Developing the Risk-Screening Environmental Indicators

Introduction

The following sections describe various options considered during development of the Risk-Screening Environmental Indicators (RSEI) model. In developing the RSEI model, the first stage was a review of many approaches to assessing and ranking the potential impact of chemicals. Offices both within EPA and organizations outside the Agency have developed systems for weighting chemicals based on potential toxicity and/or exposure. The usual purpose of such activities is to prioritize chemicals for further study or for closer regulatory scrutiny, or to target chemicals or industries for enforcement. A review of chemical scoring and ranking procedures is presented in Part A.

Previous scoring systems have used a variety of methods to weight chemicals using toxicity, exposure, and population data. The actual numerical weights applied to chemicals can be qualitative, ordinal, proportional or could be actual numerical risk values (e.g., an RfD for noncancer effects), or some combination of these approaches. The relative severity of the effects posed by chemicals can also be included, as can considerations of the quality of the toxicity data and exposure estimates. Based on EPA's review of these scoring systems, several options for an evaluation method emerged. Alternative methods, and their advantages and disadvantages, were considered by the RSEI Work Group and are summarized in Part B. Although the final method used by RSEI contains elements of the options described in Part B, the RSEI method combines these elements in a manner that is not presented explicitly in Part B.

Part C of this document describes options that were considered for computing and normalizing model results. Part describes considerations for including underground injection in RSEI modeling. Part E presents additional exposure scenarios that could be considered for future versions of the RSEI model.

Part A.

Survey of Ranking and Scoring Systems

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1. Survey of EPA Ranking and Scoring Efforts

Scoring and ranking of chemicals is not a new undertaking. Numerous efforts have focused on categorizing and ranking chemicals for a number of purposes. The most common purpose is devising a method to choose from a vast number of chemicals those that merit further scrutiny. The following is a review of sixteen EPA scoring and ranking systems that have been or are used by Office of Pollution Prevention and Toxics (OPPT) and other Agency Offices.

1.1 OPPT Efforts

1.1.1 Screening Methodology for Pollution Prevention Targeting

USEPA (date unknown), Prepared for the Office of Pollution Prevention and Toxics.

The Office of Pollution Prevention and Toxics prepared a screening method as a tool for targeting chemicals for pollution prevention. A three step scoring system, based on the toxicity (both potency and type of risk posed) and on the release/production ratio of the chemical, was used. Several risk classifications were evaluated; within each classification, a chemical was given a preliminary score of 3, 2, or 1 for high, medium, or low concern, respectively. The first risk area evaluated was cancer potency. All chemicals designated as B2 carcinogenic were given a preliminary score of 3 (high). Oncogenicity received an additional weighting factor of 3 to arrive at a raw score for cancer potency. General chronic toxicity and ecotoxicity were scored; these scores were given an overall weighting factor of 2. Reproductive effects, neurotoxicity, and developmental toxicity were also scored, but these scores were given a weighting factor of 1. The raw scores for all four risk groups were added together and multiplied by the release/production ratio to arrive at a composite score. For each chemical the composite score was calculated as:

$$CS_i = (O_i \cdot 3 + RDN_i \cdot 1 + C_i \cdot 2 + E_i \cdot 2) \cdot \frac{Release_i}{Production_i}$$

where:

CS_i = Composite score for chemical *i*;
O_i = Oncogenicity concern for chemical *i*;
RDN_i = Reproductive, developmental, neurotoxicity concern for chemical *i*;
C_i = Chronic toxicity concern for chemical *i*;
E_i = Ecological toxicity concern for chemical *i*.

This methodology was used for internal EPA chemical targeting. It has not been, to our knowledge, publicly reviewed.

Advantages - Method is simple. Broadly accounts for potency and severity of risk posed. Having three broad categories of potency allows the use of structure-activity and professional judgment to score chemicals lacking extensive toxicological databases. Includes consideration of both cancer and noncancer effects.

Disadvantages - Method groups chemicals very broadly, limiting the variation in potencies that can be expressed. Method ranks chemicals ordinally, not proportionately, which does not allow for accounting of the magnitude of differences among the chemicals. Does not have an exposure component. Assumes that carcinogenic effects are more serious than reproductive effects. To our knowledge, method has not been reviewed outside of the Agency.

1.1.2 TSCA's TRI Chemical Risk Assessment Pre-screening Methodology

USEPA (date unknown), Memo from the Office of Toxic Substances (date unknown).

The objective of this exercise was to select the most likely candidates among TRI chemicals for possible regulation under TSCA. Of the 309 TRI chemicals, 193 were eliminated outright because they were already being assessed or regulated by another EPA division, they were not subject to TSCA, or no reports of use were received by EPA.

The remaining 116 chemicals were preliminarily ranked by exposure assessment and hazard assessment. The two assessments were used in concert with the investigators' knowledge to judge which chemicals presented the most significant risks to human health. This group of roughly 20 chemicals received top priority for more extensive and rigorous investigation, including exposure and hazard assessments, to determine which of them should be considered for regulation under TSCA.

Preliminary Exposure Ranking

One hundred sixteen TRI chemicals were ranked using the Exposure Scoring System for Existing Chemicals. The system was used to rank each chemical in four pathways: surface water (drinking water), environmental (aquatic organisms), ambient air, and groundwater. These rankings were not combined in a final ranking. To perform the rankings, two measures were estimated in each pathway for each chemical.

The first measure, potential of exposure, is a measure of the presence of the chemical in the environment. If the chemical is not expected to be released to a particular pathway, it is assigned a score of "none" for no potential of exposure. Otherwise, if the chemical does not exceed thresholds for physical and chemical properties (half-life, Henry's Law constant, vapor pressure), it is assigned a "low" or "none". Those that are expected to be released in a particular pathway and exceed the thresholds are assigned "high", "medium", or "low" potential of exposure depending on the level of potential exposure that is calculated by the program. This calculation is a function of release and concentration levels at sites. Rough estimates are used if only partial information is available.

The second measure, population, is a score of the number of people that might be exposed to the chemical. It is calculated for each pathway and chemical. The system simply adds up the populations surrounding production sites, or if exposure mostly occurs during industrial use, extrapolates exposed populations from the number of industrial use sites. The final "high/medium/low/none" score is based on population thresholds.

The final score for each pathway area uses the following determination matrix:

Final Exposure Score		**Population Measure**			
		High	**Medium**	**Low**	**None**
Exposure Measure	**High**	High	High	Medium	None
	Medium	High	Medium	Low	None
	Low	Medium	Low	Low	None
	None	None	None	None	None

Preliminary Hazard Ranking

EPA intended to develop a Hazard Ranking System to rank the TRI chemicals based on measures of toxicity. However, only a preliminary search system was developed. It allowed the user to score all TRI chemicals that fit given criteria, e.g. all those with an Reportable Quantity (RQ) over 1000 lbs. This system was used to develop simple lists of high toxicity chemical groups. Using this information and their best judgement, the pre-screeners selected roughly 30 chemicals which they determined to be the most hazardous.

Note that this ranking system has only been used within EPA's Office of Toxic Substances and has not been publicly reviewed.

Advantages - Exposure screening includes four pathways of exposure. Modeling approach is used to evaluate exposure potential. Population surrounding TRI site is also included as a measure of exposure potential.

Disadvantages - Although modeling is used for exposure evaluation, the results are used to group the chemicals into low, medium and high exposure potential groups. Pathway-specific scores are not combined, thus requiring further judgments to evaluate overall exposure potential of a chemical. To our knowledge, method has not been reviewed outside of the Agency.

1.1.3 Chemical Scoring System for Hazard and Exposure Identification

O'Bryan, T. R. and Ross, R. H. (1988) Journal of Toxicology and Environmental Health, Vol (1):119-134.

This system was developed by the Office of Toxic Substances and by the Oak Ridge National Research Laboratory. It combines expert judgement and objective scores to screen chemicals for further investigation for potential regulation under TSCA. Chemicals are scored in eleven areas:

- Oncogenicity
- Developmental toxicity
- Aquatic toxicity
- Chemical production volume
- Consumer exposure
- Environmental fate
- Genotoxicity
- Acute and chronic mammalian toxicity
- Bioconcentration
- Occupational exposure
- Environmental exposure

Scores are assigned by and reconciled between two independent experts. While the scores are based on delineated parameters, they can be adjusted in accordance with expert opinion. Scores for oncogenicity, genotoxicity, developmental toxicity and the exposure measures are based on weight-of-evidence. Scores for the others are based on thresholds (e.g. a bioconcentration score of 9 is assigned for BCF levels above 1000.) Tables 1 through 3 in our August 26 memorandum delineates the numerical ranges that comprise these scoring methods. In some cases, structure activity relationships were used to supplement available data. Individual scores generally range from 0 to 10 and are intended for comparison across areas and chemicals but not as weights for the calculation of a final chemical score. In fact, the methodology does not develop a final score. Instead, the scores from all eleven areas are presented as a score profile to which expert judgement is applied to determine whether a chemical presents a great enough hazard to undergo further investigation under TSCA. Note that this methodology has been published in a peer-reviewed journal.

Advantages - System considers a large number of health endpoints (cancer, developmental toxicity, genotoxicity) in the evaluation. Makes use of both available data and expert judgment, allowing for coverage of a large number of chemicals. Published in a peer-reviewed journal.

Disadvantages - System does not combine scores for overall judgment on relative toxicity of a chemical. In fact, the method explicitly states that scores can be used for comparisons across areas, but are not intended as weights for combination into a final score. Method does not include an exposure component.

1.1.4 CERCLA Section 104 "Third Priority List" of Hazardous Substances that will be the Subject of Toxicology Profiles

USEPA 1990, Prepared for the Office of Toxic Substances, February.

EPA is using this system to select and rank the 275 most hazardous chemicals from among all substances found at National Priority List sites. Three principal criteria determine how hazardous a chemical is: 1) frequency of occurrence at NPL sites, 2) chemical toxicity, and 3) potential for human exposure. Measures of these criteria are used to calculate site and exposure ranks for each chemical, which determine the chemical's final ranking.

Frequency of occurrence is measured as the percent of sites at which the chemical is known to occur. Toxicity of the chemical is measured by its Reportable Quantity (the lowest of the mammalian, acute and chronic toxicity RQs was used.) When these ratings were not available, the chemical was assigned an RQ equivalent by the EPA Structure Activity Team. A site index was calculated for each chemical as:

$$Site\ Index = \frac{Frequency\ of\ occurrence\ (percent)}{RQ}$$

The chemicals were assigned ordinal site ranks beginning with 1 for the chemical with the highest site index, 2 for the chemical with the next highest site index, etc.

The measurement of chemical exposure is considerably more involved. First, an exposure index value is calculated for each chemical as:

$$Exposure\ index = WCR + WFR + SCR + SFR + (2 * BPR)$$

where:

WCR = the geometric mean of chemical concentration in water at all sites where the chemical occurred, ranked ordinally;
WFR = percent of sites at which the chemical occurred in water / percent of sites at which the chemical occurred in any media, ordinally ranked;
SCR = the geometric mean of chemical concentration in soil at all sites where the chemical occurred, ranked ordinally;
WFR = percent of sites at which the chemical occurred in soil / percent of sites at which the chemical occurred in any media, ordinally ranked;
BPR = boiling point of the chemical, ordinally ranked.

For WCR, the geometric mean as indicated is calculated for each chemical. The chemicals are then ranked ordinally according to this value; WCR equals the rank assigned to the chemical.

This method holds for each of the five variables listed above. Note that boiling point values are used as a correlate of potential for air migration.

Because NPL site concentration data are not available for many chemicals, a second methodology to calculate exposure was developed to complement the first. This method takes advantage of the fact that a chemical's status as a chemical of concern gives some indication of the chemical's exposure potential. Thus chemicals were ranked ordinally by the number of NPL sites at which they were listed as chemicals of concern. The lesser of this measure and the exposure index described above was used as the exposure rank.

Finally, these ranks were adjusted based on existing exposure information compiled in six databases: NRC, AHE, DOT/HMIS, NEXIS, NHATS and RTS. Because of source and methodological disparities between the databases, the data they contained were not in themselves useful. However, because the simple occurrence of a chemical in one of the databases implies some degree of exposure, the number of databases in which a chemical was listed was used to determine the adjustments made to the exposure ranks. (Note that because the first four databases contained data from overlapping sources, multiple occurrences of a chemical in these databases was taken as a single listing.) The adjustment was made as follows. The exposure rank was multiplied by a factor of 0.9 if a chemical was listed in only one database, by 0.8 if in two databases, and by 0.7 if in three databases.

The site and exposure ranks of each were combined using the following formula:

$$\text{Hazard Index} = 2/3 * \text{Site Rank} \quad + \quad 1/3 * \text{Exposure Rank}$$

The weights reflect the fact that the site rank represents two of the three principal criteria mentioned initially, while the exposure rank represents only one. The chemicals were assigned final ordinal hazard ranks beginning with 1 for the chemical with the lowest hazard index, 2 for the chemical with the next lowest site index, etc.

Advantages - Uses a peer-reviewed, well-established measure of relative toxicity (RQ) for toxicity ranking. Combines all measures (toxicity, exposure, frequency of occurrence) into a single index for each chemical.

Disadvantages - Exposure component relies on availability of site-specific concentration data for exposure potential evaluation, which is not available for our purposes. Toxicity and exposure ranked ordinally, so that proportional differences in potency and exposure potential are not captured. Use of RQ also does not capture severity of effects.

1.1.5 Toxic Chemical Release Inventory Risk Screening Guide

USEPA 1989, Prepared by the Office of Toxic Substances, Volume 1, July.

The Risk Screening Guide serves to explain both the meaning of Toxic Release Inventory (TRI) data and ways of interpreting that data. Volume One of the document is divided into five sections. The first section details the advent of the TRI program as well as the nature of, limitations on, and modes of access to the TRI data. Section Two details and explains the elements of risk assessment. Section Three presents the guide's qualitative methodology for risk assessment for each exposure route, incorporating the elements detailed in Section Two. Section Four proposes options for acting on the results of the assessment and Section Five lists a host of resources that can be used to answer any further questions.

The Risk Screening System presented in Section Three of the guide merits special attention. The system centers itself around qualitative measurements of different chemical-specific and site-specific factors. The user of the system first selects an exposure route (either air, land, surface water or POTW). The next step is to record the location of release, the zones of effect (inner and outer), and the population of interest. The user then delineates different "exposure factors" which depend upon the exposure route chosen (i.e. wind direction for air or bioconcentration factors for surface water). The scores for these factors depends upon the factor being discussed. For example, a water discharge receives a "+" if it flows to a small lake or stream and a "-" if it flows to a large body of water. Next, the user should select a toxic measure for each chemical from among a set of measures presented in Appendix A (discussed below). The user selects the lowest ranking among all of the different toxicological ranks. Next, the quantity of release should then be listed as either "high," "moderate," or "low" through the use of data presented in Appendix C. The user compares the releases as recorded in TRI to either the table of median emissions or by to local releases. Exposure factors should then be recorded as detailed in Appendix D (discussed below), including high/low environmental transformation, release rate, and any other factors which may seem relevant.

The result of the risk screening system is a profile of scores. From this information it is possible to assess the relative severity of industrial practices in the area. The user can consult local experts in order to get a feel for the individual risk.

Volume Two includes appendices which provide data and examples to facilitate the assessment process. Appendix A ranks toxicological information on chemicals according to the following scheme:

Toxicological Measure	Group 1	Group 2	Group 3
TPQ (lbs.)	1 10 100	500	1,000 10,000
RQ (lbs.)	1 10 100	1,000	5,000
RfD (mg/kg-day)	< 0.01	0.01 - 0.1	>= 1.0
WQC (mg/L)	< 1	1 - 10	>= 10
Cancer Potency	All		

These ranking boundaries are used for each of the RQs (aquatic, chronic, acute, and carcinogenic), RfDs (inhalation and oral), and WQCs (chronic and acute).

