Di-2-ethylhexyl phthalate	D. magna	LC_{50}		11.1		US EPA 1980j

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type[b]	Duration (h)	Concentration (mg/L)	Notes[c]	Reference
	Diethyl phthalate	D. magna	LC_{50}		52.1		US EPA 1980j
		Bluegill	LC_{50}		98.2		US EPA 1980j
	Butylbenzl phthalate	D. magna	LC_{50}		92.3		US EPA 1980j
		D. magna	LC_{50}	48	3.7		Gledhill et al. 1980
		Fathead minnow	LC_{50}	96	5.3	Hardness: 160	Gledhill et al. 1980
		Fathead minnow	LC_{50}	96	2.1	Hardness: 40	Gledhill et al. 1980
		Bluegill	LC_{50}		43.3		US EPA 1980j
		Bluegill	LC_{50}	96	1.7		Gledhill et al. 1980
		Rainbow trout	LC_{50}	96	3.3		Gledhill et al. 1980
	Di-n-butyl phthalate	Scud (G. pseudo-limnaeus)	LC_{50}	96	2.1		Mayer and Sanders 1973
		Fathead minnow	LC_{50}	96	1.3		Mayer and Sanders 1973
		Bluegill	LC_{50}	96	0.73		Mayer and Sanders 1973
		Rainbow trout	LC_{50}	96	6.47		Mayer and Sanders 1973
27	Amides					No toxicity data	
28	Acrylonitrile	D. magna	LC_{50}		7.55		US EPA 1980k
		Fathead minnow	LC_{50}	96	14.3		US EPA 1980k
		Fathead minnow	LC_{50}	96	18.1		US EPA 1980k
		Fathead minnow	LC_{50}	96	10.1	Flow-through test	US EPA 1980k
		Bluegill	LC_{50}	96	11.8		US EPA 1980k
		Bluegill	LC_{50}		10.1		US EPA 1980k
29	Tars					No aquatic emissions	
30	Respirable particles					No aquatic emissions	
31	Arsenic	D. magna	TL_m	48	7.4		Hohreiter 1980
		D. magna	EC_{50}	48	5.28	Immobilization	Anderson 1946
		Daphnia pulex	EC_{50}	48	1.04	Immobilization	Sanders and Cope 1966
		Stonefly (Pteronarcys californica)	LC_{50}	96	22.04		Sanders and Cope 1968
		Fathead minnow (juvenile)	LC_{50}	96	15.66	Flow-through test	Cardwell et al. 1976
		Bluegill (juvenile)	LC_{50}	96	41.76	Flow-through test	Cardwell et al. 1976
		Bluegill	LC_{50}		15.37		US EPA 1980l
		Rainbow trout	LC_{50}		13.34		US EPA 1980l
		Brook trout	LC_{50}	93	14.96	Flow-through test	Cardwell et al. 1976

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
32	Mercury (inorganic)	*D. magna*	LC_{50}	48	0.005		Biesinger and Christensen 1972
		Stonefly (*Acroneuria lycorius*)	TL_m	96	2.0		Warnick and Bell 1969
		Fathead minnow	LC_{50}		0.19		US EPA 1980m
		Rainbow trout	LC_{50}		0.31		Hohreiter 1980
		Coho salmon	LC_{50}		0.24		US EPA 1980m
		Rainbow trout (juvenile)	LC_{50}		0.155-0.4	4 tests	US EPA 1980m
	Methylmercury	Rainbow trout	LC_{50}		0.03		Hohreiter 1980
		Rainbow trout					
		(sac fry)	LC_{50}	96	0.024		Hohreiter 1980
		(fingerling)	LC_{50}	96	0.042		Hohreiter 1980
		(Juvenile)	LC_{50}		0.025		US EPA 1980m
		Brook trout					
		(juvenile)	LC_{50}	96	0.084	Flow-through test	McKim et al. 1976
		(yearling)	LC_{50}	96	0.065	Flow-through test	McKim et al. 1976
33	Nickel	*D. magna*	LC_{50}		1.81	Hardness: 51	US EPA 1980n
		D. magna	LC_{50}		2.34	Hardness: 100	US EPA 1980n
		Mayfly (*Ephemerella subvaria*)	TL_m	96	4.0	Hardness: 42	Warnick and Bell 1969
		Stonefly (*A. lycorius*)	TL_m	96	33.5	Hardness: 40	Warnick and Bell 1969
		Damselfly (unidentified)	TL_m	96	21.2	Hardness: 50	Rehwoldt et al. 1973
		Midge (*Chironomus* sp.)	TL_m	96	8.6	Hardness: 50	Rehwoldt et al. 1973
		Caddisfly (unidentified)	TL_m	96	30.2	Hardness: 50	Rehwoldt et al. 1973
		Fathead minnow	LC_{50}		4.58-5.18	Hardness: 20 2 flow-through tests	US EPA 1980n
		Fathead minnow	TL_m	96	25.0	Hardness: 210 flow-through test	Pickering 1974
		Bluegill	TL_m	96	5.18-5.36	Hardness: 20 2 tests	Pickering and Henderson 1966b
		Bluegill	TL_m	96	39.6	Hardness: 360	Pickering and

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
							Henderson 1966b
		Rainbow trout	LC_{50}	96	35.5	Flow-through test	Hale 1977
		Fish sp., general	LC_{50}	96	4.6-9.8	Soft water	Hohreiter 1980
		Fish sp., general	LC_{50}	96	39.2-42.4	Hard water	Hohreiter 1980
34	Cadmium	*D. magna*	LC_{50}		0.0099	Hardness: 51	US EPA 1980o
		D. magna	LC_{50}		0.033	Hardness: 104	US EPA 1980o
		D. magna	LC_{50}		0.049	Hardness: 209	US EPA 1980o
		Mayfly (*Ephemerella grandis grandis*)	TL_m	96	28.0		Clubb et al. 1975
		Mayfly (*E. subvaria*)	TL_m	96	2.0	Hardness: 54	Warnick and Bell 1969
		Stonefly (*Pteronarcella badia*)	TL_m	96	18.0		Clubb et al. 1975
		Damselfly (unidentified)	TL_m	96	8.1	Hardness: 50	Rehwoldt et al. 1973
		Midge (*Chironomus*)	TL_m	96	1.2	Hardness: 50	Rehwoldt et al. 1973
		Caddisfly (unidentified)	TL_m	96	3.4	Hardness: 50	Rehwoldt et al. 1973
		Fathead minnow	TL_m	96	0.630	Hardness: 20	Pickering and Henderson 1966b
		Fathead minnow	TL_m	96	72.6	Hardness: 360	Pickering and Henderson 1966b
		Bluegill	TL_m	96	1.94	Hardness: 20	Pickering and Henderson 1966b
		Bluegill	LC_{50}		21.1	Hardness: 207	US EPA 1980o
		Rainbow trout (swim-up and parr)	LC_{50}	96	0.001-0.00175	Hardness: 23 2 flow-through tests	US EPA 1980o
		Rainbow trout	LC_{50}	96	0.00175	Hardness: 31; flow-through test	US EPA 1980o
		Carp	LC_{50}		0.24	Hardness: 55	US EPA 1980o
		Chinook salmon (Parr)	LC_{50}		0.0035	Hardness: 23	US EPA 1980o
		Brook trout	LC_{50}		0.0024	Hardness: 44 (sodium sulfate)	US EPA 1980o
		Green sunfish	LC_{50}		2.84	Hardness: 20	US EPA 1980o
		Pumpkinseed	LC_{50}		1.5	Hardness: 55	US EPA 1980o

Table A-1. (continued)

RAC	Representative chemical(s)	Test organism[a]	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
35	Lead	D. magna	LC_{50}		0.612	Hardness: 54	US EPA 1980p
		D. magna	LC_{50}		0.952	Hardness: 110	US EPA 1980p
		Fathead minnow	LC_{50}	96	2.4	Hardness: 20	US EPA 1980p
		Fathead minnow	TL_m	96	482.0	Hardness: 360	Pickering and Henderson 1966b
		Bluegill	TL_m	96	23.8	Hardness: 20	Pickering and Henderson 1966b
		Bluegill	TL_m	96	442.0	Hardness: 360	Pickering and Henderson 1966b
		Rainbow trout (fry)	LC_{50}	96	0.6		Hohreiter 1980
		Rainbow trout	LC_{50}	96	1.17	Hardness: 32; flow-through test	Davies et al. 1976
		Rainbow trout	LC_{50}	96	1.0		Hohreiter 1980
		Rainbow trout	LC_{50}	96	8.0		US EPA 1980p
		Brook trout	LC_{50}	96	4.1	Hardness: 44	US EPA 1980p
36	Fluorine	D. magna		48	270.0	"Toxic threshold"	Hohreiter 1980
		Goldfish		96	120.0	100% kill	Hohreiter 1980
		Goldfish		12-29	1000.0	100% kill in soft water	Hohreiter 1980
		Goldfish		60-102	1000.0	100% kill in hard water	Hohreiter 1980
		Rainbow trout	TL_m	240	2.3-7.5	TL_m varies with temperature	Angelovic et al. 1961

[a]Latin binomials are listed in Appendix C.

[b]LC_{50} = concentration required to kill 50% of test organisms.
TL_m = median tolerance limit.
EC_{20} = effective concentraton causing a designated effect on 20% of test organismsn.

[c]Hardness values are given in milligrams per liter as CaCO3. DO = dissolved oxygen.

Table A-2. Chronic toxicity of synfuels chemicals to aquatic animals.

RAC	Representative chemical(s)	Test organism[a]	Test type	Duration (d)	Concentration (mg/L)	Notes	Reference
8	Carbon tetrachloride	Fathead minnow	Embryo-larval		>3.4		U.S. EPA, 1980a
	Chloroform	Rainbow trout	Embryo-larval	27	1.2	200 mg/L water hardness	U.S. EPA, 1980b
		Rainbow trout	Embryo-larval	27	2.0	50 mg/L water hardness	U.S. EPA, 1980b
		Rainbow trout	Embryo	23	10.6	40% teratogenesis	U.S. EPA, 1980b
12	Benzene	*Daphnia magna*	Life cycle		>98.0		U.S. EPA, 1980c
14	Naphthalene	Fathead minnow	Embryo-larval		0.62		U.S. EPA, 1980e
21	Phenol	Fathead minnow	Embryo-larval		2.56		U.S. EPA, 1980g
	2,4-Dimethylphenol	Fathead minnow	Embryo-larval		2.191		U.S. EPA, 1980h
		Fathead minnow	Embryo-larval		2.475		U.S. EPA, 1980h
22	Acrolein	*D. magna*	Life cycle		0.024		U.S. EPA, 1980i
		D. magna	Life cycle		0.034	Survival reduced after 64 days	National Research Council, 1981
		Fathead minnow	Life cycle		0.021		U.S. EPA, 1980i
26	Di-2-ethylhexyl phthalate	*D. magna*	Life cycle		<0.003		U.S. EPA, 1980j
		Rainbow trout	Embryo-larval		0.008		U.S. EPA, 1980j
	Butylbenzyl phthalate	*D. magna*	Life cycle		0.44		U.S. EPA, 1980j
		Fathead minnow	Embryo-larval		0.22		U.S. EPA, 1980j
28	Acrylonitrile	*D. magna*	Life cycle		>3.6		U.S. EPA, 1980k
		Fathead minnow	LC_{50}	30	2.6		U.S. EPA, 1980k
31	Arsenic	*D. magna*	Life cycle		0.912		U.S. EPA, 1980l
		D. magna	TLm	21	2.85		Hohreiter, 1980
		Bass sp., general		10	7.60	Toxic	Hohreiter, 1980
		Pink salmon		10	5.00	Lethal	Hohreiter, 1980
32	Mercuric chloride	*D. magna*	Life cycle		0.001 - 0.0025	4 tests	U.S. EPA, 1980m
	Methylmercuric chloride	*D. magna*	Life cycle		0.001		U.S. EPA, 1980m
		Fathead minnow			0.00023	92% dead, 3 months	Hohreiter, 1980
		Brook trout	Life cycle		0.00052		U.S. EPA, 1980m

Table A-2. (continued).

RAC	Representative chemical(s)	Test organism[a]	Test type	Duration (d)	Concentration (mg/L)	Notes	Reference
33	Nickel	*D. magna*	Life cycle		0.015	Hardness: 51 (mg/L as $CaCO_3$)	U.S. EPA, 1980n
		D. magna	Life cycle		0.123	Hardness: 105	U.S. EPA, 1980n
		Caddisfly (*Clistoronia magnifica*)	Life cycle		0.465	Hardness: 50	U.S. EPA, 1980n
		Fathead minnow	Embryo-larval		0.109	Hardness: 44	U.S. EPA, 1980n
		Fathead minnow	Life cycle		0.527	Hardness: 210	U.S. EPA, 1980n
		Rainbow trout	Embryo-larval		0.350	Hardness: 50	U.S. EPA, 1980n
34	Cadmium	*D. magna*	Life cycle		0.00015	Hardness: 53	U.S. EPA, 1980o
		D. magna	Life cycle		0.00021	Hardness: 103	U.S. EPA, 1980o
		D. magna	Life cycle		0.00044	Hardness: 209	U.S. EPA, 1980o
		Midge (*Tanytarsus dissimilis*)			0.0031		U.S. EPA, 1980o
		Fathead minnow	Life cycle		0.046	Hardness: 201	U.S. EPA, 1980o
		Bluegill	Life cycle		0.050	Hardness: 207	U.S. EPA, 1980o
		Brook trout	Embryo-larval		0.0017	Hardness: 36	U.S. EPA, 1980o
		Brook trout	Embryo-larval		0.0092	Hardness: 187	U.S. EPA, 1980o
35	Lead	*D. magna*	Life cycle		0.012	Hardness: 52	U.S. EPA, 1980p
		D. magna	Life cycle		0.128	Hardness: 151	U.S. EPA, 1980p
		Stonefly (*Acroneuria lycorias*)	LC_{50}	14	64.0		Hohreiter, 1980
		Mayfly (*Ephemerella subvaria*)	LC_{50}	7	16.0		Hohreiter, 1980
		Caddisfly (*Hydropsyche betteri*)	LC_{50}	7	32.0		Hohreiter, 1980
		Bluegill	Embryo-larval		0.092	Hardness: 41	U.S. EPA, 1980p
		Rainbow trout	Embryo-larval		0.019	Hardness: 28	U.S. EPA, 1980p
		Rainbow trout	Embryo-larval		0.102	Hardness: 35	U.S. EPA, 1980p
36	Fluorine	Rainbow trout		21	113.0	100% kill, 45 mg/L $CaCO_3$	Hohreiter, 1980
		Rainbow trout		21	250.0	100% kill, 320 mg/L $CaCO_3$, yearling trout	Hohreiter, 1980

[a]Latin binomials are listed in Appendix C.

Table A-3. Toxicity of synfuels chemicals to algae.

RAC	Representative chemical(s)	Test organism	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
12	Benzene	Chlorella vulgaris	EC_{50}	48	525.0	Reduction in cell numbers	U.S. EPA, 1980c
14	Toluene	C. vulgaris	EC_{50}	24	245.0	Reduction in cell numbers	U.S. EPA, 1980d
		Selenastrum capricornutum	EC_{50}	96	433.0	Reduction in cell numbers and chlorophyll a production	U.S. EPA, 1980d
	Naphthalene	C. vulgaris	EC_{50}	48	33.0	Reduction in extrapolated cell numbers	U.S. EPA, 1980e
		Chalamydomonas angulosa	EC_{61}	24	34.4	61% mortality of cells	U.S. EPA, 1980e
15	Fluoranthene	S. capricornutum	EC_{50}	96	54.4	Reduction in cell numbers	U.S. EPA, 1980f
		S. capricornutum	EC_{50}	96	54.6	Reduction in chlorophyll a production	U.S. EPA, 1980f
17	Aniline	Agmenellum quadruplicatum			0.010	Diffusion from disk onto algal lawn inhibited growth for 3-7 days	Batterton et al., 1978
	p-Toluidene	A. quadruplicatum			0.010	Same as above for all 4 species	Batterton et al., 1978
		Coccochloris elabens			0.010		
		Eucapsis sp.			0.010		
		Oscillatoria williamsii			0.010		
21	Phenol	S. capricornutum			20.0	Growth inhibition of 12-66% depending on time (2-3 d) and temperature (20, 24, 28°C)	U.S. EPA, 1980g
		S. capricornutum	EC_{50}	24	40.0	Reduction in cell numbers	U.S. EPA, 1980g
		Nitzschia linearis	EC_{50}	120	258.0	Reduction in cell numbers	U.S. EPA, 1980g
		Chlorella pyrenoidosa	EC_{100}	48	1500.0	Complete destruction of chlorophyll	U.S. EPA, 1980g
	2,4-Dimethylphenol	C. vulgaris	EC_{20}	80	470.0	Growth inhibition	U.S. EPA, 1980g
		C. pyrenoidosa	EC_{100}	48	500.0	Complete destruction of chlorophyll	U.S. EPA, 1980g

Table A-3. (continued).

RAC	Representative chemical(s)	Test organism	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
26	Butylbenzyl phthalate	*S. capricornutum*	EC_{50}	96	0.11	Reduction in chlorophyll *a*	U.S. EPA, 1980j
		S. capricornutum	EC_{50}	96	0.13	Reduction in cell numbers	U.S. EPA, 1980j
		Microcystis aeruginosa	EC_{50}	96	1000.0	Reduction in cell numbers	U.S. EPA, 1980j
		Navicula pelliculosa	EC_{50}	96	0.60	Reduction in cell numbers	U.S. EPA, 1980j
	Dimethyl phthalate	*S. capricornutum*	EC_{50}	96	42.7	Reduction in chlorophyll *a*	U.S. EPA, 1980j
		S. capricornutum	EC_{50}	96	39.8	Reduction in cell numbers	U.S. EPA, 1980j
	Diethyl phthalate	*S. capricornutum*	EC_{50}	96	90.3	Reduction in chlorophyll *a*	U.S. EPA, 1980j
		S. capricornutum	EC_{50}	96	85.6	Reduction in cell numbers	U.S. EPA, 1980j
31	Arsenic	*Cladophora*, *Spirogyra*, *Zygnema* sp.	EC_{100}	336	2.32	100% kill	U.S. EPA, 1980l
		Scenedesmus sp.		96	20.0	Threshold effects	Cushman et al., 1977
32	Mercuric chloride	*C. vulgaris*	EC_{50}	768	1.03	Cell division inhibition	U.S. EPA, 1980m
		Spring diatom assemblages	EC_{50}	2	0.08	Reduction in photosynthetic activity	U.S. EPA, 1980m
	Methylmercuric chloride	*Coelastrum microporum*	EC_{50}		2.4-4.8	Growth inhibition	U.S. EPA, 1980m
33	Nickel	*Chlamydomonas*, *Chlorella*, *Haematococcus*, *Scenedesmus* sp.			0.1-0.7	Growth reduced in all cultures in water with 50 mg/L $CaCO_3$	U.S. EPA, 1980n
		Phormidium ambiguum	EC_{16}	336	0.5-10.0	Growth inhibition	Cushman et al., 1977
		Scenedesmus			1.5	Threshold effects	Cushman et al., 1977
34	Cadmium	*Scenedesmus* sp.			0.0061	Reduction in cell numbers	U.S. EPA, 1980o
		Scenedesmus sp.			0.05-0.5	Growth inhibition	Cushman et al., 1977
		C. pyrenoidosa	EC_{50}		0.25	Growth inhibition	U.S. EPA, 1980o
		C. vulgaris			0.06	Growth reduction	U.S. EPA, 1980o
		S. capricornutum			0.05	Growth reduction	U.S. EPA, 1980o
		Mixed species			0.005	Population reduction	U.S. EPA, 1980o

Table A-3. (continued).

RAC	Representative chemical(s)	Test organism	Test type	Duration (h)	Concentration (mg/L)	Notes	Reference
35	Lead	Ankistrodesmus sp.	EC_{24}		1.00	Growth inhibition	U.S. EPA, 1980p
		Chlorella sp.	EC_{53}		0.50	Growth inhibition	U.S. EPA, 1980p
		Scenedesmus sp.	EC_{35}		0.50	Growth inhibition	U.S. EPA, 1980p
		Selenastrum sp.	EC_{52}		0.50	Growth inhibition	U.S. EPA, 1980p
		Anabaena sp.	EC_{50}	24	15.0-26.0	Reduction in CO_2 fixation	U.S. EPA, 1980p
		Chlamydomonas sp.	EC_{50}	24	17.0	Reduction in CO_2 fixation	U.S. EPA, 1980p
		Cosmarium sp.	EC_{50}	24	5.0	Reduction in CO_2 fixation	U.S. EPA, 1980p
		Navicula sp.	EC_{50}	24	17.0-28.0	Reduction in CO_2 fixation	U.S. EPA, 1980p
		Scenedesmus sp.			2.5	Threshold effects	Cushman et al., 1977

APPENDIX B

Terrestrial Toxicity Data

Table B-1. Toxicity of chemicals in air to vascular plants.