Appendix B aids users in assessing air releases. It discusses a generic air modeling exercise which uses the Industrial Source Complex Long-Term (ISCLT) model. It provides two graphs which display the results of generic model runs, the first plotting concentration versus distance from the release site for various stack heights, and the second plotting concentration versus distance from the release site for various durations of release. Multiplying data points on the graph by the actual release quantities provides an estimate of the concentration at different distances of concern.

Appendix C assists users in assessing the severity of chemical releases. It provides information on median chemical release data and actual TRI chemical release data (classified by SIC code) to assist in assigning a "severe," "moderate," or "low" score to the quantity of release (see the discussion on the Risk Screening System in Volume One).

Appendix D provides information on environmental fate characteristics of different chemicals to provide rankings. The characteristics used to evaluate fate in different environmental media and their rankings are listed below:

Factor	**Measure**	**High Concern** **(+)**	**Low Concern** **(-)**
Volatilization	Henry's Constant ($atm\text{-}m^3/mol$)	$\geq 10^{-2}$	$\leq 10^{-6}$
Leaching & Soil Mobility	Log_{10} (K_{oc})	≤ 1.5	≥ 4.5
Bioconcentration	BCF	$\geq$ 1,000	$\leq$ 250
Air Abiotic Persistence	Atmospheric Half-life	$\geq$ 1 year	$\leq$ 1/2 day
Water Abiotic Persistence	Aquatic Half-lives	$\geq$ 1 year	$\leq$ 1/2 day
Air Biotic Persistence	Degradation Rate	many months to years	1 to 7 days
Water Biotic Persistence	Degradation Rate	many months to years	1 to 7 days
Biological Treatment	Rate of removal in bio. treatment	Log_{10} (K_{ow}) ≤ 1.5 $H_c \leq 10^{-5}$ resistant to degr.	rapidly removed: -P for phys/chem -B for biodegr.

The measure for water abiotic persistence stems from the longest of the hydrolysis, direct photolysis, and indirect photoreaction.

Appendix H presents and describes the Roadmap database as well as other databases that contain information on Section 313 chemicals. The Roadmap database includes the following information for each chemical in tabular form:

- Federal regulations that apply to the chemical, along with relevant regulatory levels;

- States that have drinking water standards or recommendations, along with relevant regulatory levels, as reported in the Federal-State Toxicology and Regulatory Alliance Committee (FSTRAC);

- States that have ambient air information, including ambient air standards or guidelines, pollutant research information, source testing information, monitoring data, emissions inventory information, and permitting information, as reported in the National Air Toxics Information Clearinghouse (NATICH);

- States that have water monitoring information, as reported in the Storage and Retrieval Systems (STORET);

- General sources of information, including on-line databases, and documents from EPA and other sources.

This appendix includes expanded descriptions of these information sources. ROADMAPS has since been updated to include additional data. Its "Carcinogenicity Matrix" includes results from the National Toxicology Program bioassay tests (either positive or negative for carcinogenicity); the National Toxicology Program's carcinogenicity ranking; the carcinogenicity rating assigned by the International Agency for Research on Cancer; the EPA's carcinogenicity rating; and the GENETOX carcinogenicity evaluation. It also now contains a "Health and Environmental Effects" table which indicates whether a chemical is at a level of concern for heritable mutations, developmental toxicity, reproductive toxicity, acute toxicity, and chronic toxicity, as well as the references for this data (among EPA databases).

The remaining appendices contain other information to guide a user through the risk assessment process. Appendix E presents information concerning the different types of releases, the release frequency, existing controls, and estimation methods for the releases. Appendix F presents a case study using the risk screening method (described below). Appendix I presents a sample EPA Hazardous Substance Fact Sheet. Each of these sheets discusses one of the Section 313 chemicals, providing information on typical modes of exposure, means of protection, proper handling, etc. Appendix J provides an example of an EPA Chemical Profile which provides physiochemical information on the Section 313 chemicals and which also discusses topics covered on the EPA Hazardous Substance Fact Sheet.

Advantages - Appendix A of the Risk Screening Guide allows grouping of chemicals according to any of five measures of toxicity; using alternative measures of toxicity allows a larger number of chemicals to be scored than if only a single measure was used. Appendix D groups chemicals into groups of "high concern" and "low concern" based on environmental fate characteristics. The Risk Screening Guide has been peer reviewed and is published.

Disadvantages - The grouping approach allows only broad characterization of toxicity and exposure, and does not consider severity or potency. Exposure evaluation does not explicitly consider populations (although this can be considered on a site-by-site basis).

1.2 Other Agency Scoring Systems that Use TRI Data

1.2.1 Targeting Pollution Prevention Opportunities Using the 1988 Toxics Release Inventory

USEPA 1990, Prepared for the Office of Policy, Planning and Evaluation, Pollution Prevention Division, September 29.

OPPE's Pollution Prevention Division (PPD) developed a method to rank chemicals and facilities based on total volume of a subset of TRI chemicals. A list of high-priority chemicals was established for air, land, and water releases based on toxicity and exposure potential (based on the mobility of the chemical) in the TRI Risk Screening Guide. After a list was established for each media, the release volume of those chemicals became the ranking instrument. While no exposure-based adjustments were actually made to the rankings, possible methods for such adjustments were discussed in some detail in the text. The population considered at risk for each pathway varies by the mobility of the chemical. Thus, only populations relatively close to the facility are considered for low mobility chemicals, while at greater distances are included for high mobility chemicals. The table below shows how distance from facility and chemical persistence affect PPD choice of populations. PPD also proposed a method to adjust for the exposure potential of aquatic ecosystems for discharges to surface waters. Similar to human populations within circles of given radii from the facility, the stream volume acts as a proxy for aquatic exposure. The water-volume proxy assumes that densities and types of aquatic organisms are constant among all streams and are strongly positively correlated with total volume of water. Proposed methods for accounting for ecological risk from discharges to other media were resource intensive and did not lend themselves to computer automation.

This method was used for internal EPA chemical evaluation and has not been publicly reviewed.

Concentric Ring Radius From Facility For Population Count

	Mobility of Chemical		
Pathway	High	Medium	Low - No Data
Point and Non-Point Air Release	4 miles	2 miles	1 mile
Underground and Land Releases	1 mile	1/2 mile	1/4 mile
Surface Water Releases	15 miles	10 miles	5 miles

Note: Surface water distances are downstream distances from the facility.

Advantages for exposure evaluation - Combines Risk Screening Guide environmental fate groupings with simple rules for defining the size of the potentially exposed population. This is a straightforward approach that allows quick, rough weighting of emissions by potential exposure.

Disadvantages for exposure evaluation - Does not consider factors affecting differences in media concentrations among sites as part of exposure evaluation. Selection of distances to consider for exposed population is somewhat arbitrary.

1.2.2 Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters

USEPA 1991, Prepared for the Office of Policy Analysis, February 4.

The Office of Policy Analysis developed a population weighted hazard index that ranked water bodies and POTWs reported in TRI. OPA used Reportable Quantities as proxies for three risk classes for which ranks were provided. Cancer potency, chronic toxicity, and aquatic toxicity were treated separately in deriving indexes and ranks. For each risk class, each chemical release was divided by the RQ for that risk class. The weighted releases were summed over a selected set such as state or county to arrive at an unadjusted index.

The equation for calculating the unadjusted Hazard Index is:

$$H_i = \Sigma \frac{R_x}{RQ_x}$$

where:

H_i = Hazard Index for set i;
R_x = Pounds released of chemical x;
RQ_x = Reportable Quantity for chemical x.

For each state or county, unadjusted indices were calculated for cancer, chronic, and aquatic toxicity. The indices for cancer potency and chronic toxicity were adjusted using the size of the exposed population to reflect human exposure potential:

$$H_i = \Sigma \frac{R_x}{RQ_x} C * P$$

where:

P = Persons per square mile in the county of release R_x.

Aquatic toxicity indices were not adjusted using this method due to inadequate data about the size of the exposed aquatic population. Thus, the OPA work does not address the difficult question of adjusting indices based on exposure potential to aquatic life and habitats.

For releases to POTWs, the analysis addressed the hazard of POTW residuals as well as effluent. Average removal rates were applied to chemicals released to POTWs. Standard partitioning rates were applied to the portion removed by the POTW. Hazard indices were then generated for each partitioning pathway (sludge, volatilization) within the POTW.

This methodology was used within the EPA and has not been publicly reviewed.

Advantages - Uses peer-reviewed, publicly available toxicity measure (RQs) that are available for a fairly large percentage of TRI chemicals. Also considers county population density as a surrogate measure of exposure potential.

Disadvantages - Does not consider environmental fate of chemicals in exposure evaluation. Use of RQs does not include consideration of severity of effects. RQs do incorporate some consideration of potency, but groupings according to potency are broad.

1.2.3 Review of Region VII TRI Strategy

USEPA 1991, Memo from Dermont Bouchard, EPA Region VII to Loren Hall, OTS, July 9.

Region VII is developing strategies to utilize TRI data. One strategy ranks geographic areas by human health and aquatic ecological risks to determine areas most in need of investigation for further enforcement, remediation, technical assistance, or other purposes. The human health risk analysis, which is separate from the ecological risk analysis, is measured by relative daily toxic loadings (RDTLs). For a given site, an RDTL is estimated for the following categories:

- Non-cancer acute toxicity by ingestion;
- Chronic inhalation cancer;
- Chronic ingestion cancer;
- Chronic inhalation non-cancer;
- Chronic ingestion non-cancer.

A toxicity measure (for example, the inverse of the RfD for chronic ingestion non-cancer) is multiplied by the site loading to the appropriate media (surface water emission in this case) for each category. These RDTLs are not to be added, unless they are added within a category across the various chemicals present at a site. Because RDTL units are different for each category, they are comparable across sites only within categories.

Aquatic ecological risk for a site is determined in a similar manner. A multi-trophic analysis is used to identify an LC_{50} that is the lowest, most protective value for the site. The RDTL is calculated as:

$$RDTL = chemical\ loading\ volume * LC_{50} / stream\ volume$$

Total risk for a site is the sum of the RDTLs across chemicals released at that site.

The Region VII TRI strategy is currently under peer review within the EPA.

Advantages - Considers acute and chronic toxic endpoints and multiple exposure pathways. The toxicity measures used (RfDs, q*, WQC) reflect the relative potencies of chemicals. For ecological risk, more than one trophic level is considered.

Disadvantages - Scores are not combined across sites for a single chemical index; however, scores may be combined within a single site. The human health evaluation categories do not consider environmental fate or population exposure potential. This system is oriented more toward identifying problem sites than in characterizing overall risk from all sites.

1.3 OSWER Scoring and Ranking Systems

1.3.1 Hazard Ranking System; Final Rule

55 Federal Register No. 241, pp. 51532-51667, December 14, 1990.

The Hazard Ranking System (HRS) is the principal mechanism used by the EPA to place sites on the National Priorities List (NPL). It provides a methodology for scoring a site based on various site characteristics. It incorporates information representing four exposure pathways: ground water, surface water, soil and air. If the site's score exceeds an established threshold, the site qualifies for the NPL.

Hazard Ranking Score

The hazard ranking score is calculated as:

$$HRS = (S^2_{gw} + S^2_{sw} + S^2_{s} + S^2_{a})^{1/2}$$

where:

S = Scores for each of the four pathways delineated below;
gw = Ground water migration pathway;
sw = Surface water migration pathway;
a = Air migration pathway.

Using the root-mean-square calculation, low migration pathways scores yield a low HRS. However, the HRS score could be relatively high even if only one pathway score was high. This is an important requirement for HRS scoring because some extremely dangerous sites pose threats through only one migration pathway.

While the scoring system for each pathway is quite sophisticated, the pathway scores follow this general methodology:

Pathway score = Likelihood of Release * Quantity of waste at the site ***** Measure of toxicity ***** Measure of exposure

The pathway scoring systems demonstrate how toxicity and exposure characteristics can be scored (i.e. weighted). They are much more sophisticated than ordinal scoring systems that implicitly weight characteristics without any underlying justification.

Ground Water Migration Pathway

The pathway score is the product of the following three categories (divided by a scaling factor of 82,500) for the aquifer and contaminant yielding the highest pathway score.

Likelihood of Release	Waste Characteristics	Targets
Highest of: Observed release = 500 OR Potential to release = Contaminant Score * (Net precipitation score + Depth to aquifer score + Travel time score)	Score of [(Score of Toxicity score and Mobility score) * Weighted hazardous waste quantity]	Nearest well score + Weighted population + Resources score + Wellhead score

The scores for these individual components are assigned based on conditions set by the Rule. For example, the contaminant score is 10 if a liner is not present in the containment system, 9 if one is present. The toxicity score is the highest of 1) chronic toxicity score based on ranges for RfDs, 2) carcinogenicity score based on ranges for human carcinogenicity slope factors and weight-of-evidence, and 3) acute toxicity score based on ranges for oral LD_{50}, dermal LD_{50}, and various LC_{50s}. Mobility is scored based on ranges for water solubility and the distribution coefficient (which is based on soil type) of the contaminant.

The numerous inputs for the groundwater pathway analysis include both chemical- and site-specific measures. Many of these measures are not available for the sites listed on the TRI (for example, chemical waste containment conditions or the characteristics of the geology of surrounding strata.) The following list delineates those measures that are available for many of the TRI chemicals and sites:

Chronic toxicity (human) RfD
Human carcinogenicity slope factor
Human carcinogenicity weight-of-evidence
Oral LD_{50}
Dermal LD_{50}
Dust or mist LC_{50}
Gas or vapor LC_{50}
Water solubility
Distribution coefficient K_d
Quantity or volume of waste
Population
Net precipitation
Depth to the aquifer
Nearest well

Surface Water Migration Pathway

There are two components for likelihood of release, overland/flood and groundwater to surface water. Each is the higher of an observed or potential release. The component that yields the highest score when multiplied by the sum of the threat scores is the likelihood of release that is used in the HRS score for this pathway. Threats are composed of three categories: drinking water, human food chain, and environmental. The score of each threat is the product of the waste characteristics and targets for that threat.

As with the groundwater migration pathway, the surface water migration pathway is based on scoring different conditions regarding site, pathway, environmental, chemical, quantity, and population characteristics. The internal scores are used as weights, not ordinal ranks, for these parameters. The methodology is designed so that worst case conditions determine the final HRS rank. Thus if two exposure routes within a media migration pathway exist for a given site, the most damaging route (as scored) is used to calculate the rank. For example, if the risk of exposure through drinking water is worse than that through fish consumption, the surface water score for the site will be based on risks from drinking water.

The surface water migration pathway scoring system utilizes a combined rating factor to score combinations of toxicity and persistence of a chemical. The factor matrix scores twenty-four combinations yielding scores that range eight orders of magnitude.

Like the analysis of the groundwater pathway, the surface water pathway analysis incorporates many measures that are not available for the sites listed on the TRI (for example, the area over which a chemical drains into the surrounding environment.) The following list delineates those measures that are available for many of the TRI chemicals and sites:

- Quantity or volume of waste
- Chronic toxicity (human) RfD
- Human carcinogenicity slope factor
- Human carcinogenicity weight-of-evidence
- Oral LD_{50}
- Dermal LD_{50}
- Dust or mist LC_{50}
- Gas or vapor LC_{50}
- Half-life in water from combined effects of:
    - hydrolysis
    - biodegradation
    - photolysis
    - volatilization
- Log K_{ow}
- Stream volume in cubic feet per second
- BCF
- EPA chronic and acute Ambient Water Quality Criteria
- EPA chronic and acute Ambient Aquatic Life Advisory Concentrations
- Population

Air Migration Pathway

The methodology for this pathway considers gas releases and particulate releases separately. A site which has both kinds of releases is assigned an air pathway score based on whichever kind of release poses the higher risk (as determined by this methodology.) As with the two pathways described above, a release score is based either on an observed release, if present, or on the potential of the site to release. The release score is multiplied by the waste characteristic score and the target score to yield the overall pathway score.