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes[b]	Reference
1	Carbon monoxide	Grapefruit	-CO_2 uptake		1.8 E03	Detached leaves	National Research Council, 1977a
		Red clover	-20% N fixation		1.1 E05		National Research Council, 1977a
		Several species	-Growth	552	1.1 E07		National Research Council, 1977a
		Popinac	Defoliation	24	2.3 E07		National Research Council, 1977a
2	Sulfur dioxide[c]	Barley	-44% yield	72/wk	3.9 E02	Field, growing season	U.S. EPA, 1982
		Durum wheat	-42% yield	72/wk	3.9 E02	Field, growing season	U.S. EPA, 1982
		Alfalfa	-26% foliage	100	1.3 E02	5 hr/d, 5 d/wk, 4 wk	U.S. EPA, 1982
		Tobacco, Bel W3	-22% foliage	100	1.3 E02	5 hr/d, 5 d/wk, 4 wk	U.S. EPA, 1982
		Cocksfoot	-40% total wt.	2070	1.78 E02	103.5 hr/wk, 20 wk	U.S. EPA, 1982
		Broadbean	Reduced net photosynthesis	8	9.2 E01		U.S. EPA, 1982
		White pine	Needle damage threshold	6	6.5 E01	sensitive clone	U.S. EPA, 1982
		Norway spruce	-25% volume growth	1680	1.3 E02		U.S. EPA, 1982
3	Nitrogen dioxide	Wheat	-12% straw yield	334	2 E03		Zahn, 1975
		Bush bean	-27% yield	639	2 E03		Zahn, 1975
		Spruce	-7% linear growth	1900	2-3 E03	-17% linear growth in following year	Zahn, 1975
		Endive	-37% yield	620	2 E03		Zahn, 1975
		Carrot	-30% yield	357	4 E03		Zahn, 1975
		Tobacco, bean, tomato, radish, oat, soybean	Visible foliar injury	4	3.8 E03		Heck and Tingey, 1979
		Cocksfoot and meadow grass	-Yield	2070	2.1 E02	103.5 h/wk, 20 wk	Ashenden and Mansfield, 1978
4	Hydrogen sulfide	Green bean	-20% photosynthesis	3	7.0 E02		Taylor, in press
		Green bean	-25% whole plant yield	64	2.8 E02	4 h/d, 4 d/wk for 4 wk	Taylor, in press
		Alfalfa	-39% yield	672-840	4.2 E02	continuous fumigation	Thompson and Kats, 1978
		Lettuce	-66% yield	2112	4.2 E02	continuous fumigation	Thompson and Kats, 1978
		Douglas-fir	-weight and linear growth	5904	4.2 E02	continuous fumigation	Thompson and Kats, 1978
		Sugar beets	-38% sugar	3216	4.2 E02	continuous fumigation	Thompson and Kats, 1978
			+43% sugar	3216	4.2 E01	continuous fumigation	Thompson and Kats, 1978
5	Ammonia	Mustard	Injury	4	2.1 E03		National Research Council, 1979b

Table B-1. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes[b]	Reference
6	Ethylene	African marigold	Epinasty	20	1.15 E00		National Air Pollution Control Administration, 1970
		Carnation	Flowers do not open	72	1.15 E02		National Air Pollution Control Administration, 1970
		Cotton	Growth inhibition	720	6.85 E02		National Air Pollution Control Administration, 1970
		Lily family	Growth inhibition	168	8.60 E02		National Air Pollution Control Administration, 1970
		Various plants	Growth inhibition	240	2.39 E03		National Air Pollution Control Administration, 1970
7	Formaldehyde	Alfalfa	Injury	5	4.9 E02		National Research Council, 1981
		Petunia	Necrosis and leaf symptoms	48	2.47 E02		Kingsbury et al., 1979
8	Vinyl chloride	Cowpea, cotton, squash	Injury	168	2.6 E05		Heck and Pires, 1962
12	Benzene	Pinto bean	Red-bordered spots	0.6	3.0 E04		Kingsbury et al., 1979
13	Cyclohexene	Runner bean	LD_{50}, toxicity to leaves	1	1.12 E12		Ivens, 1952
14	Toluene	Pinto bean	Bronze color	0.6	1.88 E05		Kingsbury et al., 1979
17	Aniline	Loblolly pine	Damage	3	2.7 E02		Cheeseman and Perry, 1977
22	Acrolein	Alfalfa	Oxident-type damage	9	2.5 E02		Kingsbury et al., 1979
23	Carbonyl sulfide	Runner bean	LD_{50}, toxicity to leaves	1	2.7 E03		Ivens, 1952
		Green bean	-13% growth	64	4.9 E02	4 h/d, 4 d/w for 4 wk	Taylor, in press

Table B-1. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes[b]	Reference
32	Mercury (metalic)	Rose	Severe damage		1.0 E01		Stahl, 1969
		Sugar beet	Damage	5	2.8 E02		Waldron and Terry, 1975
		English ivy	Damage	12	1.5 E04		Waldron and Terry, 1975
		Coleus, Thevetia and Ricinus	Abscision	168	1.0 E01		Siegel and Siegel, 1979
	Mercuric chloride	Thevetia and Ricinus	Necrosis	168	1.0 E01		Siegel and Siegel, 1979
	Dimethylmercury	Coleus, Thevetia and Ricinus	Abscision	36	1.0 E01		Siegel and Siegel, 1979

[a]Latin binomials are listed in Appendix C.

[b]Unless "field" is noted, results are for laboratory studies.

[c]See also Table 4.

Table B-2. Toxicity of chemicals in soil or solution to vascular plants.

RAC	Representative chemical	Test organism* and life stage	Test medium	Response	Duration	Concentration (µg/g)	Reference
9	Acetic acid	Barley (seedling)	Solution in sand	Root growth inhibition	5d	600	Lynch, 1977
11	Metnyl pyridine	Alfalfa (sprout)	Solution	Root growth inhibition	4d	93.1	Naik et al.,1972
13	Hexene	Oat (seedling)	Solution	Mortality		25.2	Chen and Elofson, 1978
14	Xylene	Sugar beet (seedling)	Solution	Root growth inhibition	2d	100	Allen et al., 1961
15	Benzo(a)pyrene	Corn (sprout)	Solution	Root growth stimulation	6h	0.0005	Deubert et al., 1979
	3,4-benzopyrene	Tobacco (seedling)	Soil	78% growth stimulation	60d	0.01	Graf and Nowak, 1966
	1,2-benzanthracene	Tobacco (seedling)	Soil	80% growth stimulation	60d	0.02	Graf and Nowak, 1966
	1,2,5,6-di-benzanthrancene	Tobacco (seedling)	Soil	130% growth stimulation	60d	0.02	Graf and Nowak, 1966
16	Dimethylalkylamine	Gram, rice	Solution	Mortality		7.0	Dutta et al., 1972
19	Benzothiophene	Cucumber (sprout)	Solution	9% root growth inhibition	4d	10	Schlesinger and Mowry, 1951
	Indole, 3-ethyl-1H	Oat, cress, mustard (sprout)	Solution	Growth inhibition		100	Davies et al., 1937
	Indole-3 -acetic acid, 1H	Oat, cress, mustard (sprout)	Solution	Growth inhibition		100	Davies et al., 1937
		Cucumber	Solution	Mortality	11d	35	Hilton and Nomura, 1964
		Pea (sprout)	Solution	Germination reduced by >50%	8h	10	Shukla, 1972
20	Benzoic acid	Lettuce (seedling)	Solution on filter paper	23% growth inhibition		25	Chou and Patrick, 1976
	2-hydroxy -benzoic acid	Rice (seedling)	Soil	Seedling growth inhibition	5d	1.6	Gaur and Pareek, 1976
		Lettuce (seedling)	Solution on filter paper	61% growth inhibition		25	Chou and Patrick, 1976
21	Phenol	Durum wheat (seed)	Solution	Germination inhibition	4d	2000	Badilescu et al., 1967
22	4-hydroxy -benzaldehyde	Lettuce (seedling)	Solution on filter paper	26% growth inhibition		100	Chou and Patrick, 1976

Table B-2. (continued).

RAC	Representative chemical	Test organism* and life stage	Test medium	Response	Duration	Concentration (µg/g)	Reference
22	Acrolein	Alfalfa		Oxidant-type damage	9h	0.1	Kingsbury et al., 1979
23	Carbon disulfide	Apple	Soil	Root injury		420	Underhill and Cox, 1940
24	Etnanol	Lettuce (seed)	Solution	Germination inhibition	44h	1,000,000	Meyer and Mayer, 1971
27	N,N-dimethyl-formamide	Lettuce (seed)	Solution	Nearly total suppression of germination	24h	1,000,000	Meyer and Mayer, 1971
	2-methyl -benzamide	Poppy, chickweed, carrot, ryegrass corn, lucerne (mature)	Soil	13-87% reduction in yield	3-5w	220,000	Pizey and Wain, 1959
31	Arsenic[a]	Corn (seedling)	Soil	10% growth reduction (wet tissue weight)	4w	64	Woolson, et al., 1971
		Cotton (mature)	Soil (fine sandy loam)	Approx. 55% reduction in yield	6w	8[b]	Deuel and Swoboda, 1972
		Cotton (mature)	Soil (clay)	Approx. 40% reduction in yield	6w	28[b]	Deuel and Swoboda, 1972
		Soybean (mature)	Soil (fine sandy loam)	Approx. 45% reduction in yield	6w	3[b]	Deuel and Swoboda, 1972
		Soybean (mature)	Soil (clay)	Approx. 40% reduction in yield	6w	12[b]	Deuel and Swoboda, 1972
		Cowpea	-	Retarded growth	-	1[b]	Albert and Arndt, 1932
32	Mercury	Barley (seed-sprout)	Solution	12% growth reduction (fresh weight)	7d post germination	5 (as Hg^{++})	Mukhiya et al., 1983
		Barley (seed-sprout)	Solution	12% growth reduction (fresh weight)	7d post germination	1 (as PMA)[c]	Mukhiya et al., 1983
		Lettuce (seed-sprout)	Solution	68% reduction in elongation of lettuce hypocotyl	5d post germination	109 (as $HgCl_2$)	Nag et al., 1980
33	Nickel	Corn (mature)	Solution	10% decrease in net photosynthesis	7d	5	Carlson et al., 1975
		Sunflower (mature)	Solution	10% decrease in net photosynthesis	7d	0.8	Carlson et al., 1975

Table B-2. (continued).

RAC	Representative chemical	Test organism* and life stage	Test medium	Response	Duration	Concentration (μg/g)	Reference
33		Oats (seeds-seedlings)	Solution in coarse sand	Stunted growth	Up to 22d post germination	10	Vergnano and Hunter, 1953
		Oats (mature)	Soil	Decreased grain yield	Whole life	50	Halstead et al., 1969
		Barley (seedling)	Solution in sand	Over 50% reduction in whole plant fresh weight	3w	281 ($NiSO_4 \cdot 7H_2O$)	Agarwala et al., 1977
34	Cadmium	Corn (mature)	Solution	10% decrease in net photosynthesis	7d	0.9	Carlson et al., 1975
		Sunflower (mature)	Solution	10% decrease in net photosynthesis	7d	0.45	Carlson et al., 1975
		Soybeans (mature)	Solution in sand and vermiculite	35% decrease in fresh weight of pods	90d	2	Huang et al., 1974
		Bean (5 weeks old)	Solution	50% growth reduction	3w	0.2	Page et al., 1972
		Beet (5 weeks old)	Solution	50% growth reduction	3w	0.2	Page et al., 1972
		Turnip (5 weeks old)	Solution	50% growth reduction	3w	0.2	Page et al., 1972
		Corn (5 weeks old)	Solution	50% growth reduction	3w	1.2	Page et al., 1972
		Lettuce (5 weeks old)	Solution	50% growth reduction	3w	0.9	Page et al., 1972
		Tomato (5 weeks old)	Solution	50% growth reduction	3w	4.8	Page et al., 1972
		Barley (5 weeks old)	Solution	50% growtn reduction	3w	5.6	Page et al., 1972
		Pepper (5 weeks old)	Solution	50% growth reduction	3w	2.0	Page et al., 1972
		Cabbage (5 weeks old)	Solution	50% growth reduction	3w	9.0	Page et al., 1972
		Soybean (seedling)	Soil (silty clay loam)	15% reduction in yield (dry weight)	5w	2.5	Haghiri, 1973
		Wheat (seedling)	Soil (silty clay loam)	20% reduction in yield (dry weight)	5w	2.5	Haghiri, 1973
		Lettuce (mature)	Soil (silty clay loam)	40% reduction in yield (fresh weight)	Whole life	2.5	Haghiri, 1973

Table B-2. (continued).

RAC	Representative chemical	Test organism* and life stage	Test medium	Response	Duration	Concentration (μg/g)	Reference
34		Sycamore (sapling)	Soil (6:1 silty clay loam & perlite)	25% reduction in new stem growth	90d	39	Carlson and Bazzaz, 1977
35	Lead	Soybeans (mature)	Solution in sand and vermiculite	35% decrease in fresh weight of pods	90d	62	Huange et al., 1974
		Lettuce (44d old)	Soil (silty clay loam)	25% reduction in yield	30d	1000 $(Pb(NO_3)_2$	John and VanLaerhoven 1972
		Corn (25d seedling)	Vermiculite and solution	20% decrease in photosynthesis	11-21d	1000	Bazzaz et al., 1974
		Soybean (25d seedling)	Vermiculite and solution	20% decrease in photosynthesis	11-21d	2000	Bazzaz et al., 1974
		Sycamore (sapling)	Soil (6:1 silty clay loam & perlite)	25% reduction in new stem growth	90d	500	Carlson and Bazzaz, 1977

*Latin binomials are listed in Appendix C.

[a]Arsenic shows a stimulatory effect on plants when present at low concentrations (40-50 μg/g total As or 5 μg/g extractable As in soil) (Woolson et al., 1971).

[b]Concentration of contaminant available in solution.

[c](PMA-Phenyl mercuric acetate).

Table B-3. Toxicity of chemicals in air to animals.

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes	Reference
1	Carbon monoxide	Rabbit	Aortic lesions	4	1.51 E05		National Research Council, 1977a
		Dog	Heart damage	1008	4.3 E04		National Research Council, 1977a
		Chicken	75% egg hatch	432	4.9 E05	egg exposed	National Research Council, 1977a
		Rabbit	90% neonate survival	720	1.0 E05	mother exposed	National Research Council, 1977a
		Human	Lethality		9.2 E08		Cleland and Kingsbury, 1977
2	Sulfur dioxide	Guinea pig	Increased airway resistance	1	4.2 E02		U.S. EPA, 1982
		Guinea pig	LT_{50}	1.1	5.8 E06		U.S. EPA, 1982
		Dog	Increased airway resistance	5,400	1.3 E04		U.S. EPA, 1982
		Chicken	Modified nasal clearance		3.7 E03	Intermittent exposure, 7 d	Wakabayashi et al., 1977
	Sulfuric acid	Guinea pig	Respiratory function	1	1.0 E02		Wakabayashi et al., 1977
		Guinea pig	Lethality	8	1.8 E04		Wakabayashi et al., 1977
		Dog	Respiratory function	4,725	8.9 E02		Wakabayashi et al., 1977
3	Nitrogen dioxide	Guinea pig	LC_{50}	1	1.5 E05		National Research Council, 1977b
		Rat	11% lethality	5,120	2.3 E04		National Research Council, 1977b
		Rat	Bronchial damage	24	2.8 E04		National Research Council, 1977b
		Mouse	Defects in pulmonary microbial defense	24	3.8 E03		National Research Council, 1977b
		Rat and mouse	Pulmonary pathologies	Chronic	9.4 E02	Also decreased resistance to infection	National Research Council, 1977b
4	Hydrogen sulfide	Canaries, rats and dogs	Pulmonary irritation	Subacute	7.0 E04	No established chronic effects	National Research Council, 1979a

Table B-3. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes	Reference
5	Ammonia	Chicken	Increased disease susceptibility	72	1.3 E04	Newcastle virus	National Research Council, 1979b
		Pig	Respiratory irritation	840	4.3 E04		National Research Council, 1979b
		Rabbit	LT_{50}	33	7.0 E06		National Research Council, 1979b
		Mouse	Lethal threshold	16	7.0 E05		National Research Council, 1979b
		Human	Throat irritation	Immediate	2.8 E05		National Research Council, 1979b
6	Acetylene	Human	Unconsciousness	0.08	3.7 E08		National Research Council, 1976
7	Formaldenyde	Rat	LC_{50}	4	5.7 E05		National Research Council, 1981
		Guinea pigs	Increased airway resistance	1	3.6 E02		National Research Council, 1981
		Rat	Respiratory and eye irritation and liver weight loss	1400	1.0 E03		National Research Council, 1981
8	Chloroform	Mouse	LC_{50}		1.4 E05		Kingsbury et al., 1979
		Human	Enlarged liver	Chronic	4.9 E04	In workplace air	Kingsbury et al., 1979
9	Acetic acid	Mouse	LC_{50}	1	1.4 E07		Kingsbury et al., 1979
		Human	Irritation	0.05	2.0 E06		Kingsbury et al., 1979
		Human	Respiratory, stomach and skin irritation	Chronic	1.5 E05	7-12 years, workplace exposure	National Research Council, 1976
10	Furan	Rat	Lethal threshold	8-48	2.4 E08		Kingsbury et al., 1979
	Thiophene	Mouse	Lethal threshold	8-48	3.0 E07		Kingsbury et al., 1979
11	Pyridine	Rat	LC_{50}	4	1.3 E07		Kingsbury et al., 1979
	2-Ethylpyridine	Rat	LC_{100}	3	2.4 E07		Kingsbury et al., 1979
12	Benzene	Human	Lethal threshold	Chronic	1.9 E05	Workplace exposure	National Research Council, 1976

Table B-3. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes	Reference
13	Pentane	Mouse	Lethality	--	3.8 E08		Kingsbury et al., 1979
	Cyclopentane	Mouse	Lethality	--	1.1 E08		Kingsbury et al., 1979
	Hexane	Mouse	Lethality		1.2 E08		Kingsbury et al., 1979
		Human	Dizziness	0.17	1.8 E07		Kingsbury et al., 1979
	Cyclohexane	Rabbit	Lethality	1	9.2 E07		Kingsbury et al., 1979
		Rabbit	Narcosis and convulsions	1	4.5 E07		Kingsbury et al., 1979
	Heptane	Human	Dizziness	0.10	4.1 E06		Kingsbury et al., 1979
	Butadiene	Human	Respirtory and eye irritation	8	1.8 E07		Kingsbury et al., 1979
	Cyclopentadine	Rat	Liver and kidney damage	245	1.4 E06	expsoure = 7 hr/day for 35 days	Kingsbury et al., 1979
14	Toluene	Rat	Lethal threshold	4	1.5 E07		Kingsbury et al., 1979
		Human	Psychological effects	--	3.8 E05		Kingsbury et al., 1979
	Ethyl benzene	Rat	Lethal threshold	4	1.7 E07		Kingsbury et al., 1979
		Human	Eye irritation	<0.08	8.8 E05		Kingsbury et al., 1979
	p-Xylene	Mouse	Lethal threshold	4	1.5 E07		Kingsbury et al., 1979
	Tetrahydro-naphthalene	Guinea pig	Lethal threshold	136	1.5 E06	8 hours for 17 days	Kingsbury et al., 1979
	Naphthalene	Human	Eye irritation and damage	--	7.9 E04		Kingsbury et al., 1979
15	(No data on respiratory toxicity but several members of this RAC are carcinogens)						Kingsbury et al., 1979
16	Ethylamine	Rat	Lethal threshold	4	5.5 E06		Kingsbury et al., 1979
		"Animals"	Lung, liver and kidney damage	1008	1.8 E05		Kingsbury et al., 1979
	1-Aminopropane	Rat	LC_{50}	4	5.6 E06		Kingsbury et al., 1979
17	Aniline	Rat	LC_{50}	4	9.5 E05		Kingsbury et al., 1979
	Dimethylanaline	Mouse	LC_{50}	7	7.4 E05	Mixed isomers	Kingsbury et al., 1979
18	(No data on respiratory toxicity)						
19	(No data on respiratory toxicity)						
20	(No data on respiratory toxicity)						
21	(No data on respiratory toxicity)						