The air water migration pathway methodology is based on scoring different conditions regarding site, pathway, environmental, chemical, quantity, and population characteristics. Specifically, the waste characteristic score comprises measures of toxicity, mobility, and quantity of the chemical released. The target score comprises measures of the nearest individual, surrounding population, natural resources and sensitive environments. Many of the criteria on which scores of these qualities are based are not appropriate for the Indicator methodology (e.g. acreage of a nearby sensitive wetland environment.) However, many physical and chemical properties of the chemicals are used as criteria to measure toxicity, mobility, and migration potential.

As with the groundwater and surface water migration pathways, internal scores of the air migration pathway are used as weights, not ordinal ranks, in the calculation of the pathway score.

In addition, as with the other pathways, the air pathway methodology is designed so that worst case conditions determine the final HRS rank.

Like the analyses of the first two pathways, the air migration pathway analysis incorporates many measures that are not available for the sites listed on the TRI (for example, containment measures in effect and their degree of effectiveness.) The following list delineates those measures that are available for many of the TRI chemicals and sites:

Vapor pressure
Henry's constant
Quantity or volume of waste
Chronic toxicity (human) RfD
Human carcinogenicity slope factor
Human carcinogenicity weight-of-evidence
Oral LD_{50}
Dermal LD_{50}
Dust or mist LC_{50}
Gas or vapor LC_{50}
Population

Note that this ranking system has been published in the Federal Register and has been publicly reviewed.

Advantages - A reviewed and published method for evaluating and ranking hazardous waste sites. Evaluates four exposure pathways and adds the scores to yield a single site score. Considers many relevant site and chemical characteristics when scoring exposure. Toxicity score is based on highest of cancer, noncancer and acute toxicity subscores, thereby incorporating consideration of a range of health endpoints. Scores are used as weights, not ranks, so magnitude of exposure and toxicity can be considered.

Disadvantages - Exposure evaluation requires much more detailed site-specific data than are available for TRI sites.

1.3.2 Application of the Hazard Ranking System to the Prioritization of Organic Compounds Identified at Hazardous Waste Remedial Action Sites

Hallstedt, P. A., Puskar, M. A., and Levine, S. P (1986) Hazardous Waste and Hazardous Materials, Vol (3):2, pp. 221-232.

This system ranks chemicals by relative risk to target those chemicals that are of highest concern with respect to hazardous waste cleanup and the reduction of hazards to human health. The authors' measure of relative risk incorporates the methodology of the first (unrevised) EPA Hazard Ranking System to score chemical toxicity and persistence.

The risk formula that determines the ranking score is straightforward:

*Score = Measure of Hazard * Exposure*

The measure of hazard is based on a chemical's toxicity and persistence characteristics. Each characteristic is ranked from 0 to 3, 3 representing the highest order of toxicity or persistence. The methodologies underlying these rankings are referenced and can be explored if necessary. The overall measure of hazard reflects a synergistic effect between toxicity and persistence and is summarized in the following table:

Measure of Hazard		**Persistence**			
		0	**1**	**2**	**3**
Toxicity	**0**	0	0	0	0
	1	3	6	9	12
	2	6	9	12	15
	3	9	12	15	18

Exposure is measured as the percentage of the sample sites that release a chemical weighted by the concentration of each release. Thus, exposure is not an absolute measure of population exposure but a relative measure that is a function of the sample of sites that is used. Concentration of release was used in lieu of volume of release, because data on the latter was unavailable.

Note that this methodology has been published in a peer-reviewed journal.

Advantages - Simple, straightforward assignment of chemicals to categories based on toxicity and persistence. Provides relative ranks of chemicals based on toxicity-persistence matrix. Allows for categorization of large number of chemicals, based on available data, SAR, and Best Professional Judgment. Has been published in peer-review journal.

Disadvantages - Broad groupings do not permit refined accounting of relative toxicity or persistence of chemicals. Exposure component inappropriate for our purposes, since it considers only the frequency of occurrence of chemicals, and not their concentrations or volumes. Populations exposed are not considered.

1.4 Office of Water Scoring and Ranking Systems

1.4.1 A Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants

USEPA 1985, July 3 (Office unknown).

This methodology was developed to determine which chemicals should be added to or subtracted from the Priority Pollutants List, a list of chemicals that pose the greatest hazard to human health and the environment nationwide in surface water bodies. Chemicals are list candidates if they are either very toxic or exposed to a large population. This system does not attempt to rank chemicals, but simply provides the decision rule for inclusion or exclusion in the list. However, because the chemicals are scored in the process of determining exclusion or inclusion, this system is relevant to the ranking discussion. It is unknown whether this methodology has been peer-reviewed or made available for public comment.

To evaluate toxicity, the following five categories are considered, followed by the variables considered in each category:

- Aquatic Toxicity: acute (LC_{50}), chronic (MATC);
- Mammalian Toxicity: acute oral (LD_{50}), acute dermal (LD_{50}), chronic/sub-chronic (LDLo and TDLo);
- Human Health: Evidence of carcinogenicity, mutagenicity and teratogenicity;
- Bioaccumulation: BCF, BAF, Log P;
- Environmental Persistence: environmental half-life, hydrolysis rate, Henry's constant, KD value.

Because the variables in a category are often well-correlated, they are considered together to avoid biasing the system by considering the same topic twice. A score is developed for each category by considering the most potent effect of any of the variables in that category. For example, the scoring system for Aquatic Toxicity is:

Score	**Acute (LC_{50}) (mg/L)**	**Chronic (MATC) (mg/L)**
12	< 0.1	< 0.01
10	0.1 to 1.0	0.01 to 0.1
5	1.0 to 10.0	0.1 to 1.0
3	10.0 to 100	1.0 to 10.0
0	> 100	> 10
0	Insufficient information	

The values of the scores assigned to each category were based on expert judgment. The scoring systems are similar for the other categories. One of the advantages of this method is that data gaps in one variable may be filled by data from another within the same category. Note that in the Human Health category, weight of evidence classes, not numeric measures (such as q*), are assigned score values. If the sum of the scores over the five categories is greater than 10, then the chemical is listed.

National exposure potential is evaluated in a similar manner. The following categories are individually scored on a scale of 0 to 10 based on numerical thresholds as above:

- Amount of discharge nationwide (metric tons per year);
- Number of sites of discharge having detectable concentrations;
- Frequency of detection in ambient waters (percent);
- Frequency of detection in aquatic sediments (percent);
- Frequency of detection in industrial or municipal effluents (percent).

If the sum of the scores over the five categories is greater than 10, then the chemical should be listed.

Advantages - Considers a range of acute and chronic toxicities. Includes persistence and bioaccumulation. Allows for more than one measure to be used to rank a chemical within one category, thus allowing a wider range of chemicals to be scored. Allows use of expert judgment to fill in data gaps.

Disadvantages - Toxicity ranks are ordinal, not proportional. Since this system was not intended for site-specific use, it is limited in its consideration of exposure potential; exposure potential is based only on environmental fate properties of the chemicals and frequency of occurrence.

1.4.2 Screening Procedure for Chemicals of Importance to the Office of Water

USEPA 1986, Prepared by the Office of Health and Environmental Assessment, November 14.

This screening method was developed by ORD for the Office of Water to differentiate quickly and inexpensively between higher and lower risk chemicals so that the Office could set priorities for more intensive review of a small set of chemicals. Each chemical is identified as having "high", "low" or "unknown" toxicity and "high", "low" or "unknown" exposure. Chemicals are categorized using this matrix:

Rank Categories		Toxicity		
		High	**Low**	**Unknown**
Exposure	**High**	1	2	2
	Low	3	4	4
	Unknown	3	4	4

A fifth and lowest category is reserved for chemicals that are clearly not an environmental problem. Chemicals in this category must either 1) have a half-life of less than a few minutes and not be highly toxic (acute only), 2) be easily treatable, or 3) have not been shown to be toxic at high concentrations.

The criteria for labeling a chemical as having "high" toxicity is different depending on the exposure pathway and exposed population. For example, a chemical exposed to human populations is "highly" toxic if it is a definite, probable or possible carcinogen, or if it is developmentally toxic. A chemical exposed to aquatic life populations is "highly" toxic if $LC_{50} <$ 100 mg/l or if chronic toxicity < 1 mg/l.

The criteria for labeling a chemical as having "high" exposure is also different depending on the exposure pathway and exposed population. Usually several conditions must be met. Among these, for example, are BCF thresholds and whether or not the chemical has been detected (at any level) in a relevant water pathway.

While "high" criteria are not comparable across pathways and populations, this method succeeds in grouping chemicals roughly by risk. Chemicals not labeled "high" for toxicity or exposure are labeled "low", unless information is unavailable. Data gaps are minimized by using chemical estimation models (ENPART, a fate model; CHEMFATE; CHEMEST.)

It is unknown whether this methodology has undergone peer-review or public comment.

Advantages - Quick, easy to understand. Assigns rank based on toxicity and exposure potential simultaneously rather than considering these elements separately. Allows scoring of a large number of chemicals based on available data, SAR, and Best Professional Judgment. Considers a range of health endpoints. Implicitly weights cancer and noncancer by automatically assigning "high" ranks to cancer and developmental toxicity.

Disadvantages - Consideration of potency, severity and weight-of-evidence are implicit, not explicit, in assignment of chemical to one of the toxicity categories. Limited consideration of exposure, based on environmental fate properties and the frequency of detection in U.S. waters.

1.5 Air Office Scoring and Ranking Systems

1.5.1 The Source Category Ranking System: Development and Methodology

USEPA 1990, Prepared for the Office of Air Quality Planning Standards, Chemicals and Petroleum Branch, February 16.

This system was devised to rank sources of different emissions in order to prioritize air pollutant source categories. The scoring system looks at both long- and short-term effects of pollutants, taking into consideration pollutant concentrations, maximum and average exposure, the total exposed population, and health risks associated with the exposure. To our knowledge, this system has only been used internally by the EPA and has not been publicly or peer-reviewed.

Health effects scores are based upon carcinogenicity, reproductive and developmental toxicity, acute toxicity data, and nonlethal health effects. Before calculating health risk scores, all health effects are scaled by dividing by the respective maximum health score so that the maximum equals one. Scores for a particular site are then added across pollutants.

Exposure scores were calculated using an algorithm integrated with the Industrial Source Complex Long-Term Model (ISCLT). Exposures per unit loss rates were calculated for both long-term (average) and short-term (peak) chemical releases. These were then scaled by dividing by the maximum exposure score such that the greatest exposure would equal one.

Advantages - System was devised to rank air pollutant source categories. It utilizes data on acute and chronic toxicity, pollutant concentrations (as obtained from air modeling), populations exposed and human health risk. Scores are developed for carcinogenicity and other health end points. Scores are summed across pollutants to obtain source specific values. Normalizes scores by dividing each score by maximum value possible in that category.

Disadvantages - System is media-specific to EPA's Air Program. The system neither incorporates severity of health effects nor does it allow weight-of-evidence considerations in scoring. Unknown if system has been peer-reviewed. The system also does not include non-human health effects in establishing a source-specific score.

1.5.2 Measuring Air Quality: The New Pollutants Standards Index

USEPA 1978, Prepared for the Office of Policy Analysis, July.

This index measures air quality based on the potential acute human health effects of five major pollutants: carbon monoxide, photochemical oxidants, nitrogen dioxide, sulfur dioxide, and particulate matter. The index is formed by calculating the following subindex for each pollutant:

$$Subindex = \frac{100 * Observed\ Concentration}{National\ Ambient\ Air\ Quality\ Standard\ (NAAQS)}$$

The Index value (ranging from 0 to 500) is equal to the highest of the five subindices. The pollutant responsible for the highest subindex and all pollutants with subindices greater than 100 are named (a subindex greater than 100 indicates that the pollutant concentration violates the NAAQS.) Because of the limited definition, indices calculated in this way on a regional or local basis are not comparable because variables such as area of effect, duration of concentration, and exposed population are not controlled.

This index has been published and was designed specifically for public use.

Advantages - This index provides a measure of overall air quality based on the potential acute human health effects of five criteria air pollutants. The index is simple and easy to understand. Subindices are calculated for each pollutant by dividing the observed concentration by the relevant National Ambient Air Quality Standard.

Disadvantages - This index is severely limited to just the five criteria air pollutants. The index only incorporates acute health effects data along with ambient air concentration data. It does not look at chronic health effects, ecological effects, populations exposed, weight of evidence considerations, or severity of effects. Additionally, the index does not allow for combining values into a single score.

1.5.3 National Emissions Standards for Hazardous Air Pollutants for Source Categories: Proposed Regulations Governing Compliance Extensions for Early Reductions of Hazardous Air Pollutants

USEPA 1991, Prepared for the Office of Air Quality Planning Standards.

This proposed rule will implement provisions of the Clean Air Act Amendments of 1990 that allow a source to obtain an extension for compliance with air emissions standards if the source has achieved an overall emission reduction of 90% or more by specified dates. Reductions are calculated based on overall emissions from the source; therefore, a source can use greater than 90% reductions from some pollutants to offset less than 90% reductions for other pollutants to achieve the overall 90% reduction. However, certain rules govern this practice of offsetting for "high-risk" pollutants. Offsetting of these "high-risk" pollutants with lower risk pollutants is calculated based on the relative toxicity of the chemicals. For carcinogens, weighting factors are applied to the emissions of these "high-risk" chemicals, so that every 1 pound of these carcinogens equals between 10 and 1,000,000 pounds of lower risk carcinogens. For noncarcinogens, weighting factors are not developed; rather, chemicals are categorized into two groups, high risk and low risk. High risk noncarcinogens can be traded on a one-to-one basis with other high risk noncarcinogens and with carcinogens on a ten-to-one basis. Reductions in high-risk noncarcinogens can offset low risk noncarcinogens, but not vice versa.

To identify high-risk chemicals in both the carcinogen and noncarcinogen categories, OAQPS first gathered available health data on the chemicals. For carcinogens, potency data was taken from Integrated Risk Information System (IRIS) and from CERCLA Reportable Quantities. Weight-of-evidence classifications and CERCLA hazard ranking (low, medium, high) was also recorded. IRIS was also used to obtain data for noncarcinogens. IRIS was supplemented by RTECS, where IRIS data were not available.

After health data were gathered, OAQPS performed generic exposure modeling based on average meteorologic conditions. If the chemical concentration 500 meters from the source posed greater than 1×10^{-4} risk, or if the concentration exceeded the reference dose (or the LOEL/100 or LD50/1000, if no RfD was available) by an order of magnitude or more, the chemical was preliminarily designated "high-risk". The weighting factors for carcinogens were determined based on the ratio of the potency estimates of the high-risk chemicals to the potency estimates of the lower risk chemicals. In contrast, noncarcinogens were simply placed into high- and low-risk groups, without specific weighting factors. The last step in the analysis was to determine if any U.S. facilities actually emit these chemicals in sufficient quantities to reach the health effects benchmark of concern. This determination was based on TRI emissions data and other sources of emissions data. If at least one facility released the chemical in sufficient quantities to reach the benchmark exposure level, the chemical was included on the final "high-risk" list. Note that these emissions standards will be published in the Federal Register.

Advantages - The relevant aspect of this proposal is the identification of chemicals that will count toward early emission reduction goals. Importantly, chemicals are ranked as high- or low-risk using generic air exposure modeling; this would support our use of such a generic approach. Secondly, the system implicitly ranks carcinogens against non-carcinogens by allowing weighted trading among the tow types of chemicals. The relative emission trading amounts would support a cancer versus non-cancer severity weighting. The approach will be published in the Federal Register.

Disadvantages - System considers only air emissions. System is tailored to a particular requirement of the Clean Air Act Amendments. The system does not address ecological effects.

1.6 Other Agency Scoring and Ranking Systems

1.6.1 USEPA Unfinished Business Report: A Comparative Assessment of Environmental Problems

USEPA 1987, Prepared for the Administrator by
Richard Morgenstern, Director, Office of Policy Analysis
Don Clay, Deputy Assistant Administrator for Air and Radiation
Gerald Emison, Director, Office of Air Quality Planning and Standards
Rebecca Hanmer, Deputy Assistant, Administrator for Water
Marcia Williams, Director, Office of Solid Waste
PB88-127048, February 1987.