Table B-3. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes	Reference
22	Acrolein	Rat	LC_{50}	4	1.8 E04		National Research Council, 1981
		Monkey	Respiratory system damage	2,160	5.1 E02		National Research Council, 1981
	Acetaldehyde	Mice, rabbits and guinea pigs	LC_{50}	4	2.0 E06		National Research Council, 1981
	Proprionaldehyde	Rat	LC_{50}	0.5	6.2 E07		National Research Council, 1981
		Rat	Reduced weight gain	36	3.1 E06	6 h/d x 6 d	National Research Council, 1981
	Butyraldehyde	Rat	LC_{50}	0.5	1.7 E08		National Research Council, 1981
	Butanone	Mouse	LC_{50}	0.75	6.1 E08		National Research Council, 1981
23	Methyl mercaptan	Rat	Lethal threshold	--	2.0 E07		Kingsbury et al., 1979
	Ethyl mercaptan	Rat	LC_{50}	--	1.1 E07		Kingsbury et al., 1979
		Human	Central nervous system effects	--	1.0 E04		Kingsbury et al., 1979
	n-Butyl mercaptan	Rat	LC_{50}	4	1.5 E07		Kingsbury et al., 1979
		Human	"Toxic effect"	3	1.0 E04		Kingsbury et al., 1979
	Thiophenol	Rat	LC_{50}	4	1.5 E05		Kingsbury et al., 1979
	Carbon disulfide	Human	Central nervous system effects		5.0 E04	7 years exposure	Cleland and Kingsbury, 1977
24	Methanol	Monkey	LC_{50}		1.3 E06		Kingsbury et al., 1979
		Human	Central nervous system effects		7.5 E04		Kingsbury et al., 1979
	Ethanol	Human	Eye and respiratory irritation and mental effects		1.9 E06		Kingsbury et al., 1979
25	(No data on respiratory toxicity)						Kingsbury et al., 1979
26	Methyl acetate	Human	Severe toxic effects	1	1.5 E06		Kingsbury et al., 1979
	Methyl methacrylate	Rat	LC_{50}	1	1.5 E07		Kingsbury et al., 1979
	Butyl acetate	Human	Throat irritation		9.6 E05		Kingsbury et al., 1979
		Human	Toxic effects	1	9.6 E06		Kingsbury et al., 1979
	n-Amyl acetate	Human	Toxic threshold	0.5	1.0 E06		Kingsbury et al., 1979
27	(No data on respiratory toxicity)						Kingsbury et al., 1979
28	Acetonitrile	Rat	Lethal threshold	4	1.3 E07		Kingsbury et al., 1979
		Human	Bronchial effects		2.7 E05		Kingsbury et al., 1979
	Acrylonitrile	Rat	Lethal threshold	4	1.1 E06		Kingsbury et al., 1979

Table B-3. (continued).

RAC	Representative chemical	Test organism[a]	Response	Exposure Duration (hours)	Exposure Concentration ($\mu g/m^3$)	Notes	Reference
29	(No data on respiratory toxicity)						Kingsbury et al., 1979
30	Fly ash	Monkey	Slight lung fibrosis	13,390	4.6 E02		National Research Council, 1979c
31	Arsenic trioxide	Rat	Weight lag and physiological effects	24	2.5 E01		National Research Council, 1977c
32	Mercury (metal)	Human	Toxic threshold		1.0 E03		Cassidy and Furr, 1978
		Rabbit	Toxic threshold		2.9 E04		Cassidy and Furr, 1978
		Human	Central nervous system effects		1.7 E02	40 yr. exposure	Kingsbury et al., 1979
33	Nickel carbonyl	Rat	LC_{50}	0.5	2.4 E05		National Research Council, 1975
34	Cadmium oxide fumes	Human	Lethality	8	5.0 E03		Hammons et al., 1978
	Cadmium oxide dust	Human	Impaired lung function		3.15 E03	20 yr. exposure	Hammons et al., 1978
	Cadmium	Human	Pulmonary and renal effects		1.0-27 E01	Occupational exposure	Kingsbury et al., 1979
35	Lead	Human	Threshold of overt poisoning		5.0 E02	Occupational exposure	National Research Council, 1972

[a]Latin binomials are lised in Appendix C.

APPENDIX C

Common and Scientific Names of Animals and Plants

Animals

Common name	Scienfitic name
Bigmouth buffalo	Ictiobus cyprinellus
Black crappie	Pomoxis nigromaculatus
Bluegill	Lepomis macrochirus
Brook trout	Salvelinus fontinalis
Brown trout	Salmo trutta
Canary	Serinus canarius
Carp	Cyprinus carpio
Channel catfish	Ictalurus punctatus
Chicken	Gallus gallus
Chinook salmon	Oncorhynchus tshawytacha
Coho salmon	Oncorhynchus kisutch
Dog	Canis familiaris
Fathead minnow	Pimephales promelas
Goldfish	Carassius auratus
Green sunfish	Lepomis cyanellus
Guinea pig	Cavia cobaya
Human	Homo sapiens
Largemouth bass	Micropterus salmoides
Monkey	Macaca sp.
Mosquitofish	Gambusia affinis
Mouse	Mus musculus
Northern pike	Esox lucius
Pig	Sus scrofa
Pink salmon	Oncorhynchus gorbuscha
Pumpkinseed	Lepomis gibbosus
Rabbit	Oryctolagus cuniculus
Rainbow trout	Salmo gairdneri
Rat	Rattus rattus
Smallmouth buffalo	Ictiobus bulbalus
White bass	Morone chrysops

Plants

Common name	Scientific name
African marigold	*Tagetes* sp.
Alfalfa	*Medicago sativa*
Apple	*Malus sylvestris*
Barley	*Hordeum vulgare*
Bean	*Phaseolus vulgaris*
Broadbean	*Vicia faba*
Bush bean	*Phaseolus vulgaris*
Cabbage	*Brassica oleracea*
Carnation	*Dianthus caryophyllos*
Carrot	*Daucus carota*
Chickweed, common	*Stellaria media*
Cocksfoot	*Dactylis glomerata*
Coleus	*Coleus blumei*
Corn	*Zea mays*
Cotton	*Gossypium hirsutum*
Cowpea	*Vigna sinensis*
Cress	*Lepidium sativum*
Cucumber	*Cucumis sativus*
Durum wheat	*Triticum durum*
Endive	*Cicorium endivia*
English ivy	*Hedera helix*
Gram	*Cicer arietinum*
Grapefruit	*Citrus paradisi*
Green bean	*Phaseolus vulgaris*
Lettuce	*Lactuca sativa*
Loblolly pine	*Pinus taeda*
Lucerne	*Medicago sativa*
Meadowgrass	*Poa pratensis*
Mustard	*Brassica alba*
Norway spruce	*Picea abies*
Oat	*Avena sativa*
Oat, wild	*Avena fatua*
Pea	*Psoralea corylifolia*
Pepper	*Capsicum frutescens*
Petunia	*Petunia* sp.
Pinto bean	*Phaseolus vulgaris*
Popinac	*Acacia farnesiana*
Poppy	*Papaver* sp.
Radish	*Raphanus sativus*
Red clover	*Trifolium pratense*
Rice	*Oryza sativa*
Ricinus	*Ricinus communis*
Rose	*Rosa* sp.
Runner bean	*Phaseolus vulgaris*
Ryegrass, Italina	*Lolium multiflorum*
Soybean	*Glycine max*
Spruce	*Picea abies*
Squash	*Cucurbita* sp.

Plants (continued)

Common name	Scientific name
Sugar beet	*Beta vulgaris*
Sunflower	*Helianthus annuus*
Sycamore	*Platanus occidentalis*
Thevetia	*Thevetia neriifolca*
Tobacco	*Nicotiana tabacum*
Tomato	*Lycopersicon esculentum*
Turnip	*Brassica napus*
Wheat	*Triticum durum*
White pine	*Pinus strobus*

APPENDIX D

Species-specific Results of the Analysis of Extrapolation Error

Table D-1. Predicted geometric mean maximum allowable toxicant concentrations (PGMATCs) for each RAC and each species of fish.

	RAC	PGMATC (μg/l)									
		Carp	Buffalo	Channel Catfish	White Bass	Green Sunfish	Bluegill Sunfish	Largemouth Bass	Black Crappie	Rainbow Trout	Brook Trout
1	Carbon monoxide										
2	Sulfur oxides										
3	Nitrogen oxides										
4	Acid gases	8.8	8.8	11.6	3.3	6.7	3.1	2.5	1.6	2.6	2.6
5	Alkaline gases	43.5	43.5	32.9	18.0	18.0	18.0	18.0	18.0	15.3	14.9
6	Hydrocarbon gases	1,565,162	1,565,162	11,313	29,185	29,185	29,185	29,185	29,185	19,705	19,705
7	Formaldehyde	No data									
8	Volatile organochlorines	533	1245	600	135	705	814	744	110	566	566
9	Volatile carboxylic acids	941	933	518	213	213	213	213	213	252	252
10	Volatile O&S heterocyclics	No data									
11	Volatile N heterocyclics	No data									
12	Benzene	421	252	144	116	116	116	116	116	125	86
13	Aliphatic/alicyclic hydrocarbons	218	255	166	66	66	66	66	66	68	68
14	Mono/diaromatic hydrocarbons	120	146	91	65	65	65	65	65	65	50
15	Polycyclic aromatic hydrocarbons	190	190	134	79	121	98	86	22	74	74
16	Aliphatic amines	No data									
17	Aromatic amines	No data									
18	Alkaline N heterocyclics	562	590	590	347	141	141	141	141	159	159
19	Neutral N, O&S heterocyclics	No data									
20	Carboxylic acids	48,548	48,548	1435	2001	2001	2001	2001	2001	1317	1317
21	Phenols	462	387	207	182	308	302	271	52	208	131
22	Aldehydes and ketones	12.7	12.7	11.7	4.9	10.7	5.4	8.1	2.4	4.0	4.4
23	Nonheterocylic organosulfur	No data									
24	Alcohols	No data									
25	Nitroaromatics	No data									
26	Esters	33.0	287.4	160.9	133.0	40.5	26.6	22.8	8.1	145.9	97.6
27	Amides	No data									
28	Nitriles	215	389	237	65	236	220	196	41	160	160
29	Tars	No data									
30	Respirable particles	No data									
31	Arsenic	238	479	247	229	409	424	383	67	257	281
32	Mercury (inorganic)	34.2	34.2	26.9	14.0	14.0	14.0	14.0	14.0	11.9	12.0
32A	Mercury (methyl)	11.7	11.7	10.9	4.5	4.5	4.5	4.5	4.5	2.3	4.4
33	Nickel	94	876	410	433	147	124	110	26	552	296
34	Cadmium	11.1	1.5	2.0	0.5	76.7	57.0	51.3	14.8	0.2	0.3
35	Lead	54	171	104	77	393	404	364	65	61	102

Table D-2. Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2572	0.2572	0.2616	0.2616	Class
Bigmouth buffalo	0.2572	0.2572	0.2616	0.2616	Class
Smallmouth buffalo	0.2572	0.2572	0.2616	0.2616	Class
Channel catfish	0.3397	0.3397	0.3177	0.3177	Class
White bass	0.6205	0.6205	0.4039	0.4039	Class
Green sunfish	0.6205	0.6205	0.4039	0.4039	Class
Bluegill sunfish	0.6205	0.6205	0.4039	0.4039	Class
Largemouth bass	0.6205	0.6205	0.4039	0.4039	Class
Black crappie	0.6205	0.6205	0.4039	0.4039	Class

Table D-3. Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.3257	0.0326	0.2786	0.0366	Family
Bigmouth buffalo	0.2786	0.0279	0.2530	0.0312	*
Smallmouth buffalo	0.2786	0.0279	0.2530	0.0312	*
Channel catfish	0.4281	0.0428	0.3419	0.0652	Class
White bass	1.0832	0.1083	0.5145	0.1557	Class
Green sunfish	1.0832	0.1083	0.5145	0.1557	Class
Bluegill sunfish	1.0832	0.1083	0.5145	0.1557	Class
Largemouth bass	1.0832	0.1083	0.5145	0.1557	Class
Black crappie	1.0832	0.1083	0.5145	0.1557	Class

*Fathead minnow - Cypriniformes.