This EPA report assesses 31 prominent environmental problems currently facing the United States. It attempts to rank them by the risk each poses to society in an effort to prioritize how EPA should use its resources. The environmental problems were defined along existing program lines, e.g. criteria air pollutants, hazardous air pollutants, contaminants in drinking water, Superfund sites, pesticide residues on food, worker exposure to toxic chemicals, etc. The ranking system that the authors employed has been published and peer reviewed by the Scientific Advisory Board.

Four different types of risks were evaluated for each environmental problem: cancer risks, non-cancer health risks, ecological effects, and welfare effects (visible impairment, materials damage, etc.). These risk evaluations did not consider the economic or technical controllability of the risks or the benefits to society of the activities causing the environmental problems. No attempt was made to combine the risk evaluations, so in effect four separate rankings of the 31 problems were generated.

The risk assessments were based on pollutant exposure and effects data. However, because the data were largely incomplete and the methodologies for evaluating them are undeveloped or crude, assessments were ultimately based on the collective informed judgement of the experts involved. Wherever possible, these judgements were made using formal and systematic methods.

Cancer Risk

To assess carcinogenic risk, EPA relied on the Carcinogen Assessment Group's evaluation of the magnitude of risk. However, final rankings were based on judgment of the weight-of-evidence as well as magnitude.

Non-Cancer Health Risk Evaluation

Each environmental problem was ranked based on the incidence of effects of the chemicals associated with each problem and weighted by the severity of the effects. The methodology began by selecting a few representative chemicals, for which incidence of exposure was estimated:

*Incidence = number of people exposed * chemical potency*

(potency = exposure dose divided by reference dose)

Data was often unavailable, in which case the authors' judgement was used. Incidences were summed, weighted by an effect severity index. The final rank was determined by scaling the sum by the authors' estimate of how much of the problem was not captured by the representative chemicals.

Ecological Risk

The authors attempted a broad assessment of environmental impacts on all kinds of ecosystems from terrestrial and freshwater types to marine and estuarine types. However, their assessment of ecological risk was the least rigorous of the four risk evaluations conducted. Each environmental problem was ranked by subjective consensus as high, medium or low for each type of ecosystem. The rankings were based on expert judgment of: 1) potential anthrogenic impact on the environment at the local, regional and biospheric levels and, 2) the severity of the impact in terms of number of years required for ecosystem recovery once the stress was removed.

The judgments for a particular environmental problem were systematically aggregated across ecosystems to generate a high, medium or low overall ranking for the problem. However, the authors felt that their method was too inexact to try to establish relative rankings within these categories.

Welfare Risk

A full range of welfare effects were considered, including soiling and other material damages, recreation, natural resources, damages to other public and commercial property and ground water supplies, and losses in aesthetics and non-user values. The environmental problems were ranked by consensus through a subjective review of the extent and cost of existing and potential damage.

Advantages - Method is simple. Incorporates four broad risks/effects categories: cancer risks, non-cancer risks, ecological effects, and welfare effects. These categories allow and require professional judgment in score determination. The cancer risk score uses both magnitude of risk as well as the weight-of-evidence. The non-cancer risk score uses exposure as well as severity of effect. This system has been published and reviewed by the Scientific Advisory Board.

Disadvantages - The four different categories cannot be combined into a unified score. The professional judgment went into the score determination rather than the data selection, a process which would prove too unwieldy for the entire TRI database. Both the ecological and welfare ranks were subjective and relied upon site-by-site judgment rather than a rigorous method for calculation.

1.6.2 Integrated Environment Management Program

USEPA 1986, Prepared for the Environmental Criteria and Assessment Office, March.

The IEMP is one system which seeks to incorporate the severity of the toxicity effect into a chemical release ranking system. The ranking of the chemical release is based upon its relative risk index score (RRIS), calculated as:

*RRIS = (Dose) * (Est. Potency for Human Health Effect) * (Weighting Factor)*

Though the algorithm for determining the dose is not specified, the calculation is based upon: (1) pollutant loadings; (2) an exposure analysis using established Agency fate and transport models; (3) the population base identified; and (4) assumptions about body weight and routes of uptake.

Human health effects are divided into eight different categories, i.e. carcinogenicity, mutagenicity, etc. The health score is a function of the probability that the effect occurs in humans (T - based upon a set of decision rules regarding weight-of-evidence) and the probability of occurrence of the toxic effect (P). For carcinogens, P equals the risk per unit dose. For non-carcinogens,

$$P = \frac{I}{MED}$$

where:

I = Observed incidence of effects above the control incidence at the MED;
MED = Minimum effective dose expressed as (mg/kg/day).

The weighting factor is actually a severity factor for each toxic effect. They are intended to reflect the significance of the quality of life lost, years of life lost, and economic cost of the disease.

To the best of our knowledge, this system has been used only within the EPA and has not been publicly reviewed.

Advantages - Method is simple. It uses both exposure and routes of exposure in its dose calculation. It incorporates eight different health effects in its health score and relies upon the weight-of-evidence. It can use one or all of these effects, allowing for gaps in the data. It contains a weighting factor for the severity of effect. It also generates a single score for carcinogens and non-carcinogens.

Disadvantages - The system has not, to our knowledge, been peer-reviewed. The specifics of the determination of the dose score and health score are not specified in the literature. The allowance of one to all of the health effects in the scoring makes a "fair" comparison among chemicals uncertain.

1.6.3 Examination of the Severity of Toxic Effects and Recommendation of a Systematic Approach to Rank Adverse Effects

USEPA 1986, Prepared for the Environmental Criteria and Assessment Office, March.

Although this paper did not present a scoring system, it presents information on one aspect of scoring: the weighting of severity among different types of health non-cancer effects. Note that it is an internal EPA document and has not undergone public review. The purpose of this paper is to differentiate the effects of chemicals upon the human body and then to rank those effects. For example, two different chemicals may have identical LOELs (Lowest Observable Effect Level) but their "effects" may be entirely different, i.e. slight changes in the liver versus kidney and/or heart failure. Thus, while current research focuses on comparing chemicals according to these quantities, the author believes in the necessity of a simultaneous ranking system based upon both the type and magnitude of different toxic effects. This paper presents two ranking systems, one for histopathological lesions (direct physical impact upon organs) and one for biochemical effects.

The histopathological scheme lists the severity of effect as a function of the severity of the lesion, modified by any additional non-histopathological effects, and the affected organ. The expression for the severity score is:

*Score = ((Lesion Severity) + (Non-hist. Modifier)) * Organ Factor*

The lesion severity is determined from a table which lists eight possible ranges of effects and then assigns a score from one to eight (eight being the most severe) for that range. The modifier is simply an addend for three different non-histopathological effects: organ weight change, biochemical change, and organ system impairment. For an observed effect in each category, the modifier is one. For no observable effect, the modifier is zero. If it is unknown whether these effects accompany the lesion, the modifier is one-half. A value is assigned to the organ factor according to a table which ranks each of the four "Organ Categories" defined in the report.

The algorithm for the endpoint toxicity scheme is similar. The severity score may be expressed as:

*Score = ((Endpoint Severity) + (Endpoint Modifier)) * Organ Factor*

The endpoint severity is determined from a table which lists seven possible ranges for the biochemical change or system impairment as well as the category of the affected organ. The table assigns a score, from one to seven, for each range, with seven being the most severe. The modifier, as in the first scheme, is equal to one, zero, or one-half, depending upon an observed, non-observed, or uncertain accompanying histopathological lesion or organ weight change. For example, a body weight change in an organism receives a score of one, the absence of organ weight change and lesions creates a modifier of zero for both and therefore a total modifier of zero. No effect in category one organs (lung, heart, brain, etc.) is an organ factor of one, yielding a total score of one.

The author cautions that these proposed schemes are not suitable for use in the comparison of chemicals because, since factors such as duration of exposure and route of exposure were not variables in the derivation of the schemes, these would need to be held as fixed in comparing chemicals, a situation which never occurs in toxic releases.

Advantages - A relatively simple method. It examines the differences in the severity of effects. It includes rankings according to the organs affected, biochemical effects, and histopathological effects.

Disadvantages - This is not an overall scoring system. The author even cautions against its integration into a scoring system because certain site-specific variables, such as duration or route of exposure, were not incorporated into the scheme. This system has not been peer-reviewed.

In developing this severity ranking scheme, the authors of this paper reviewed several other systems that use severity as a factor in the comparison of chemicals. The following describes systems used by the author to develop their scoring systems.

Assessment of Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities

One hundred of the 501 RCRA wastes handled by treatment, storage, and disposal facilities (TSDFs) were ranked according to two types of health data, toxic effects and carcinogenic effects. Two factors were created, the toxicity hazard factor and the carcinogenicity hazard factor. These are described as:

$$THF = \frac{gas - \ phase\ equil\ conc.}{Threshold\ Limit\ Value}$$

$$CHF = \frac{gas - \ phase\ equil\ conc.}{max\ allow.\ conc.\ at\ the\ 1E-5\ risk\ level}$$

The maximum allowable concentration at the 100,000 risk level is the concentration at which there is a 95% confidence that the limit on the cancer risk is one in one hundred thousand people. Each of these factors is then multiplied by the wastes' aqueous and nonaqueous disposal volumes in order to generate volume-weighted hazard scores.

In addition to the determination of these factors, a weighting factor is created from carcinogenicity, teratogenicity, and acute toxic effects of each contaminant (using data from RTECS). The score for each lies between zero and three. This weighting factor was then multiplied by the scores.

Advantages - Simple system. Incorporates two different health effects, toxic effects and carcinogenic effects. It uses the volume of release directly in the score determination. Includes a weighting factor based upon carcinogenicity, teratogenicity, and acute toxic effects.

Disadvantages - The two scoring factors for toxic and carcinogenic effects cannot be combined. The factors rely upon the Threshold Limit Value and the Maximum Allowable Concentration at the 1E-5 Risk Level respectively, data which exists for few chemicals. Does not have an exposure component.

RCRA Risk-Cost Analysis Model

This model follows a five-step process in order to determine human health risks resulting from releases of chemicals. After chemical selection, concentrations of the contaminants are estimated for three transport processes (air, surface water, and groundwater). The model then estimates the total human intake, calculates the risk to an individual, and then estimates the population risk by multiplying by the total population in a given area. This process assigns a risk score which then ranks the releases.

Two equations were developed in order to model the process. They are:

$$\text{Carc. Risk} = (\text{risk per unit dose}) * (\text{severity index}) * (\text{dose})^{\text{shape}} * (\text{population exposed})$$

$$\text{Non-Carc. Risk} = (\text{risk per unit dose}) * (\text{dose}) * (\text{population exposed})$$

The severity index follows from a 1984 EPA ranking system developed to quantify statutory reportable quantities of hazardous substances. It assigns a value of 0.1 for severities 1-2, 0.5 for severities 3-7, and 1.0 for severities 8-10. The shape is merely an exponent to determine the shape of the curve.

Advantages - Simple system, requiring only a dose for mammalian species based upon either human or animal chronic or acute doses. Considers three different routes of exposure: oral, inhalation, and dermal.

Disadvantages - Relies upon a narrow range of health effects. Does not have an exposure or a volume component (it ranks chemicals, not releases). Though the score only requires the dose, the calculation of the dose is cumbersome and the process is difficult to understand.

Toxicity Scoring System Using RTECS Databases

Though the scoring algorithm is simple, requiring only a dose, the methodology requires detailed toxicity data for input into the algorithm.

The only dose considered are those for mammalian species. This method only considers oral, inhalation and dermal routes of exposure, assuming each of equal importance and the absorption to be 100%. Four subscores are considered for each substance: human acute, animal acute, human chronic, and animal chronic. The final score is taken from the following hierarchy:

- minimum of human and animal chronic doses, if both have entries;
- chronic dose for humans or animals, if only one has entry;
- minimum of human and animal acute doses, if both have an entry and there are no chronic entries; and
- acute dose for humans or animals, if this is the only category with any entries

In using RTECS, chronic exposures are those resulting in effects other than death or are effects such as cancer which may result in mortality. Selecting a human chronic effect requires comparison in the RTECS databases, where carcinogenic effects are classified as a carcinogenic response (CAR), a neoplastic response (NEO), or an equivocal tumorigenic agent (ETA). The lowest effect level for carcinogenicity is chosen by selecting the lowest dose of CAR or NEO. If neither exists, the lowest ETA is multiplied by two. The selected dose is modified when there are multiple carcinogenicity entries by decreasing the selected dose 10 percent per additional positive result, to a maximum of 50%. Teratogenic doses from individual studies are ranked and the dose at the 20th percentile is selected as the teratogenic dose. This dose is lowered in the same manner as the carcinogenic dose.

Advantages - Simple system. Incorporates exposure data for three different routes, air, surface water, and groundwater. It also incorporates the severity of effect according to a 1984 EPA ranking system, making its inclusion simple and straightforward.

Disadvantages - Relies strictly upon the cancer slope of a chemical, limiting the number of allowable chemicals by available data. The two separate scores calculated, carcinogenic and non-carcinogenic, may not be compared.

2. Survey of TRI Ranking and Indexing Efforts Outside EPA

A number of organizations outside of the Agency have also developed ranking/scoring systems for their own purposes, such as targeting chemicals for state regulation; identifying chemicals for pollution prevention projects; and assessing the hazard of TRI emissions in particular communities. For this effort, a number of organizations were contacted which have utilized TRI data in publications. The organizations were asked about the scope and methodology used in their reports.

2.1 Rhone-Poulenc

Rhone-Poulenc memo July 25, 1991.

In Paris, this company developed an Environmental Index (EI) to access the aqueous effluent impact of wastes. They computed a raw indicator as a weighted average of the daily mass of six types of wastes (toxic materials, suspended solids, nitrogen, phosphorus, salts, and chemical organics). No justification is given for these weights. The raw indicator is multiplied by 100 and divided by the average from the prior year to arrive at the final EI for the month. This transformation is intended to make comparisons easy. If the index is greater than 100 the impact has been greater, values less that 100 indicate improvement.

2.2 Chemicals on Which Data Are Currently Inadequate: Selection Criteria for Health and Environmental Purposes

Organization for Economic Co-operation and Development, Berlin, March 1985.

This report itself did not present a chemical ranking system. Rather, the purpose of this task was to develop a rational methodology by which countries could select chemicals that most urgently need attention. The elements of this methodology were: identifying selection elements, exploring ways of weighting and combining elements and reviewing data sources. Selection elements identified included workplace exposure, general population exposure, environmental exposure, human and environmental effects. OECD also included recommendations for applying these elements. Importantly, OECD emphasized the importance of clarifying the purpose and scope of the selection exercise in order to define limits and interpretations. OECD also supported the use of expert judgment to fill in data gaps. Finally, OECD strongly urged consideration of data quality in the ranking and selection of chemicals.

For each of the elements of the methodology, OECD broke the approach down into four steps: compilation, screening, refinement and review. The report then suggested topics to consider in each of the four phases.

2.3 Polaroid Corporation

Conversation with Polaroid Corporation representatives, June 1991).

This company has developed a 5-category scheme for all chemicals that they use. Chemicals in categories i and ii are highly toxic (known and possible carcinogens). Category V chemicals are non-toxic solid waste. Chemical categories have been used to establish goals for 50 percent reduction in chemical use by category. The focus on chemical use reduction rather than chemical release reduction is based on the Massachusetts Toxics Use Reduction Act. Category specific goals are designed to prevent strategies that claim a "50 percent use reduction" but are based exclusively on reductions in use of low toxicity wastes.

2.4 Toxic Chemicals In Massachusetts

The Boston Herald, Monday, May 13, 1991, p. 8.

The Boston Herald published a series of articles under the heading of "Ill wind," covering environmental releases of toxic chemicals in Massachusetts. The *Herald* concentrated mostly upon volumetric data but also developed an algorithm for ranking the chemical releases according to volume and toxicity. The algorithm multiplied the volume of release by a decimal number derived from the inhalation risk number. This enabled the article to rank individual emitters by order of “cancer risk.” The *Herald* acknowledged that the ranking did not incorporate human exposure into its calculation and cautioned against using their calculation as an “actual measurement of risk.”

2.5 Air Toxic "Hot Spots" Program Risk Assessment Guidelines

California Air Pollution Control Officers Association, March 1990.

This system is designed to prioritize facilities in accordance with the Air Toxics "Hot Spots" Information and Assessment Act of 1987. According to this Act, any facility which qualifies as a "high priority" facility must perform a health risk assessment. Localities determine the priority level (high, intermediate, or low) of the facilities in their district based upon the facility's reported emissions of one or more of some 500 chemicals. Separate calculations and priority levels are used for carcinogenic and non-carcinogenic substances. The higher of the two levels as calculated is assigned to the facility.

The score for a facility emitting carcinogens is equal to the sum of the scores generated for each carcinogen. Each contaminant's score is calculated as

$$TS = \text{emissions [lbs/yr]} * \text{unit risk } [\mu g/m^3]^{-1} * \text{distance factor} * \text{normalization factor}$$

The distance factor is determined from the distance from the source of the emissions to the nearest populated area. That quantity corresponds to a value relating the change in concentration with distance through the use of a Gaussian plume dispersion model. A total score of ten roughly corresponds to a risk of one in ten thousand and a total score of one similarly corresponds to a risk of one in one hundred thousand. This methodology places any facility scoring above ten in the "high priority" category and those scoring below one in the "low priority" category. A score between one and ten requires further analysis.

The score for a facility emitting non-carcinogens is determined much in the same way. The total score for the facility is the sum of the scores of each substance emitted by the facility. The substance score may be expressed as:

$TS = emissions\ [lbs/yr^{1}] * distance\ factor * normalization/acceptable\ exposure\ level\ [\mu g/m^{3}]$

The non-carcinogenic scores are considered identically to the carcinogenic scores, with "high priority" assignment to facilities with totals over ten and "low priority" assignment to facilities with total scores below one. Note that the carcinogenic and non-carcinogenic scores are not added together.

2.6 Louisiana's Environmental Action Plan "Leap to 2000"

Public Advisory and Steering Committee Risk Ranking Retreat Briefing Material
March 26, 1991.

Louisiana formed a Political Advisory Committee (PAC) to rank 33 environmental issues by the severity of risks they posed to the State. Risks were divided into three categories: human health, ecological effects, and quality of life. The issues were ranked separately within each of these categories based upon available scientific information and the judgment of assembled experts. Informed by the three rankings, the PAC settled the final comprehensive risk ranking by voting on the issues.

2.6.1 Health Effects

This method estimates risk to human health from the cancer and non-cancer effects. Cancer risk was calculated based on chemicals representative of each issue:

$$Risk = Environmental\ Concentration * Potency * Population\ Exposed$$

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[1] maximum lbs/yr for substances associated with acute toxicity and average lbs/yr for substances associated with chronic toxicity

Thus the issues were ranked by estimated cancer cases that would be caused by a particular environmental problem. The issues were categorized as high, medium or low based on breaks in the data of these results.

Non-cancer health risk was estimated from chemicals representative of each issue. Three exposure pathways were considered: air inhalation, food and liquid ingestion, and skin adsorption. Risk presented by each issue was calculated for each applicable exposure scenario as:

$$\textit{Risk} = \textit{Severity Index} * \textit{Dose} * \textit{Population Score}$$

The severity index is a standard ordinal ranking of body organs affected by a chemical and the severity of those affects. Dose is an ordinal score based on ranges of RfD divided by average contaminant concentration in the population's environment. Population score is an ordinal rank of ranges of population sizes.

Non-cancer health risk for an issue is calculated as the average of the risks posed by each exposure pathway. Issues were again ranked high, medium or low based on breaks in the data of these results.

The final issue ranking placed equal weight on the cancer and non-cancer effects. The nine possible combinations of the elements of the two categories were assigned very high, high, medium high, medium, and low ranks based on a committee consensus.

2.6.2 Ecological Effects

The ranking committee ranked the environmental issues based on the degree to which nine ecosystems were affected by each issue. Impacts on each of the nine ecosystems were evaluated on an issue by issue basis by examining how stressors associated with an issue impacted the stress indicators in an ecosystem. For example, for the Terrestrial Habitat Loss issue, stressors like industrial development and proposed road construction were rated on a scale of 0 to 10 for how they affect such stress indicators as Changes in Nutrient Cycling and Loss of Habitat. A stressor's score was the weighted average of ratings across stress indicators, the weights reflecting the committee's assessment of relative importance of the stress indicators. Stressor scores were averaged to determine the final rating of the importance of the issue to the particular ecosystem.

The rank of the issue was calculated as the weighted average of these ecosystem-specific ratings, the weights reflecting the committee's assessment of the value of each ecosystem. Breaks in the ranking figures determined how the issues were divided into five categories (very high through low.) Separately, committee members voted on the ecological importance of each issue using the same five categories and compared this ranking to the quantitative one. The four issues that were not placed in the same categories by the two systems were recategorized by consensus.

2.6.3 Quality of Life

This analysis attempted to rank the issues into high, medium and low categories based on the costs associated with damages not accounted for in the two other rankings. Among these costs are health care costs, recreation losses, materials damage and aesthetic losses. The issues were first ranked based on the dollar value estimates of costs as determined by various relevant economic studies. The issues were ranked again based on qualitative assessments of changes in quality of life using such measures as the number of people suffering damages, and the reversibility of those damages. Equal weight was given to the quantitative and qualitative rankings in determining the final ranking (again using the very high through low categories.)

2.7 Purposes of and Criteria for Development of Chemical Hazard Lists from Ten Domestic and International Organizations

USEPA 1985, Prepared for the Office of Pesticides and Toxic Substances, Economics and Technology Division, December 31.

This report reviewed various systems by which different organizations have compiled lists of chemicals which they believe ought to be monitored. Each of these steps involved selecting criteria in order to determine their placement upon the list as well as ranges. The following summarizes the findings of this report:

2.7.1 The European Communities Council Directive Chemical Hazard List

82/501/EEC, OJ No L 230, 5.3.82, pp. 1-18, June 24, 1982.

The EC has mandated that any industry must list their use of any of the 178 chemicals upon this list. The chemicals on this list fall into two toxic categories: very toxic substances, and other toxic substances. The qualifications for these categories are as follows:

"Very Toxic" Substances	Other Toxic Substances
LD_{50} (oral) ≤5; or LD_{50}(cutaneous) ≤ 10; or LC_{50} (inhalation) ≤ 0.1 or 5< LD_{50} (oral) ≤ 25; or 10 < LD_{50} (cutaneous) ≤ 50; or 0.1 < LC_{50} (inhalation) ≤ 0.1 and Physical and chemical properties which cause effects similar to those caused by chemicals which fall into the above criteria	25 < LD_{50} (oral) ≤ 200; or 50 < LD_{50} (cutaneous) ≤ 400; or 0.5 < LC_{50} (inhalation) ≤ 2

2.7.2 California Air Resource Board Toxic Chemical List & NIOSH/OSHA Pocket Guide

Air Resources Board of the State of California.

The NIOSH/OSHA Pocket Guide to Chemical Hazards is a list of 380 chemicals, all under federal regulation, which includes information on and recommendations concerning each of these chemicals. The object of this list is to compile chemicals most likely to travel downwind in the event of an accidental release. The California Air Resources Board included on its list any chemical from the guide with an IDLH (Immediately Dangerous to Life and Health - maximum concentration of a substance from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects) below 2000 ppm and a vapor pressure greater than 20 mmHg.

2.7.3 New Jersey Department of Environmental Protection Highly Toxic Substances List

State of New Jersey Department of Environmental Protection, Division of Environmental Quality.

The division of Environmental Quality in the Department of Environmental Protection in New Jersey sought to prepare a list of chemicals which would cause acute health effects if released into the air. Their toxicity criterion was based upon a Threshold Limit Value (TLV - time-weighted average concentration to which nearly all workers may be repeatedly exposed without adverse effect) of one pm. An additional criterion for inclusion on the list was reactivity. Volatility and usage were used to rank the chemicals, but the methodology is not included in the report.

2.7.4 Department of Transportation Poisonous Substances List

DOT Hazardous Materials Regulations 49 CFR 172.101.

The DOT's Hazardous Materials Table includes two categories for poisonous substances, Poison A and Poison B. Poison B materials meet the following requirements:

$$LD_{50}(\text{oral}) \leq 50 \text{ mg/kg}$$

$$LC_{50} (\text{inhalation}) \leq 2 \text{ mg/l (if such a conc. is likely)}$$

$$LD_{50} (\text{cutaneous}) \leq 200 \text{ mg/kg}$$

The Poison List has 153 chemicals of which 141 are Poison B materials.

2.7.5 Philadelphia Air Pollution Control Board Toxic Air Contaminants List

Air Management Regulation VI: Control of Emissions of Toxic Air Contaminants, Air Pollution Control Board of the Philadelphia Department of Public Health, 1981.

Two lists were developed in order to require emissions reports from industry. The criteria for the development of Schedule A are not specified, though the methodology incorporated risk of immediate harm, carcinogenicity, mutagenicity, teratogenicity, bioaccumulative effects, and whether the chemical is known to be present in the Philadelphia area. The criteria for schedule B are identical and also meet the definition of "pollutant" as established by the EPA. The two schedules encompass a total of 104 chemicals.

2.7.6 Union Carbide Corp. Industrial Hygiene Sampling and Monitoring Program List

Union Carbide Institute plant, 1984.

Union Carbide developed a list of priority chemicals for their monitoring program at their plant in Institute, West Virginia. The chemicals have been ranked ordinally from one to four in the following system:

Rating 4	3. Have OSHA, ACGIH, or UCC standards (whichever is lower) including permissible exposure limits (PEL) of less than 5 pm or less than 0.1 mg/m8 as TWA8 (time weighted average for normal 8 hr. day); 4. known carcinogens; 5. result in mutagenesis, teratogenesis, or fertility impairment in humans; 6. result in irreversible nerve damage; 7. result in irreversible long-term organ toxicity; 8. are fast-acting and can produce major injury.
Rating 3	9. $5 < \text{PEL} < 25$ or $0.11 < \text{TWA}_8 < 1.0$; 10. supposed human carcinogens, mutagens and teratogens; 11. result in hematologic disturbances; 12. result in respiratory of skin sensitization; 13. produce narcosis.
Rating 2	14. $26 < \text{PEL} < 200$ or $1.1 < \text{TWA}_8 < 5$; 15. produce severe irritation of the skin, eyes, or respiratory system; 16. are anoxiants.
Rating 1	17. $\text{PEL} > 200$ or $\text{TWA}_8 > 5$; 18. classified as simple asphyxiants or nuisances; 19. have generally low risk effects.

The ranking of the chemical determines how often they are to be sampled within the plant.

As can be noted, each of these systems represents a methodology for chemical selection and presents, at best, a simplistic means for ranking chemicals according to different properties. Nonetheless, it presents a large sample of properties (PEL, IDLH, etc.) which have been used in the differentiation of chemical toxicity.

3. Other Systems

Our research has uncovered three systems for which we were unable to obtain documentation. They are an Office of Water TRI chemical ranking system, an EPA compound evaluation system, and the National Air Toxics Information Clearinghouse pollutant selection and prioritization method. We also found two systems that were not relevant to this indicator discussion. The documents supporting these systems are titled *Existing Chemicals of Environmental Relevance* (German Chemical Society, October 1985) and *Chemical Scoring System Development* (Oak Ridge National Laboratory).

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Part B.

Options for a Risk-Screening Environmental Indicator Ranking/Scoring System

Table of Contents

1. Introduction

This Part describes the general elements required for a chemical weighting system and then describes three options that combine different possibilities for the individual elements. The Risk-Screening Environmental Indicator described in the body of this methodology document is similar to Option 2 described below, but because these options were considered early in the development of the Indicator, the Risk-Screening Environmental Indicator has features that differ from this option.

2. Elements of a Scoring System

Appendix A summarizes a number of chemical scoring and ranking procedures used by Offices within the Agency and by organizations outside of the Agency. From the review of these scoring systems, several common issues emerge. These issues must be considered for the development of a ranking system for the Risk-Screening Environmental Indicator. These issues include:

a. Selecting measures on which the ranking will be based.
    Choosing measures to describe a chemical's toxicity and potential exposure

b. Selecting a method to score the measures. Options include:
    Qualitative - high, medium or low
    Ordinal - 1, 2, 3
    Weighted Categories - 10, 100, 1,000
    Calculated - continuous values

c. Defining criteria for weighted categories.
    For example, an chemical may be scored a 1 if its RfD falls between 0.5 to 5 and a 10 if its RfD falls between 0.05 and 0.5
    Weight-of-evidence categories might also be scored

d. Factoring data quality into the Indicator.

e. Using severity of effect to weight chemical scores.

f. Ranking individual chemicals or forming sub-indices.
    Each chemical can cause a range of effects (e.g. acute toxicity, neurotoxicity, cancer). If the relative importance of effects is established, a chemical can be scored on each type of effect that it causes, then its scores can be combined across effect categories to form a single score for that chemical. If the relative importance of risks cannot be established, a separate indicator for each type of

toxicity can be generated, or the weight can be based on the most sensitive effect caused by the chemical.

g. Methods of establishing the relative importance of categories.
If different categories are used, the relative importance can be reflected by the methodology used to combine the category scores. Various methods include simple summation, multiplication, other mathematical functions, matrices, taking the worst score, and establishing decision rules.

h. Weighting scores: an alternative to methods presented in Section 2.7 (item ‘g’ above).

The review of the scoring systems within and outside of the Agency has suggested a number of approaches for handling each of these issues. Several alternative approaches for each issue, and their advantages and disadvantages, are described below.

2.1 Selecting Measures on Which the Ranking will be Based (a.)

Measures upon which to base scoring include those that describe the toxicity and physicochemical properties of a chemical (e.g., LD_{50}, RfD, solubility), and others that describe exposure at a site (e.g., volume of release, population, site environments). The Section 313 criteria lists ten parameters that EPA must consider when evaluating a chemical for addition to TRI: carcinogenicity, chronic toxicity, acute toxicity, reproductive toxicity, heritable gene and chromosomal mutations, developmental toxicity, neurotoxicity, environmental toxicity, persistence and bioaccumulation. Most of the scoring systems reviewed consider at least some of these categories, although they are frequently merged into fewer parameters.

The indicator could also incorporate measures of potential exposure including media-specific emissions volumes, site characteristics and physicochemical properties. Site characteristics include the potential population exposed through different media, and factors such as stream volume and wind speed that influence the transport and dispersion of a chemical in the environment. Physicochemical properties typically include partitioning, dilution, and dispersion coefficients of contaminants.

2.2 Selecting a Method to Score the Measures (b.)

A system for evaluating the measures of toxicity and exposure potential must be chosen. The goal is to derive some way of scoring chemicals relative to one another within each category. Possible categories might be human carcinogenicity, human chronic toxicity, mammalian acute toxicity, chronic toxicity for aquatic species, and physicochemical exposure potential.

One possible system uses qualitative divisions to score chemicals within a category. For example, the carcinogenicity of a chemical might be scored "high", "medium", or "low." An advantage to using qualitative scores is that a broad range of information, qualitative and quantitative, can be used to evaluate chemicals; this would allow assignment of scores to chemicals without specific toxicity or exposure data. A disadvantage of qualitative scores is that they only broadly distinguish toxicity and exposure potentials and limit the usefulness of the Indicator as a priority-setting system. Ordinal systems (e.g. 1, 2, or 3) use numbers rather than “low,” “medium” or “high” to rank chemicals. Note that ranking formulas that incorporate ordinal scores should not be used to attribute proportional meaning to the ordinal scores. Because assigning an ordinal rank of 3 to chemical A and 1 to chemical B does not mean chemical A is three times worse than chemical B, mathematical functions involving these two scores only convey information on order, not on proportional magnitude.