Table D-4. Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0440	0.0044	0.0497	0.0021	Family
Bigmouth buffalo	0.0362	0.0036	0.0603	0.0043	Class
Smallmouth buffalo	0.0362	0.0036	0.0603	0.0043	Class
Channel catfish	0.0580	0.0058	0.1063	0.0121	Class
White bass	0.0813	0.0081	0.1010	0.0072	Class
Green sunfish	0.0813	0.0081	0.1010	0.0072	Class
Bluegill sunfish	0.0813	0.0081	0.1010	0.0072	Class
Largemouth bass	0.0813	0.0081	0.1010	0.0072	Class
Black crappie	0.0813	0.0081	0.1010	0.0072	Class

Table D-5. Probabilities of chronic toxic effects on fish populations due to RAC 20 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0034	0.0003	0.0047	0.0001	Class
Bigmouth buffalo	0.0034	0.0003	0.0047	0.0001	Class
Smallmouth buffalo	0.0034	0.0003	0.0047	0.0001	Class
Channel catfish	0.1147	0.0115	0.3107	0.1540	Class
White bass	0.0823	0.0082	0.1229	0.0129	Class
Green sunfish	0.0823	0.0082	0.1229	0.0129	Class
Bluegill sunfish	0.0823	0.0082	0.1229	0.0129	Class
Largemouth bass	0.0823	0.0082	0.1229	0.0129	Class
Black crappie	0.0823	0.0082	0.1229	0.0129	Class

Table D-6. Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0396	0.0040	0.0478	0.0022	Family
Bigmouth buffalo	0.0473	0.0047	0.0783	0.0065	Class
Smallmouth buffalo	0.0473	0.0047	0.0783	0.0065	Class
Channel catfish	0.0885	0.0089	0.1455	0.0198	Class
White bass	0.1003	0.0100	0.1226	0.0100	Class
Green sunfish	0.0594	0.0059	0.0669	0.0032	Genus
Bluegill sunfish	0.0606	0.0061	0.0568	0.0020	Species
Largemouth bass	0.0675	0.0068	0.0824	0.0050	Family
Black crappie	0.3539	0.0354	0.3230	0.0698	Family

Table D-7. Probabilities of chronic toxic effects on fish populations due to RAC 22 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2082	0.0208	0.2301	0.0342	Class
Bigmouth buffalo	0.2082	0.0208	0.2301	0.0342	Class
Smallmouth buffalo	0.2082	0.0208	0.2301	0.0342	Class
Channel catfish	0.2258	0.0226	0.2566	0.0479	Class
White bass	0.5397	0.0540	0.3769	0.0689	Class
Green sunfish	0.2466	0.0247	0.2241	0.0225	Genus
Bluegill sunfish	0.4890	0.0489	0.3412	0.0422	Species
Largemouth bass	0.3255	0.0325	0.2601	0.0249	Species
Black crappie	1.1049	0.1105	0.5182	0.1561	Family

Table D-8. Probabilities of chronic toxic effects on fish populations due to RAC 28 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0509	0.0051	0.0596	0.0029	Family
Bigmouth buffalo	0.0282	0.0028	0.0566	0.0046	Class
Smallmouth buffalo	0.0282	0.0028	0.0566	0.0046	Class
Channel catfish	0.0462	0.0046	0.0968	0.0115	Class
White bass	0.1690	0.0169	0.2090	0.0316	Class
Green sunfish	0.0464	0.0046	0.0509	0.0021	Genus
Bluegill sunfish	0.0500	0.0050	0.0449	0.0013	Species
Largemouth bass	0.0560	0.0056	0.0680	0.0037	Family
Black crappie	0.2706	0.0271	0.2805	0.0542	Family

Table D-9. Probabilities of chronic toxic effects on fish populations due to RAC 34 at annual median ambient concentrations for EDS.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0069	0.0069	0.0022	0.0022	Species
Bigmouth buffalo	0.0501	0.0501	0.0814	0.0814	Class
Smallmouth buffalo	0.0501	0.0501	0.0814	0.0814	Class
Channel catfish	0.0388	0.0388	0.0782	0.0782	Class
White bass	0.1468	0.1468	0.1692	0.1692	Class
Green sunfish	0.0010	0.0010	0.0000	0.0000	Genus
Bluegill sunfish	0.0014	0.0014	0.0001	0.0001	Species
Largemouth bass	0.0015	0.0015	0.0003	0.0003	Family
Black crappie	0.0052	0.0052	0.0086	0.0086	Family

Table D-10. Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for SRC-I.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.4208	0.4208	0.3420	0.3420	Class
Bigmouth buffalo	0.4208	0.4208	0.3420	0.3420	Class
Smallmouth buffalo	0.4208	0.4208	0.3420	0.3420	Class
Channel catfish	0.5558	0.5558	0.3982	0.3982	Class
White bass	1.0152	1.0152	0.5031	0.5031	Class
Green sunfish	1.0152	1.0152	0.5031	0.5031	Class
Bluegill sunfish	1.0152	1.0152	0.5031	0.5031	Class
Largemouth bass	1.0152	1.0152	0.5031	0.5031	Class
Black crappie	1.0152	1.0152	0.5031	0.5031	Class

Table D-11. Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for SRC-I.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.3257	0.0326	0.2786	0.0366	Family
Bigmouth buffalo	0.2786	0.0279	0.2530	0.0312	*
Smallmouth buffalo	0.2786	0.0279	0.2530	0.0312	*
Channel catfish	0.4281	0.0428	0.3419	0.0652	Class
White bass	1.0832	0.1083	0.5145	0.1557	Class
Green sunfish	1.0832	0.1083	0.5145	0.1557	Class
Bluegill sunfish	1.0832	0.1083	0.5145	0.1557	Class
Largemouth bass	1.0832	0.1083	0.5145	0.1557	Class
Black crappie	1.0832	0.1083	0.5145	0.1557	Class

*Fathead minnow-Cypriniformes.

Table D-12. Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for SRC-I.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0203	0.0020	0.0199	0.0005	Family
Bigmouth buffalo	0.0167	0.0017	0.0278	0.0014	Class
Smallmouth buffalo	0.0167	0.0017	0.0278	0.0014	Class
Channel catfish	0.0268	0.0027	0.0565	0.0048	Class
White bass	0.0375	0.0038	0.0475	0.0023	Class
Green sunfish	0.0375	0.0038	0.0475	0.0023	Class
Bluegill sunfish	0.0375	0.0038	0.0475	0.0023	Class
Largemouth bass	0.0375	0.0038	0.0475	0.0023	Class
Black crappie	0.0375	0.0038	0.0475	0.0023	Class

*Fathead minnow-Cypriniformes.

Table D-13. Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for SRC-I.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.1890	0.0189	0.1951	0.0203	Family
Bigmouth buffalo	0.2257	0.0226	0.2449	0.0393	Class
Smallmouth buffalo	0.2257	0.0226	0.2449	0.0393	Class
Channel catfish	0.4229	0.0423	0.3539	0.0841	Class
White bass	0.4792	0.0479	0.3550	0.0624	Class
Green sunfish	0.2836	0.0284	0.2517	0.0293	Genus
Bluegill sunfish	0.2896	0.0290	0.2422	0.0228	Species
Largemouth bass	0.3226	0.0323	0.2799	0.0383	Family
Black crappie	1.6908	0.1691	0.5918	0.2159	Family

Table D-14. Probabilities of chronic toxic effects on fish populations due to RAC 35 at annual median ambient concentrations for SRC-I.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0212	0.0212	0.0203	0.0203	Family
Bigmouth buffalo	0.0067	0.0067	0.0096	0.0096	Class
Smallmouth buffalo	0.0067	0.0067	0.0096	0.0096	Class
Channel catfish	0.0109	0.0109	0.0241	0.0241	Class
White bass	0.0148	0.0148	0.0162	0.0162	Class
Green sunfish	0.0029	0.0029	0.0010	0.0010	Genus
Bluegill sunfish	0.0028	0.0028	0.0005	0.0005	Species
Largemouth bass	0.0031	0.0031	0.0015	0.0015	Family
Black crappie	0.0177	0.0177	0.0380	0.0380	Family

Table D-15. Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2334	0.2334	0.2472	0.2472	Class
Bigmouth buffalo	0.2334	0.2334	0.2472	0.2472	Class
Smallmouth buffalo	0.2334	0.2334	0.2472	0.2472	Class
Channel catfish	0.3087	0.3087	0.3028	0.3028	Class
White bass	0.5639	0.5639	0.3851	0.3851	Class
Green sunfish	0.5639	0.5639	0.3851	0.3851	Class
Bluegill sunfish	0.5639	0.5639	0.3851	0.3851	Class
Largemouth bass	0.5639	0.5639	0.3851	0.3851	Class
Black crappie	0.5639	0.5639	0.3851	0.3851	Class

Table D-16. Probabilities of chronic toxic effects on fish populations due to RAC 8 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0037	0.0004	0.0020	0.0000	Family
Bigmouth buffalo	0.0016	0.0002	0.0023	0.0001	Class
Smallmouth buffalo	0.0016	0.0002	0.0023	0.0001	Class
Channel catfish	0.0033	0.0003	0.0066	0.0003	Class
White bass	0.0145	0.0014	0.0273	0.0015	Class
Green sunfish	0.0028	0.0003	0.0010	0.0000	Genus
Bluegill sunfish	0.0024	0.0002	0.0004	0.0000	Species
Largemouth bass	0.0026	0.0003	0.0012	0.0000	Family
Black crappie	0.0177	0.0018	0.0402	0.0030	Family

Table D-17. Probabilities of chronic toxic effects on fish populations due to RAC 12 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0039	0.0004	0.0020	0.0000	Family
Bigmouth buffalo	0.0064	0.0006	0.0094	0.0003	Class
Smallmouth buffalo	0.0064	0.0006	0.0094	0.0003	Class
Channel catfish	0.0113	0.0011	0.0251	0.0015	Class
White bass	0.0140	0.0014	0.0153	0.0004	Class
Green sunfish	0.0140	0.0014	0.0153	0.0004	Class
Bluegill sunfish	0.0140	0.0014	0.0153	0.0004	Class
Largemouth bass	0.0140	0.0014	0.0153	0.0004	Class
Black crappie	0.0140	0.0014	0.0153	0.0004	Class

Table D-18. Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.1219	0.0122	0.1335	0.0100	Family
Bigmouth buffalo	0.1002	0.0100	0.1410	0.0157	Class
Smallmouth buffalo	0.1002	0.0100	0.1410	0.0157	Class
Channel catfish	0.1606	0.0161	0.2117	0.0353	Class
White bass	0.2251	0.0225	0.2242	0.0269	Class
Green sunfish	0.2251	0.0225	0.2242	0.0269	Class
Bluegill sunfish	0.2251	0.0225	0.2242	0.0269	Class
Largemouth bass	0.2251	0.0225	0.2242	0.0269	Class
Black crappie	0.2251	0.0225	0.2242	0.0269	Class

Table D-19. Probabilities of chronic toxic effects on fish populations due to RAC 15 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0026	0.0003	0.0036	0.0001	Class
Bigmouth buffalo	0.0026	0.0003	0.0036	0.0001	Class
Smallmouth buffalo	0.0026	0.0003	0.0036	0.0001	Class
Channel catfish	0.0037	0.0004	0.0081	0.0004	Class
White bass	0.0062	0.0006	0.0037	0.0000	*
Green sunfish	0.0041	0.0004	0.0014	0.0000	Genus
Bluegill sunfish	0.0050	0.0005	0.0011	0.0000	Species
Largemouth bass	0.0057	0.0006	0.0032	0.0000	Family
Black crappie	0.0225	0.0022	0.0421	0.0028	Family

*Bluegill-Perciformes.