Unlike ordinal systems, that simply rank relative attributes of chemicals, order-of-magnitude scoring systems (e.g. 1, 10, 100, 1000) still use numerical scores, but attempt to incorporate more information about the proportional differences between chemicals. For example, proportional scores for toxicity could reflect the proportional magnitudes of cancer potencies among chemicals. Weighting chemicals using proportional categories of toxicity uses more information about the chemicals but also avoids the impression of accuracy where such accuracy does not exist. Also, defining categories of weights allows EPA analysts to use all relevant toxicity information about chemicals to make approximate judgments about relative order of magnitude of toxicity, even for chemicals where specific slope factors and RfD values have not yet been developed by the Agency, thus allowing more chemicals to be included in the Indicator. Finally, chemicals are likely to remain in the order-of-magnitude toxicity category to which they are originally assigned, unless significant new and different toxicity data become available. Thus, the weights applied to these chemicals are not likely to be revised frequently, lending stability to the Indicators over time.

Another way to score chemicals within a category is to use an actual numerical value of a measure or mathematical function of the measure. For example, carcinogenicity might be scored by using the actual slope factor of each chemical. Such a system compares chemicals on a continuous scale and allows for the greatest use of quantitative data and results in the greatest distinction among chemicals. However, continuous weights based upon specific information (based on q_1* or on chemical-specific decay rates, for example) have some disadvantages. First, continuous weights would imply that we know the toxicity of the chemical with enough accuracy to distinguish among relatively small differences in these values. Second, it would limit the number of chemicals in the Indicator to those for which the specific information is available, and limits the use of qualitative information and professional judgment.

2.3 Selecting Measures by Which to Define Categories (c.)

If a proportional, order-of-magnitude system is used to rank chemicals, then the categories must be defined be assigned to a range of values of the underlying measure. For example, the 307(a) Priority Pollutants Chemical Ranking methodology used the following ranges to score the aquatic toxicity of chemicals:

Score	LC_{50} (mg/L)
2	< 0.1
10	0.1 - 1.0
5	1.0 - 10.0
3	10.0 - 100
0	> 100

The categories can be defined using ranges of a number of types of data; for toxicity weights, for example, RfDs (non-carcinogens) and q_1* (carcinogens), RQs (or TPQs where RQs not available), and occupational levels could be used.[2] The selection of ranges forces a tradeoff between 1) using a large number of narrow ranges, which might imply that the data is more refined than it really is, and 2) using a small number of broad ranges which inflates or diminishes the importance of the boundaries and the measures that fall near them.

More than one kind of measure can be used to score chemicals within a category. This approach takes advantage of a broader data set to score chemicals, including structure activity relationships. For example, for acute mammalian toxicity, we may have several kinds of toxicity data that describe a chemical's potency, such as acute oral LD_{50} and acute dermal LD_{50}. If only one measure were available, it would be used to determine the chemical's rank in that category. If both were available, the more restrictive value could be used. Alternatively, a hierarchy of preferred measures could be established; for example, RfDs may be preferred over RQs. The advantage is that a larger number of chemicals can be assigned a weight.

The selection measures, boundaries for scoring measure ranges, and category scores are presented in Exhibits 1, 2, 3 and 4 for the selected scoring systems reviewed. The review demonstrates that vast effort and expertise has already been devoted to scoring and categorizing chemicals, both within the Agency and externally. This expertise could be built upon in the development of the Indicator.

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[2] Edward J. Calabrese and Elaina M. Kenyon, "The Perils of State Air Toxic Programs," *Environmental Science and Technology*, Vol. 23, No. 11 (November 1989), 1326-9. This article warns against using occupational levels for general population risk screening, for several reasons: (a) occupational levels consider a recovery period between exposures; (b) occupational levels consider the "healthy worker" effect (that is, the levels are set for protection of relatively healthy populations), (c) the ACGIH levels are set based on data of unknown quality (d) the levels do not account for environmental fate (persistence, bioconcentration) and multiple exposure sources.

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity			Human Chronic Toxicity			
Screening Methodology for Pollution Prevention Targeting (USEPA, date unknown, prepared for Office of Toxic Substances)				Carcinogenicity:	Neuro:	Developmental:	
				high = 3	high = 3	high = 3	
				med = 2	med = 2	med = 2	
				low = 1	low = 1	low = 1	
				all B2 carc. given a score of 3			
Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters (USEPA 1991, prepared for the OPA, February)				Carcinogenicity:	Non-cancer chronic:		
				Cancer RQ Value Used Directly	Chronic RQ Value Used Directly		
Hazard Ranking System; Final Rule (55 Federal Register No. 241, pp.51532-667, 12/14/90)				Carcinogenicity:			
	LD50 (oral)	LD50 (dermal)	Ranking:	Class A, Slope Factor	Class B, Slope Factor	Class C, Slope Factor	Ranking:
	< 5 mg/kg	< 2 mg/kg	1,000	0.5 <	5 <	50 <	10,000
	5-50	2-20	100	0.05-0.5	0.5-5	5-50	1,000
	50-500	20-200	10	< 0.05	0.05-0.5	0.5-5	100
	> 500	> 200	1	-	< 0.05	< 0.5	10
	not available	not available	0	not available	not available	not available	0

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity			Human Chronic Toxicity	
Hazard Ranking System; Final Rule (55 Federal Register No. 241, pp.51532-667, 12/14/90) (concluded)				Non-cancer chronic:	
	LC50	LC50		RfD	
	(dust or mist)	(gas or vapor)	Ranking:	<0.0005 mg/kg/day	Ranking:
	< 0.2 mg/l	< 20 mg/l	1,000	0.0005-0.005	10,000
	0.2-2	20-200	100	0.005-0.05	1,000
	2-20	200-2,000	10	0.05-0.5	100
	> 20	> 2,000	1	0.5 <	10
	not available	not available	0	not available	1
					0
USEPA Unfinished Business Report				Dose/RfD	Score
				1-10	1
				10-100	2
				100-1,000	3
				> 1,000	4
"Hot Spots" Program				Air:	
				Carcinogenicity:	Non-cancer chronic:
				q*	RfD
				Used	Used
				Directly	Directly

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity			Human Chronic Toxicity
Land Disposal Branch Office of Solid Waste				Threshold Limit Value (TLV) Used Directly (Concentration Units)
European Communities Council Directive Chemical Hazard List	LD50	LD50	LC50	
	(oral)	(cutaneous)	(inhalation)	
	"very toxic"	"very toxic"	"very toxic"	
	<= 25	<= 50	<= 0.5	
	"other toxic"	"other toxic"	"other toxic"	
	25-200	50-400	0.5-2	
A Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants (USEPA 1985, July)				Score Carcinogenicity: 12 Proven human carcinogen 10 Potential human carcinogen, proven animal carcinogen 5 Potential animal carcinogen, proven mutagen, proven teratogen 2 Potential mutagen, potential teratogen 0 No carcinogenic, mutagenic, or teratogenic properties

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity					Human Chronic Toxicity	
TSCA Chemical Scoring System for Hazard and Exposure Identification	Inhalation	Dermal	Oral	Exposure		Score	Genotoxicity:
	LC50	LD50	LD50	Level	Score	9	Evidence of mammalian mutagenicity/clastogenicity, interaction with mammalian
	< 50 mg/m3	< 200 mg/kg	< 50 mg/kg	Low	7-9		germ cell DNA, or epidemiological data suggesting genotoxicity in humans
	50-500	200-500	50-500	Medium	4-6	8	Evidence of genotoxicity in non-mammalian germ cell assays, or evidence of
	> 500	> 500	> 500	High	1-3		mammalian dominant lethality
						5-7	Evidence of genotoxicity in more than one test system, other than above
						2-4	Limited evidence of genotoxicity, including mixed positive and negative results
						1	Limited evidence of nongenotoxicity
						0	Negative test results indicating lack of known genotoxicity
						Score	Carcinogenicity:
						8-9	Evidence of oncogenicity from epidemiological studies or positive results
							in two or more mammalian species
						6-7	Evidence of oncogenicity in either sex of a single mammalian species
						4-5	Suggestive evidence of oncogenic potential from epidemiological studies,
							mammalian bioassays, cell transformation in vitro, or
							promoter/carcinogenic activity
						3	Evidence of genotoxic potential
						1-2	Limited evidence of lack of oncogenic potential
						0	No evidence of oncogenic potential from well-conducted and well-designed

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity		Human Chronic Toxicity				
				mammalian studies in two or more animal species			
TSCA Chemical Scoring System for Hazard and Exposure Identification (continued)			Score	Developmental Effects:			
			8-9	Evidence of adverse developmental effects in humans or at least two other mammalian species			
			6-7	Evidence of adverse developmental effects in one mammalian species			
			5	Developmental effects at doses accompanied by maternal toxicity or otherwise equivocal test results			
			4	Adverse developmental effects in nonmammalian species or in vitro test systems			
			3	Indirect evidence suggesting possible adverse developmental effects			
			2	Indirect evidence of lack of adverse developmental effects			
			1	Limited evidence of lack of developmental effects			
			0	No evidence of developmental toxicity potential			
Toxic Chemical Release Inventory Risk Screening Guide (USEPA 1989, prepared by the Office of Toxic Substances, Volume 1, July)	Acute RQ	Ranking	Inhalation or Oral Rfd		Cancer or Chronic RQ	TPQ	Ranking
	<=100 lbs	Group 1	<0.01 mg/kg-day	Q1*	<=100 lbs	=100 lbs	Group 1
	1,000	Group 2	0.01-0.1	All	1,000	500	Group 2
	5,000	Group 3	>=1.0		5,000	>=1,000	Group 3

Exhibit 1.
Human Toxicity Parameter Ranges

Ranking Systems	Human Acute Toxicity	Human Chronic Toxicity	
Louisiana's Environmental Action Plan "Leap to 2000" (Public Advisory and Steering Committee Risk Ranking Retreat Briefing Material March 26, 1991)		Dose/Rfd	Score
		1-2	1
		2-10	2
		10-100	3
		> 100	4

Exhibit 2.
Environmental Toxicity Ranges

<table>
<tr><th>Ranking Systems</th><th>Aquatic Toxicity</th><th>Ecotoxicity</th><th>Mammalian Toxicity</th></tr>
<tr><td>Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters (USEPA 1989, prepared for OPA, February)</td><td>RQ
Used
Directly</td><td></td><td></td></tr>
<tr><td>Hazard Ranking System; Final Rule (55 Federal Register No. 241, pp. 51532-667, 12/14/90)</td><td></td><td>Surface Water:
<table>
<tr><th>Acute
AWQC or
AALAC</th><th>Chronic
AWQC or
AALAC</th><th>Assigned
Value</th></tr>
<tr><td>< 1 µg/l</td><td>< 100 µg/l</td><td>10,000</td></tr>
<tr><td>1-10</td><td>100-1,000</td><td>1,000</td></tr>
<tr><td>10-100</td><td>1,000-10,000</td><td>100</td></tr>
<tr><td>100-1,000</td><td>10,000-100,000</td><td>10</td></tr>
<tr><td>> 1,000</td><td>> 100,000</td><td>1</td></tr>
</table></td><td></td></tr>
<tr><td>TSCA Chemical Scoring
System for Hazard and Exposure Evaluation</td><td>
<table>
<tr><th>Acute
LC50 or EC50</th><th>Life cycle
or Chronic
NOEL</th><th>Score</th></tr>
<tr><td>< 1</td><td>< 0.1</td><td>8-9</td></tr>
<tr><td>1-10</td><td>0.1-1</td><td>6-7</td></tr>
<tr><td>10-100</td><td>1-10</td><td>4-5</td></tr>
<tr><td>100-1,000</td><td>10-100</td><td>1-3</td></tr>
<tr><td>> 1,000</td><td>> 100</td><td>0</td></tr>
</table></td><td></td><td></td></tr>
</table>

Exhibit 2.
Environmental Toxicity Ranges

Ranking Systems	**Aquatic Toxicity**			**Ecotoxicity**	**Mammalian Toxicity**	
	WQS	Aquatic RQ	Ranking		TPQ	Ranking
Toxic Chemical Release Inventory Risk Screening Guide (USEPA 1989, prepared by the Office of Toxic Substances, Volume 1, July)	<= 100 lbs	<= 100 lbs	Group 1		<= 100 lbs	Group 1
	500	1,000	Group 2		500	Group 2
	>=1000 lbs	5,000	Group 3		> = 1,000	Group 3

Exhibit 3.
Exposure Parameter Ranges

Ranking Systems	Exposure Potential				Exposure Level	Population Level
Hazard Ranking	Surface Water:					
	Half Life (Lakes)	Half Life (Other)	Log Kow	Assigned Value		
	< 0.02 days	< 0.2 days	< 3.5	0.0007		
	0.02-2	0.2-0.5	3.5-4	0.07		
	2-20	0.5-1.5	4-4.5	0.4		
	> 20	> 1.5	> 4.5	1		
	Surface Water:					
	Use priority: availability of BCF, LogKow, water solubility					
	Assigned Value	BCF	Log Kow	Water Solubility		
	50,000	> 10,000	5.5-6.0	< 25 mg/l		
	5,000	1,000-10,000	4.5-5.5	25-500		
	500	100-1,000	3.2-4.5	500-1,500		
	50	10-100	2.0-3.2	-		
	5	1-10	0.8-2.0	-		
	0.5	< 1	< 0.8	> 1,500		

Exhibit 3.
Exposure Parameter Ranges

<table>
<tr><th>Ranking Systems</th><th>Exposure Potential</th><th>Exposure Level</th><th>Population Level</th></tr>
<tr><td>Hazard Ranking System: Final Rule (concluded)</td><td>Air:
<table>
<tr><th>Vapor Pressure</th><th>Henry's Constant</th><th>Assigned Value</th></tr>
<tr><td>> 10 Torr</td><td>> 0.001 atm-m3/mol</td><td>3</td></tr>
<tr><td>10-0.001</td><td>10E-5 to 0.001</td><td>2</td></tr>
<tr><td>0.001-0.00001</td><td>10E-7 to 10E-5</td><td>1</td></tr>
<tr><td>< 0.00001</td><td>< 10E-7</td><td>0</td></tr>
</table>
Ground Water:
<table>
<tr><th>Water</th><th colspan="4">Distribution Coefficient (Kd) (ml/g)</th></tr>
<tr><th>Solubility</th><th>Karst</th><th>< 10</th><th>10-1,000</th><th>> 1,000</th></tr>
<tr><td>Liquid</td><td>1</td><td>1</td><td>0.01</td><td>0.0001</td></tr>
<tr><td>> 100 mg/l</td><td>1</td><td>1</td><td>0.01</td><td>0.0001</td></tr>
<tr><td>1-100</td><td>0.2</td><td>0.2</td><td>0.002</td><td>2.0e-05</td></tr>
<tr><td>0.01-1</td><td>0.002</td><td>0.002</td><td>2.0e-05</td><td>2.0e-07</td></tr>
<tr><td>< 0.01</td><td>2.0e-05</td><td>2.0e-05</td><td>2.0e-07</td><td>2.0e-09</td></tr>
</table>
</td><td></td><td></td></tr>
</table>

Exhibit 3.
Exposure Parameter Ranges

Ranking Systems	Exposure Potential	Exposure Level	Population Level
USEPA Unfinished Business Report: A Comparative Assessment of Environmental Problems (USEPA, 1987, prepared by OPA, OAR, OAQPS, OW, and OSW, February)			Non-Cancer Effects: People Exposed — Score <1,000 — 1 1,000-10E5 — 2 10E5-10E7 — 3 > 10E7 — 4
TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology (concluded)	none = no expected release	Criteria — Score > 700 mg/yr — 3 70 to 700 — 2 < 70 — 1	Surface Water: Criteria — Score > 10E6 people — 3 10E5-10E6 — 2 < 10E5 — 1 Ambient Air: Criteria — Score > 10E5 people — 3 10E4-10E5 — 2 < 10E4 — 1

Exhibit 3.
Exposure Parameter Ranges

Ranking Systems	Exposure Potential	Exposure Level	Population Level
TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology (concluded)			Ground Water: Criteria — Score > 25,000 people — 3 5,000-25,000 — 2 < 5,000 — 1
California Air Resource Board Toxic Chemical List & NIOSH/OSHA Pocket Guide (Air Resources Board of the State of California)	Air: Dangerous: IDLH < 2000 ppm and vapor pres. > 20 mmHg		
A Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants (USEPA 1985, July)	Half Life / Hydrolysis Rate / Score > 12 mo / - / 8 6-12 mo / - / 5 3-6 mo / > 3 mo / 2 48 hr - 3 mo / 48 hr - 3 mo / 0 24-48 hr / < 48 hr / -5 < 24 hr / - / -8		

Exhibit 3.
Exposure Parameter Ranges

Ranking Systems	Exposure Potential			Exposure Level	Population Level
A Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants (USEPA 1985, July)	Henry's Constant	KD value	Score		
	< 10E-3	< 0.01	2		
	0.001-0.01	10E2-10E4	0		
	> 0.01	> 10E4	-5		
	BAF	Log P	Score		
	< 4,000	< 6	8		
	700-4,000	4.5-6	5		
	300-700	4-4.5	2		
	> 300	>4	0		
TSCA Chemical Scoring System for Hazard and Exposure Identification (O'Bryan, T.R. and Ross, R.H. 1988, Journal of Toxicology and Environmental Health, Vol (1):119-134)	Half-life	Score			
	> 1 yr	5			
	8-52 wk	4			
	2-8 wk	3			
	1-14 days	2			
	< 1 day	1			
	BCF	Log P	Score		
	> 1,000	> 4.35	9		
	200-1,000	3.5-4.35	7		
	100-200	3.18-3.5	5		

Exhibit 3.
Exposure Parameter Ranges

Ranking Systems	Exposure Potential	Exposure Level	Population Level
	10-100 2.0-3.18 3 < 10 < 2.0 0		
Louisiana's Environmental Action Plan "Leap to 2000" (Public Advisory and Steering Committee Risk Ranking Retreat Briefing Material, March 26, 1991)			Population Exposed Score 1-400 1 400-4,000 2 4,000-40,000 3 40,000-400,000 4 > 400,000 5
Screening Procedure for Chemicals of Importance to the Office of Water (USEPA 1987, prepared by OPA, OAR, OAQPS, OW, and OSW, February)	For human and aquatic populations: BCF Score > 1,000 High < 1,000 Low		

Exhibit 4.
Severity of Measured Effects

Ranking Systems	**Severity of Effect**		
	Organ	Histopathological Severity	Toxicity Endpoint
Examination of the Severity of Toxic Effects and Recommendation of a Systematic Approach to Rank Adverse Effects (USEPA 1986, prepared for ECAO, March)	Loss of which is fatal and are irreplaceable (I) = 1.5	No change = 1.0	Body wt. change, food and/or water cons. change, impairment of organs (IV) = 1.0
	Loss of which may be fatal yet are replaceable or organs which are necessary for proper function of immunity (II) = 1.0	Effects evident only at EM level = 2.0	Small hematological changes, impairment of organs (III), weight change in organs (II, III, IV) = 2.0
	Loss of which is not fatal but may result in functional or emotional handicap (III) = 0.5	Swelling, degeneration, fatty change, pigment = 3.0	mild impairment of organs (II), severe impairment of organs (III), minor organ weight change (I) = 3.0
	Not found in humans and toxic lesions found may not transfer to humans (IV) = 0.25	Atrophy, hypertrophy, cytomegaly, homorrhage = 4.0	mild impairment of organs (I), major impairment of organs (II), major organ weight change (I) = 4.0
		Necrosis, mineralization, emphysema, infarction = 5.0	Functional impairment of organs (I), = 5.0
		Fibrosis/regeneration, atypia hyperplasia/proliferation = 6.0	Major degree of funct'l impairment in organs (I) = 6.0
		Teratogenesis with maternal toxicity, fetotoxicity w/o maternal toxicity = 7.0	Nervous System, respiratory, or cardiovascular depression, mortality, developmental toxicity w/o maternal toxicity = 7.0
		Teratogenesis w/o maternal toxicity = 8.0	

Exhibit 4.
Severity of Measured Effects

Ranking Systems	Severity of Effect
USEPA Unfinished Business Report: A Comparative Assessment of Environmental Problems (USEPA 1987, prepared by OPA, OAR, OAQPS, OW, and OSW, February)	Ranking of Organs Category I Includes organs, impairment or loss of which is fatal and cannot be compensated for at all, or only heroic measures (i.e. expensive mechanical devices, transplantation). Also includes gonads, loss of which prevents reproductions. Lung, heart, brain/spinal cord, kidney, liver, bone marrow, gonads Category II Includes organs whose loss or impairment may be fatal, but which can be compensated for by replacement therapy. Also includes organs, impairment or loss of which indicates as adverse effect on immune function or hematopoietic function which may be life threatening. Adrenal, thyroid, parathyroid, pituitary, pancreatic islets, pancreas, esophagus, stomach, small intestine, large intestine, lymph node, spleen, thymus, trachea, pharynx, urinary bladder, skin Category III Impairment or loss of any of these organs is not life threatening but may result in severe functional or emotional handicaps. Accessory reproductive organs (oviduct, epididymis, uterus, prostate, coagulating gland, seminal vesical, ductus deferens, penis, vagina), eye, bone, nose, nerve, muscle, urinary bladder, blood vessel, ear, gall bladder, harderian and lacrimal gland, larynx, mammary gland, salivary gland, tongue, tooth, ureter, urethra Category IV These organs are not found in humans and toxic lesions (noncarcinogenic) in these organs are not readily extrapolable to humans. Clitoral/preputial gland, zymbal's gland, anal glands

2.4 Factoring Data Quality/Uncertainty into the Index (d.)

There are differences among chemicals in the supporting health effects and exposure data. Health data for one type of effect (e.g., cancer) may be based on animal studies, while evidence of other types of effects may be derived from epidemiology (e.g. neurological effects of lead). Even specific numerical estimates of a single type of effect, cancer potency, have varying levels of evidence to support the estimate. For some chemicals without any specific toxicity data, other information, such as structure-activity relationships, could be used to estimate the relative rankings. There will also be differences in levels of uncertainty associated with exposure scenarios. For example, it may be possible to model air and water emissions from certain facilities, but have less information on releases from TSDFs and POTWs.

One system reviewed that attempted to measure and incorporate any element of data uncertainty was the method for determining carcinogenicity RQ. This system employs an ordinal scoring for carcinogenic weight-of-evidence. This score is combined with a score based on q_1* using a matrix in which each cell is assigned a high, medium or low rank. This same approach could be used to weight ranks in the non-cancer toxicity categories, as well as in exposure categories. Alternatively, numerical uncertainty scores could be used to adjust chemical scores within a category.

2.5 Using Severity Indices to Weight Chemical Scores within a Category (e.)

Several systems develop human health effects scores that are comparable across different kinds of non-cancer risks. These systems employ effect severity indices to weight different effects by the relative risks they pose. For example, a report done for EPA/ECAO develops two scales that ordinarily rank non-carcinogenic toxic effects, one by lesion severity, another by type of effect. Both scales rank the effects relative to each other, but do not measure the magnitude of the overall risk. No attempt was made to rank these effects relative to cancer; nor did the report focus on reproductive or mutagenic effects. These scales would therefore be useful for ranking only non-carcinogenic human health risks.

2.6 Ranking Individual Chemicals for Toxicity or Forming Subindices (f.)

Once chemicals are scored relative to one another within each category, each chemical can be characterized by its profile of scores. At this point, a chemical's scores can be combined across categories to form a rank for that chemical in each area of interest (e.g., cancer risk, non-cancer risk, environmental risk). These ranks would be used to calculate the Indicator. One advantage to this method is that such ranks indicate the relative importance of a chemical with a single number. Many systems, however, do not aggregate scores across categories (see the Region 7 and the OTS/ORNL scoring systems) because this requires making the difficult judgment about the relative importance of different kinds of risk.

Alternatively, scores can be aggregated within a category across chemicals to form a category subindicator. For example, mammalian acute toxicity scores of all chemicals might be added together (possibly weighted by exposure scores) to calculate the 'mammalian acute toxicity subindex.' This could be done for each category, creating an aggregate profile of all of the TRI chemicals. Movements within these subindices would provide measures of environmental improvement.

2.7 Methods of Establishing the Relative Importance of Risks Among Categories (g.)

If a single rank is to be calculated for each chemical from the various categorical scores, one of several calculation methods could be used. The simplest ways to combine numerical scores is to multiply or add them together. The flaw in this approach is that ordinal scores have no specific numerical meaning except within the categories, and even then they do not reflect the magnitude of the differences, but only the order of the ranks (see above.)

Another approach is to scale the scores then multiply or add them together so that the scores have a common denominator. For example, we could divide the exposure value at a facility by the maximum exposure value observed over all facilities. We can then add the scores in different categories because they have a similar scale.

A third approach is to create a matrix of categories and then rank each cell of the matrix separately. The cells may (but do not have to) reflect a mathematical function of the individual ranks of row and column that make up the cell. In this approach, individual chemicals would not be ranked; only the categories into which they fell would have ranks. This method is particularly appropriate for combining several qualitative (i.e. high, medium, low) scores. For example:

Aquatic Risk Rank		Persistence			
		0	1	2	3
Acute Aquatic Toxicity	Low	0	0	0	0
	Medium	3	6	9	12
	High	6	9	12	15
	Very High	9	12	15	18

A fourth option is simply to select the worst score that a chemical has in any category and use that value as the chemical's rank. This would require that all of the scores be of the same type, i.e. qualitative or numerical. It also implies that scales of the scores can be equated. The methods for determining scores in each of the categories would have to meet these criteria.

Ranks in one category could also be conditional on a rank in a different category. For example, non-carcinogenic chronic toxicity might only be meaningful if exposure is above threshold RfD. Criteria for ranking a chemical might require that the non-carcinogenic toxicity score and exposure score meet separate criteria at the same time.

Special decision rules may be applied in conjunction with the overall scoring system. This may be useful in cases in which a particular score category is of overwhelming importance given certain conditions. For example, an extreme carcinogenicity score, regardless of other scores, might automatically classify a chemical as "high". A *de minimis* emissions score might eliminate the chemical from further consideration regardless of toxicity scores. Chemicals with very low toxicity in all categories might also be eliminated.

2.8 Weighting Scores: An Alternative to Methods Presented in 2.7 (h.)

One option discussed in Section 2.7 was to combine scores across categories to derive a single score for the chemical. A scoring algorithm to combine a chemical's scores across categories into a single rank requires the assignment of weights to each of the scoring elements. This is probably the most controversial and difficult step in the process because of the difficulty in evaluating the relative importance of different kinds of risk. In fact, some of the systems we reviewed avoided this step altogether. However, in order to develop a single index that encompasses different kinds of risk (e.g. a human health index which incorporates both carcinogenic and non-carcinogenic risks), a weighting system which implies relative importance of effects will have to be used.

The primary issue in comparing two risks of different nature centers on attributing a common unit of value to the risks so that their relative magnitude can be compared. Of the EPA and non-EPA ranking systems reviewed under this assignment, only the Office of Toxic Substances Production-Based Targeting Methodology explicitly assigns relative values to different kinds of risks. Risks from oncogenicity, reproductive and neurotoxicity, chronic toxicity, and ecotoxicity were assigned relative weights of 3, 1, 2 and 2, respectively. Outside of the Agency, Louisiana's Environmental Action Plan gave equal weight to human cancer and non-cancer risks.

Other ranking systems implicitly weight different toxicity risks. For example, RQs indirectly address disparate risk comparisons by restricting the possible scores depending on the particular RQ being developed: cancer RQs can only range from 1-100, while aquatic toxicity RQs can range from 1-5000. The Hazard Ranking System employs a toxicity scale from 0 to 10,000 that enters into the calculation of site ranking without adjustment for the kind of toxic risk measured. The scale is based on various measures depending on the kind of toxicity being incorporated:

Human Chronic Toxicity	**Human Carcinogenicity**			**Acute Human Toxicity**				**Assigned Value**
Reference dose (RfD) (mg/kg-day)	Weight-of-Evidence and Slope Factor (SF) (mg/kg-day)			Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Dust or mist LC_{50} (mg/l)	Gas or Vapor LC_{50} (ppm)	
	A	B	C					
< 0.0005	0.5 <	5 <	50 <	NA	NA	NA	NA	10,000
0.0005 to 0.005	0.5 to 0.05	**5 to 0.5**	50 to 5	< 5	< 2	< 0.2	< 20	1,000
0.005 to 0.05	< 0.05	0.5 to 0.05	5 to 0.5	5 to 50	2 to 20	0.2 to 2	20 to 200	100
0.05 to 0.5	NA	< 0.05	< 0.5	50 to 500	20 to 200	2 to 20	200 to 2,000	10
0.5 <	NA	NA	NA	500 <	200 <	20 <	2,000 <	1

This system implies that risk from a class B carcinogen with a slope factor between 5 and 0.5 is ten times greater than the risk posed by a chronic toxic effect with an RfD between 0.005 and 0.05. The 307(a) Priority Pollutant Chemical Ranking System employs a similar method to develop toxicity scores.

There are also several approaches described in the economics literature that could be used to develop the relative severity ranking. First, economists use various techniques to determine the willingness-to-pay to avoid various health effects. Other studies examine direct risk/risk tradeoffs. One methodology involves asking respondents to choose between a number of hypothetical scenarios, two at a time. A point of indifference can be established between two scenarios through multiple iterations of questioning. This value determines a relative weight for the health effect being measured. Another method, the health status index, measures health effects in terms of changes in quality of life. While the scope of this project does not allow for original research, we could examine the available economics literature for results that would be applied in this context.

3. Options for Ranking of Chemicals

Section 2 described the elements of a scoring system. The components described in that section can be combined in numerous ways to produce an index. The following is a discussion of three possible options. **The options presented below should in no way be considered the universe of possible options.** Rather, they should be considered as points of departure for discussion of an appropriate algorithm for constructing the TRI index. The elements of each of the options were drawn from (or are modifications of) scoring systems discussed in the review memorandum entitled "Previous Work on Scoring Systems and Chemical Indices." However, none of the options presented below follows one system in its entirety; the specific combinations of components are original to this exercise. Option 1 ranks chemicals ordinally, based on selected measures of the toxicity and exposure potential of a chemical. These ranks are combined with population and emissions data to determine the final Indicator. Option 2 takes the same general approach but instead of ordinal ranks uses actual toxicity data values to develop unique rankings for each chemical. Option 2 also uses modeling to evaluate exposure potential. Option 3 describes an approach where categories of chemicals are defined based on relevant toxicity and exposure potential combinations. The categories (rather than the chemicals themselves) are assigned relative ranks. Chemicals are then assigned to the categories. Site-specific population and emissions data are then combined with the categorical ranks to calculate the Indicator.

Step-by-step descriptions of each of these options are presented below. For each step, we identify previous EPA or other scoring systems that have used similar approaches. Summaries of other EPA and non-EPA scoring systems are presented in the memorandum entitled "Previous Scoring and Ranking Systems" (hereafter referred to as the scoring system review memo). To illustrate the use of these options, we have created a sample data set of six hypothetical chemicals and three hypothetical facilities. The chemical-specific and site-specific data for these six chemicals are shown in Exhibits 5 and 6. For each of the options proposed, we provide an example of how the Indicator would be constructed based on the sample data set.[3] The sample data set is kept simple intentionally, since our current focus is the conceptual structure of the Indicator rather than the vagaries of our data set. Of course, the actual data set will be far more complicated, uncertain and incomplete than the sample data presented here.