Table D-20. Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0704	0.0070	0.0856	0.0053	Family
Bigmouth buffalo	0.0840	0.0084	0.1252	0.0133	Class
Smallmouth buffalo	0.0840	0.0084	0.1252	0.0133	Class
Channel catfish	0.1574	0.0157	0.2103	0.0353	Class
White bass	0.1783	0.0178	0.1918	0.0209	Class
Green sunfish	0.1055	0.0106	0.1162	0.0078	Genus
Bluegill sunfish	0.1078	0.0108	0.1044	0.0053	Species
Largemouth bass	0.1201	0.0120	0.1373	0.0113	Family
Black crappie	0.6293	0.0629	0.4189	0.1107	Family

Table D-21. Probabilities of chronic toxic effects on fish populations due to RAC 26 at annual median ambient concentrations for SRC-II.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0444	0.0044	0.0486	0.0020	Family
Bigmouth buffalo	0.0051	0.0005	0.0070	0.0002	Class
Smallmouth buffalo	0.0051	0.0005	0.0070	0.0002	Class
Channel catfish	0.0091	0.0009	0.0201	0.0011	Class
White bass	0.0110	0.0011	0.0112	0.0003	Class
Green sunfish	0.0361	0.0036	0.0362	0.0012	Genus
Bluegill sunfish	0.0551	0.0055	0.0482	0.0014	Species
Largemouth bass	0.0641	0.0064	0.0751	0.0041	Family
Black crappie	0.1813	0.0181	0.2178	0.0336	Family

Table D-22. Probabilities of chronic toxic effects on fish populations due to RAC 5 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2338	0.2338	0.2472	0.2472	Class
Bigmouth buffalo	0.2338	0.2338	0.2472	0.2472	Class
Smallmouth buffalo	0.2338	0.2338	0.2472	0.2472	Class
Channel catfish	0.3087	0.3087	0.3028	0.3028	Class
White bass	0.5639	0.5639	0.3851	0.3851	Class
Green sunfish	0.5639	0.5639	0.3851	0.3851	Class
Bluegill sunfish	0.5639	0.5639	0.3851	0.3851	Class
Largemouth bass	0.5639	0.5639	0.3851	0.3851	Class
Black crappie	0.5639	0.5639	0.3851	0.3851	Class

Table D-23. Probabilities of chronic toxic effects on fish populations due to RAC 13 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.4187	0.0419	0.3244	0.0485	Family
Bigmouth buffalo	0.3582	0.0358	0.2966	0.0416	*
Smallmouth buffalo	0.3582	0.0358	0.2966	0.0416	*
Channel catfish	0.5504	0.0550	0.3872	0.0820	Class
White bass	1.3927	0.1393	0.5599	0.1847	Class
Green sunfish	1.3927	0.1393	0.5599	0.1847	Class
Bluegill sunfish	1.3927	0.1393	0.5599	0.1847	Class
Largemouth bass	1.3927	0.1393	0.5599	0.1847	Class
Black crappie	1.3927	0.1393	0.5599	0.1847	Class

*Fathead minnow-Cypriniformes.

Table D-24. Probabilities of chronic toxic effects on fish populations due to RAC 14 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0542	0.0054	0.0620	0.0030	Family
Bigmouth buffalo	0.0445	0.0045	0.0728	0.0057	Class
Smallmouth buffalo	0.0445	0.0045	0.0728	0.0057	Class
Channel catfish	0.0714	0.0071	0.1239	0.0152	Class
White bass	0.1001	0.0100	0.1209	0.0096	Class
Green sunfish	0.1001	0.0100	0.1209	0.0096	Class
Bluegill sunfish	0.1001	0.0100	0.1209	0.0096	Class
Largemouth bass	0.1001	0.0100	0.1209	0.0096	Class
Black crappie	0.1001	0.0100	0.1209	0.0096	Class

Table D-25. Probabilities of chronic toxic effects on fish populations due to RAC 20 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0042	0.0004	0.0063	0.0002	Class
Bigmouth buffalo	0.0042	0.0004	0.0063	0.0002	Class
Smallmouth buffalo	0.0042	0.0004	0.0063	0.0002	Class
Channel catfish	0.1416	0.0142	0.3278	0.1657	Class
White bass	0.1015	0.0102	0.1439	0.0165	Class
Green sunfish	0.1015	0.0102	0.1439	0.0165	Class
Bluegill sunfish	0.1015	0.0102	0.1439	0.0165	Class
Largemouth bass	0.1015	0.0102	0.1439	0.0165	Class
Black crappie	0.1015	0.0102	0.1439	0.0165	Class

Table D-26. Probabilities of chronic toxic effects on fish populations due to RAC 21 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2022	0.0202	0.2048	0.0221	Family
Bigmouth buffalo	0.2415	0.0242	0.2548	0.0420	Class
Smallmouth buffalo	0.2415	0.0242	0.2548	0.0420	Class
Channel catfish	0.4524	0.0452	0.3649	0.0888	Class
White bass	0.5126	0.0513	0.3678	0.0667	Class
Green sunfish	0.3034	0.0303	0.2633	0.0317	Genus
Bluegill sunfish	0.3098	0.0310	0.2542	0.0250	Species
Largemouth bass	0.3451	0.0345	0.2917	0.0413	Family
Black crappie	1.8089	0.1809	0.6034	0.2248	Family

Table D-27. Probabilities of chronic toxic effects on fish populations due to RAC 22 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.2563	0.0256	0.2608	0.0423	Class
Bigmouth buffalo	0.2563	0.0256	0.2608	0.0423	Class
Smallmouth buffalo	0.2563	0.0256	0.2608	0.0423	Class
Channel catfish	0.2780	0.0278	0.2869	0.0577	Class
White bass	0.6644	0.0664	0.4177	0.0840	Class
Green sunfish	0.3035	0.0304	0.2592	0.0292	Genus
Bluegill sunfish	0.6019	0.0602	0.3858	0.0540	Species
Largemouth bass	0.4006	0.0401	0.3001	0.0327	Species
Black crappie	1.3601	0.1360	0.5561	0.1800	Family

Table D-28. Probabilities of chronic toxic effects on fish populations due to RAC 28 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0641	0.0064	0.0753	0.0041	Family
Bigmouth buffalo	0.0355	0.0036	0.0692	0.0061	Class
Smallmouth buffalo	0.0355	0.0036	0.0692	0.0061	Class
Channel catfish	0.0582	0.0058	0.1145	0.0148	Class
White bass	0.2127	0.0213	0.2404	0.0398	Class
Green sunfish	0.0584	0.0058	0.0651	0.0031	Genus
Bluegill sunfish	0.0629	0.0063	0.0586	0.0021	Species
Largemouth bass	0.0705	0.0070	0.0850	0.0052	Family
Black crappie	0.3407	0.0341	0.3160	0.0664	Family

Table D-29. Probabilities of chronic toxic effects on fish populations due to RAC 34 at annual median ambient concentrations for H-Coal.

Species	Ambient conc/PGMATC		Probability of exceeding the PGMATC		Level of extrapolation
	TMT1	TMT2	TMT1	TMT2	
Carp	0.0036	0.0036	0.0006	0.0006	Species
Bigmouth buffalo	0.0259	0.0259	0.0442	0.0442	Class
Smallmouth buffalo	0.0259	0.0259	0.0442	0.0442	Class
Channel catfish	0.0200	0.0200	0.0440	0.0440	Class
White bass	0.0758	0.0758	0.0990	0.0990	Class
Green sunfish	0.0005	0.0005	0.0000	0.0000	Genus
Bluegill sunfish	0.0007	0.0007	0.0000	0.0000	Species
Largemouth bass	0.0008	0.0008	0.0001	0.0001	Family
Black crappie	0.0027	0.0027	0.0037	0.0037	Family

APPENDIX E

Detailed Methods and Assumptions for Ecosystem Uncertainty Analysis

APPENDIX E

DETAILED METHODS AND ASSUMPTIONS FOR ECOSYSTEM UNCERTAINTY ANALYSIS

E.1 ORGANIZING TOXICITY DATA

The first step in Ecosystem Uncertainty Analysis (EUA) is selection of appropriate toxicity data and association of the data with components of SWACOM.

Toxicity data on phytoplankton are sparse. It is possible to find values for green algae, such as Selenastrum capricornutum, and these data are used for all 10 algal populations if no other information is available. If data are available on diatoms and blue-greens, then a further division is possible based on physiological parameters in the model and past experience with SWACOM. Like diatoms, species 1-3 appear early in the spring and are associated with low temperatures and high nutrient concentrations. Species 4 to 7 dominate the spring bloom and are associated with intermediate temperatures and light. Species 8 to 10 appear in the summer and are tolerant of high temperatures and low nutrient concentrations.

The identification of the zooplankton is more tenuous. Based on model behavior and physiological parameters, species 12 and 13 are identified with Cladocerans. The ubiquitous data for Daphnia magna are used for species 12. When data are available for Daphnia pulex, they are used for species 13. The remaining zooplankters (species 11, 14 and 15, and species 13 when no data was available for D. pulex) are simply identified as crustaceans. Of the available data, the smallest concentration is assigned to 15 and the largest to 11. Species 14 (and 13 when necessary) is assigned an intermediate value between these extremes. Assuming species 15 to be the most sensitive is conservative. Since blue-green algae increase is one of our endpoints, we assign the greatest sensitivity to the consumer (i.e., 15) which is most abundant during the summer of the simulated year.

LC_{50} data for fathead minnow (Pimephales sp.), bluegill (Lepomis macrochirus), and guppy (Poecilia reticulata) are assigned to forage fish (species 16, 17 and 18). When data on these species are not available, others are substituted, such as goldfish or mosquitofish. The game fish (species 19) was identified as rainbow trout.

E.2 TRANSFORMING TOXICITY DATA

A critical step in applying EUA involves changing parameter values in SWACOM. This requires three important assumptions which are outlined below.

E.2.1 The General Stress Syndrome (GSS)

Toxicity tests provide information on mortality (or similar endpoint) but provide little insight on the mode of action of the chemicals. Thus, some assumption must be made about how the toxicant affects physiological processes in SWACOM. In an application that focuses on a single chemical it may be possible to obtain detailed information on modes of action. However, the present effort must cover a number of Risk Assessment Units, and it was necessary to make a single overall assumption.

We assumed that organisms respond to all toxicants according to a General Stress Syndrome (GSS). For phytoplankton, this involved decreased maximum photosynthetic rate, increased Michaelis-Menten constant, increased susceptibility to grazing, decreased light saturation, and decreased nutrient assimilation. For zooplankton and fish, the syndrome involves increased respiration, decreased grazing rates, increased susceptibility to predation, and decreased nutrient assimilation. For all organisms, the optimum temperature was assumed to be unchanged. The GSS represents how organisms respond to most toxicants. Where observations were recorded for the chemicals used in this assessment, the researchers noted hyperactivity, increased operculation and other symptoms consistent with the assumption of the GSS. However, some organics might have a "narcotic" effect which would be opposite to the reaction assumed here.

The General Stress Syndrome defines the direction of change of each parameter in SWACOM. It is also necessary to make an assumption about the relative change in each parameter. We have assumed that all parameters of SWACOM change by the same percentage. This assumption can be removed only if considerable information is available on modes of action of each chemical.

E.2.2 The MICROCOSM Simulations

The key to arriving at new parameters is simulation of the experiments which generated the toxicity data. This involves simulating each species in isolation with light, temperature, food supply, and nutrients set at constant levels that would maintain the population indefinitely. Then the parameters are altered together in the direction indicated by the GSS until we duplicate the original experiment. Thus, for an LC_{50} (96 hours), we find the percentage change which halves the population in 4 d.

At the conclusion of the MICROCOSM simulations, we have the percentage change in the parameters which matches the experiment. We must now make an additional assumption to arrive at the expected response for concentrations below the LC_{50} or EC_{50}. We assume a linear dose response. Thus, an environmental concentration 1/5 of the LC_{50} would cause a 10% reduction in the population. The MICROCOSM simulations are then repeated with this new endpoint to arrive at a new percentage change in the parameters. Since most response curves are concave, our assumption should be conservative.

E.2.3 Choosing Uncertainties

To implement the analysis, it is necessary to associate uncertainties with the parameter changes. We assume that all parameter changes have an associated uncertainty of plus or minus 100%. This assumption seems sufficiently conservative. One might wish to adopt a more complex strategy which would combine information on modes of action with a Delphi survey of experienced researchers to arrive at more specific estimates of uncertainty.

ORNL/TM-9074

INTERNAL DISTRIBUTION

1-2. S. I. Auerbach
3-7. C. F. Baes III
8-12. L. W. Barnthouse
13-17. S. M. Bartell
18. R. O. Chester
19. C. C. Coutant
20. W. F. Furth
21-25. R. H. Gardner
26. C. W. Gehrs
27. A. K. Genung
28. J. M. Giddings
29. M. R. Guerin
30. S. G. Hildebrand
31. S. V. Kaye
32. L. E. McNeese
33. R. E. Millemann
34. C. W. Miller
35-39. R. V. O'Neill
40. D. E. Reichle
41. A. E. Rosen
42. L. L. Sigal
43-47. G. W. Suter II
48. C. C. Travis
49. P. J. Walsh
50. H. E. Zittel
51. Central Research Library
52-71. ESD Library
72-73. Laboratory Records Dept.
74. Laboratory Records, ORNL-RC
75. ORNL Y-12 Technical Library
76. ORNL Patent Office

EXTERNAL DISTRIBUTION

77. J. Frances Allen, Science Advisory Board, Environmental Protection Agency, Washington, DC 20460
78. Richard Balcomb, TS-769, Office of Pesticide Programs, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
79. Nathaniel F. Barr, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
80. Colonel Johan Bayer, USAF OHEL, Brook AFB, TX 78235
81. Frank Benenati, Office of Toxic Substances, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
82. K. Biesinger, Environmental Protection Agency, National Water Quality Laboratory, 6201 Congdon Boulevard, Duluth, MN 55804
83. J. D. Buffington, Director, Office of Biological Services, U.S. Fish and Wildlife Services, 1730 K Street, NW, Washington, DC 20240
84. J. Cairns, Center for Environmental Studies, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
85. Melvin W. Carter, Georgia Institute of Technology, School of Nuclear Engineering and Health Physics, Atlanta, GA 30332
86-90. M. G. Cavendish, 619 C, Dewdrop Circle, Cincinnati, OH 45240
91. Paul Cho, Health and Environmental Risk Analysis Program, HHAD/OHER/ER, Department of Energy, Washington, DC 20545
92. C. E. Cushing, Ecosystems Department, Battelle-Northwest Laboratories, Richland, WA 99352
93. R. C. Dahlman, Carbon Cycle Program Manager, Carbon Dioxide Research Division, Office of Energy Research, Room J-311, ER-12, Department of Energy, Washington, DC 20545

94. Sidney Draggan, Ecologist-Policy Analyst, Division of Policy Research and Analysis, National Science Foundation, Washington, DC 20550
95. Charles W. Edington, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
96. Gerhard R. Eisele, Comparative Animal Research Laboratory, 1299 Bethel Valley Road, Oak Ridge, TN 37830
97. David Flemar, Environmental Protection Agency, Washington, DC 20460
98. G. Foley, Environmental Protection Agency, MC RD-682, 401 M Street, SW, Washington, DC 20460
99. Ralph Franklin, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
100. David Friedman, Hazardous Waste Management Division (WH-565), Office of Solid Waste, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
101. Norman R. Glass, National Ecological Research Laboratory, Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR 97330
102. D. Heyward Hamilton, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
103. Leonard Hamilton, Department of Energy and Environment, Brookhaven National Laboratory, Upton, NY 11973
104. Norbert Jaworski, Environmental Research Laboratory-Duluth, 6201 Congdon Boulevard, Duluth, NM 55804
105. The Institute of Ecology, 1401 Wilson Blvd., Box 9197, Arlington, VA 22209
106. Donald Johnson, Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, IL 60631
107. Library, Bureau of Sport Fisheries and Wildlife, Department of the Interior, Washington, DC 20240
108. Library, Food and Agriculture, Organization of the United Nations, Fishery Resources and Environment Division, via delle Termi di Caracalla 001000, Rome, Italy
109. Library, Western Fish Toxicology Laboratory, Environmental Protection Agency, Corvallis, OR 97330
110. Ronald R. Loose, Department of Energy, Washington, DC 20545
111. Helen McCammon, Director, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, ER-75, Room E-233, Department of Energy, Washington, DC 20545
112-161. A. Alan Moghissi, Environmental Protection Agency, MC RD-682, 401 M Street, SW, Washington, DC 20460
162. Dario M. Monti, Division of Technology Overview, Department of Energy, Washington, DC 20545
163. Harold A. Mooney, Department of Biological Sciences, Stanford University, Stanford, CA 94305
164. Sam Morris, Brookhaven National Laboratory, Associated Universities, Inc., Upton, NY 11973
165. Haydn H. Murray, Director, Department of Geology, Indiana University, Bloomington, IN 47405

166. J. Vincent Nabholz, Health and Environmental Review Division, Office of Toxic Substances, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
167. Barry E. North, Engineering-Science, 10 Lakeside Lane, Denver, CO 80212
168. Goetz Oertel, Waste Management Division, Department of Energy, Washington, DC 20545
169. William S. Osburn, Jr., Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, EV-33, Room F-216, Department of Energy, Washington, DC 20545
170. F. L. Parker, College of Engineering, Vanderbilt University, Nashville, TN 37235
171. G. P. Patil, Statistics Department, 318 Pond Laboratory, Pennsylvania State Universtiy, University Park, PA 16802
172. Ralph Perhac, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94304
173-177. C. D. Powers, Science Applications, Inc., 100 Jackson Plaza, Oak Ridge, TN 37830
178. J. C. Randolph, School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405
179. Irwin Remson, Department of Applied Earth Sciences, Stanford University, Stanford, CA 94305
180. Abe Silvers, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
181. David Slade, Office of Health and Environmental Research, Department of Energy, Washington, DC 10545
182. R. J. Stern, Director, Division of NEPA Affairs, Department of Energy, 4G064 Forrestal Building, Washington, DC 20545
183. Frank Swanberg, Jr., U.S. Nuclear Regulatory Commission, Washington, DC 20555
184. The Institute of Ecology, 1401 Wilson Blvd., Box 9197, Arlington, VA 22209
185. Burt Vaughan, Battelle-Pacific Northwest Laboratory, Richland, WA 99352
186-192. D. S. Vaughan, National Fisheries Service, Beaufort Laboratories, Beaufort, NC 28516
193. John Walker, Assessment Division, TS 778, Office of Toxic Substances, U.S. Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
194. Robert L. Watters, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, ER-75, Room F-226, Department of Energy, Washington, DC 20545
195. D. E. Weber, Office of Energy, Minerals, and Industry, Environmental Protection Agency, Washington, DC 20460
196. A. M. Weinberg, Institute of Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, TN 37830
197. Ted Williams, Division of Policy Analysis, Department of Energy, Washington, DC 20545

198. Frank J. Wobber, Division of Ecological Research, Office of Health and Environmental Research, Office of Energy Research, MS-E201, Department of Energy, Washington, DC 20545
199. M. Gordon Wolman, The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD 21218
200. Bill Wood, TS-798, U.S. Environmental Protection Agency, 401 M Street, SW, Washington, DC 20460
201. Robert W. Wood, Director, Division of Pollutant Characterization and Safety Research, Department of Energy, Washington, DC 20545
202. R. Wyzga, Manager, Health and Environmental Risk Department, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
203. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations, P. O. Box E, Department of Energy, Oak Ridge, TN 37831
204-230. Technical Information Center, Oak Ridge, TN 37831

☆U.S. GOVERNMENT PRINTING OFFICE: 1984-544-045/4260