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[3] While the examples provided show how a human-health based Indicator would be developed, the same principles can be applied to the development of an ecological indicator.

Exhibit 5.
Chemical Specific Data

Chemical	Toxicity Data				Physicochemical Data						
	Cancer		Chronic Toxicity Other Than Cancer		Volatility		Partitioning			Persistence	
	WOE	q1* (kg-day/mg)	RfD (mg/kg-day)	Chronic Effect of Concern	Vapor Pressure (torr)	Henry's Law Constant (atm-m3/mol)	Koc (cm3/g)	BCF	Solubility (mg/l)	Photolysis (1/hr)	Hydrolysis (1/hr)
A	B2	10	0.1	liver hypertrophy	3.00e+03	2.00e-07	4.00e+01	10	4.00e+05	5.00e-03	6.80e-05
B	B2	0.001	0.2	nerve damage	1.00e+02	2.00e-02	2.00e+02	50	8.00e+02	3.00e-08	4.00e-08
C	B2	1	0.02	spontaneous abortion	4.00e-03	1.00e-05	1.10e+03	200	5.00e+00	4.00e-03	4.00e-02
D	A	0.03	0.05	liver toxicity	4.00e-04	1.00e-03	3.00e+03	1000	2.00e-01	1.00e-05	7.00e-03
E (metal)	C	5	0.005	slowed neural response	0	0	na	0	5.00e-01	0	0
F (metal)	B2	45 (I)	0.001	decreased spermatogenesis	0	0	na	0	5.00e+01	0	0

Exhibit 6.
Site-Specific Exposure Data

Facility and Chemicals	**Emissions**		**Population Exposed**		**Characteristics of Facility**	
	Air (lbs/yr)	**Water (lbs/yr)**	**Air (no. people)**	**Water (no. people)**	**Air**	**Water**
Facility 1					High Dispersion	Low Stream Flow
A	1000	6000	3000	500		
B	2000	4000	3000	500		
C	2000	1000	3000	500		
E	4000	3000	3000	500		
Facility 2					Low Dispersion	Medium Stream Flow
C	3000	1000	1000	6000		
D	4000	5000	1000	6000		
F	10000	2000	1000	6000		
Facility 3					Medium Dispersion	High Stream Flow
A	2000	4000	2000	2000		
C	4000	2000	2000	2000		
D	6000	10000	2000	2000		
E	1000	6000	2000	2000		

3.1 Option 1

Step 1. Using an ordinal scale, rank chemicals within each toxicity evaluation criterion. Ordinal ranking is a common approach in a number of ranking systems. Often, ranks are assigned on an ordinal scale (from 0-10, for example) rather than assigning unique values to each chemical. The ranking of the chemicals is based on quantitative dose-response information if possible. Several systems we reviewed used ordinal scales for ranking toxicity, including the TRI Risk Screening Guide, OTS pollution prevention screening, the OTS/ORNL chemical ranking scheme, and the Louisiana Environmental Action Plan.

Step 2a. Within each of these toxicity categories, assign severity rank (e.g., cellular change versus organ damage) for non-carcinogens. Chemicals that have similar reference doses may pose dissimilar health risks. Severity ranking attempts to weight chemicals based on the relative gravity of the non-cancer health effects risks posed. Severity ranking has been used in several previous ranking/scoring efforts, such as the OTS pollution prevention screening, the Integrated Environmental Management Program, and the Louisiana Environmental Action Plan. A scheme for severity ranking was presented in the ECAO report entitled "Examination of the Severity of Toxic Effects and Recommendations of a Systematic Approach to Rank Adverse Effects," which is presented in detail in the scoring systems review memo.

Step 2b. Assign ranks based on weight-of-evidence (e.g., substantial evidence versus suggestive evidence) ranks for carcinogens. This step is an attempt to recognize the uncertainty in the classification of a chemical as a human carcinogen. This step uses the CAG weight-of-evidence (WOE) classification scheme (where A = known human carcinogen; B = probable human carcinogen; and C = possible human carcinogen) to weight carcinogens. Ranking based on weight-of-evidence classification has been used in the OTS pollution prevention screening and in the Integrated Environmental Management Program, and has played a role in other schemes that use "best professional judgment" to assign ranks to chemicals (such as the Unfinished Business report).

Step 3. Determine relative weights for each toxicity category relative to other categories (e.g., hepatic effects versus cancer). This is likely to be among the most controversial steps in the process. Many scoring systems have avoided combining dissimilar risks and have instead developed separate scores for different types of risks. For example, the Region VII TRI strategy is to derive separate indices for chemicals based on acute effects, chronic non-cancer, cancer and aquatic toxicity. However, a few weighting schemes (notably, two regulatory efforts) have compared different types of toxicity. The Hazard Ranking System (used to place sites on the NPL) implicitly assigns relative weights to cancer and non-cancer effects by using the same scale to score chemicals on these attributes (see the scoring systems review memo for further detail). Also, OAQPS has proposed a scheme for establishing off-setting emissions credits in the program governing early emissions reductions of hazardous air pollutants. The scheme explicitly allows emissions trading among carcinogens and other chemicals, where emissions from carcinogens are (numerically) weighted more heavily than non-carcinogens.

Step 4. The categorical toxicity rank for each chemical is the product of the raw toxicity rank, the severity/WOE rank and the categorical rank. The overall toxicity rank for a chemical is the average of its ranks in the four toxicity categories. Another possible approach would be to take the root mean square of the four toxicity category ranks (an approach used in the Hazard Ranking System).

Step 5. For the exposure evaluation criteria, use photolysis rate, solubility, and bioconcentration factor to rank chemicals for the inhalation, drinking water, and fish ingestion exposure pathways, respectively. A number of systems use relevant physicochemical values to evaluate exposure potential in various media. The Risk Screening Guide used selected physicochemical parameters to qualitatively evaluate mobility of chemicals in each media. The Hazard Ranking System also uses selected parameters to score exposure potential, although a greater number of parameters are included in the HRS exposure evaluation because some site-specific data are generally available for HRS evaluations.

Step 6. Multiply the media-specific exposure rank and toxicity rank by population exposed and emissions for that pathway for each facility. This step combines the toxicity considerations with the factors that determine exposure potential (i.e., the chemical's exposure rank and emissions, and population size). Size of exposed population is used as a ranking criterion in many of scoring systems we reviewed, including: the PPD TRI pollution prevention targeting; OPA ranking of discharges to POTWs and surface waters; OTS TSCA pre-screening of TRI chemicals; the Hazard Ranking System; the Integrated Environmental Management Program; the Louisiana Environmental Action Plan; and the California Air Toxics Hot Spots Program.

The use of population size as a prominent weighting factor may be unacceptable to those who feel that such an emphasis undervalues risks to rural populations. Furthermore, various regulatory efforts in the Agency focus risks to the Most Exposed Individual (MEI); an Indicator method which does not consider MEI risks would conflict with this philosophy. There are also difficulties associated with characterizing the size of exposed populations for certain exposure pathways (such as solid waste disposal). These difficulties will result in unequal levels of uncertainty in the exposure potential evaluation across exposure pathways.

On the other hand, overall population risk has been used elsewhere (notably, in the Unfinished Business report) to characterize general environmental progress; avoidance of population risk, not MEI risk, is also used in cost-benefit analyses to describe potential benefits of implementing environmental regulations.

Step 7. The final index is the sum of the weighted volumes for all TRI chemicals for all pathways across all facilities. A step-by-step example demonstrating Option 1 for the sample data set is found in **Figure 1.**

Advantages - This option allows fine-scale tracking of subtle differences among chemicals. Importantly, by calculating media-chemical-facility subindices, we can easily identify underlying reasons for changes in the overall index by tracking individual media, industries, or chemicals. However, the final calculation yields a single index rather than a series of subindices across categories that may be hard for the public to interpret.

Disadvantages - Determining appropriate and sensible weighting factors for the different elements is difficult. Retaining a proportional scoring system based largely on ordinal ranks and performing mathematical functions on them may give the false impression that the absolute magnitude of the ranks have numerical meaning.

Figure 1. Example Calculation for Option 1 Ranking System

Step 1. Using an ordinal scale, rank chemicals within each selected toxicity evaluation criteria.

For this and subsequent steps, ranks are ordered low to high.

Chemical	Cancer	Chronic Toxicity Other Than Cancer		
		Liver	Neurologic	Reproductive
A	5	1		
B	1		1	
C	3			1
D	2	2		
E (metal)	4		2	
F (metal)	6			2

Step 2. Within each of these categories, assign severity and weight of evidence rank to each chemical.

Step 2.a. For this step, we use weights from 1 to 3 to rank the relative severity of chronic effects.

Chemical	Chronic Toxicity Other Than Cancer		
	Liver	Neurologic	Reproductive
A	1		
B		3	
C			2
D	3		
E (metal)		1	
F (metal)			1

Step 2.b. We use weights from 1 to 3 for assigning carcinogens by their weight of evidence classification.

Chemical	Cancer (WOE)
A	2
B	2
C	2
D	3
E (metal)	1
F (metal)	2

Step 3. Determine weights for each toxicity category.

For the purposes of this example, the relative weights are:

Cancer	10
Reproductive Effects	7
Neurological Effects	5
Other Chronic Effects	2

Step 4. Derive categorical toxicity rank by multiplying toxicity rank, effect-specific severity rank, weight of evidence rank and cross-category severity rank. To get overall rank, average the chemical's rank in each category.

Chemical	Cancer (a)	Chronic Toxicity Other Than Cancer (b)			OVERALL AVERAGE (a+b)/2
		Liver	Neurologic	Reproductive	
A	5 * 2 * 10 = 100	1 * 1 * 2 = 2			51
B	1 * 2 * 10 = 20		1 * 3 * 5 = 15		17.5
C	3 * 2 * 10 = 60			1 * 2 * 7 = 14	37
D	2 * 3 * 10 = 60	2 * 3 * 2 = 12			36
E (metal)	4 * 1 * 10 = 40		2 * 1 * 5 = 10		25
F (metal)	6 * 2 * 10 = 120			2 * 1 * 7 = 14	67

Step 5. Derive Rank for each exposure pathway based on salient physicochemical parameter.

Chemical	Air	Drinking Water	Fish Ingestion
	Based on Photosynthesis	Based on Solubility	Based on BCF
A	1	6	3
B	4	5	4
C	2	3	5
D	3	1	6
E (metal)	5	2	1
F (metal)	5	4	1

Step 6. Combine exposure and toxicity ranks with population and emissions data to obtain media-specific indices.

Facility	Chemical	Emissions (lbs/yr) (a)	Pop. Exposed (no. people) (b)	Toxicity Rank (c)	Exposure Rank (d)	AIR INDEX e=a*b*c*d
Facility 1	A	1000	3000	51	1	1.5E+08
Facility 3	A	2000	2000	51	1	2.0E+08
Facility 1	B	2000	3000	17.5	4	4.2E+08
Facility 1	C	2000	3000	37	2	4.4E+08
Facility 2	C	3000	1000	37	2	2.2E+08
Facility 3	C	4000	2000	37	2	5.9E+08
Facility 2	D	4000	1000	36	3	4.3E+08
Facility 3	D	6000	2000	36	3	1.3E+08
Facility 1	E	4000	3000	25	5	1.5E+09
Facility 3	E	1000	2000	25	5	2.5E+08
Facility 2	F	1000	1000	67	5	3.4E+09
TOTAL:						8.9E+09

FOR WATER:

We obtain an average rank for water exposures using the following formula:
Total exposure to water sources is expressed as : 2L drinking water + [0.14 kg fish x BCF (L/kg)]
Average rank for water = (Rank for drinking water * (2 L/total exp.)) + (Rank for fish * (0.14 x BCF)/total exp.)

Facility	Chemical	Emissions (lbs/yr) (a)	Pop. Exposed (no. people) (b)	Toxicity Rank (c)	Drinking Water Exposure Rank (d)	Fish Ingestion Exposure Rank (e)	BCF Value (f)	Average Water Rank (g)=(d)*2L/tot exp +(e)*0.14(f)/tot exp	WATER INDEX h=a*b*c*g
Facility 1	A	6000	500	51	6	3	10	5	7.3E+08
Facility 3	A	4000	2000	51	6	3	10	5	1.9E+09
Facility 1	B	4000	500	17.5	5	4	50	4	1.5E+08
Facility 1	C	1000	500	37	3	5	200	5	9.0E+07
Facility 2	C	1000	6000	37	3	5	200	5	1.1E+09
Facility 3	C	2000	2000	37	3	5	200	5	7.2E+08
Facility 2	D	5000	6000	36	1	6	1000	6	6.4E+09
Facility 3	D	10000	2000	36	1	6	1000	6	4.3E+09
Facility 1	E	500	500	25	2	1	0	2	7.5E+07
Facility 3	E	2000	2000	25	2	1	0	2	6.0E+08
Facility 2	F	6000	6000	67	4	1	0	4	3.2E+09
TOTAL:									1.9E+10

Step 7. Sum media-specific indices for overall TRI index.

Facility	Chemical	AIR INDEX (a)	WATER INDEX (b)	TOTAL INDEX c=(a+b)
Facility 1	A	1.5E+08	7.3E+08	8.8E+08
Facility 3	A	2.0E+08	1.9E+09	2.1E+08
Facility 1	B	4.2E+08	1.5E+08	5.7E+08
Facility 1	C	4.4E+08	9.0E+07	5.3E+08
Facility 2	C	2.2E+08	1.1E+09	1.3E+09
Facility 3	C	5.9E+08	7.2E+08	1.3E+09
Facility 2	D	4.3E+08	6.4E+09	6.8E+09
Facility 3	D	1.3E+09	4.3E+09	5.6E+08
Facility 1	E	1.5E+09	7.5E+07	1.6E+09
Facility 3	E	2.5E+08	6.0E+08	8.5E+08
Facility 2	F	3.4E+09	3.2E+09	6.6E+09
TOTAL:		8.9E+09	1.9E+10	2.8E+10

3.2 Option 2

Step 1. Rank chemicals using actual proportional measures for the categories of concern. For carcinogens, use q_1^* values. The q_1^* expresses risk to an individual per milligram (mg) of chemical per kilogram of body weight per day (mg/kg-day). For non-carcinogens, use the inverse of the RfD. The RfD is the dose (expressed as mg of chemical per kg body weight per day) below which no adverse effects are expected to occur. Using proportional measures for toxicity ranking is a common approach in other ranking systems. For example, RQs were used by OPA in ranking discharges to POTWs and to surface water bodies; OTS TSCA pre-screening of TRI chemicals used RQ as a cutoff for high concern chemicals. RfDs and Q* are proposed as the basis for toxicity ranking in Region VII's TRI strategy. Outside the Agency, the California Air Toxics Hot Spots program uses actual dose-response data (in conjunction with exposure modeling - discussed below) in their identification and ranking of air toxics problems in the state.

Step 1a. Since toxicity values in different categories have dissimilar units (e.g., cancer potency estimate versus an RfD), normalize the values by expressing the chemical's toxicity value in a given category as a fraction of the maximum value possible in that category. The resulting fraction is the chemical's rank in that category. Expressing the ranks in this manner will also allow us to combine the ranks with exposure potential ranks that have been normalized in a similar manner (see below). This normalizing approach was used in OAQPS' Source Category Ranking System, which ranks potential air toxics problems across industries.

Once the toxicity ranks within categories are determined, the next three steps are the same as those described in Option 1.

Step 2a and 2b. Within each toxicity category, assign severity and weight-of-evidence (WOE) ranks to each chemical.

Step 3. Determine relative weights for each toxicity category relative to other categories.

Step 4. Determine the categorical toxicity rank for each chemical. The categorical rank is the product of the raw toxicity rank, the severity rank, the WOE rank and the categorical rank. The overall toxicity rank is the average of its ranks in the four toxicity categories.

Step 5. For the exposure evaluation, model the fate and transport of the chemicals. To do so, use the emissions data, site-specific environmental characteristics (or default values where these are not available), and physicochemical properties to obtain ambient media concentrations at specified distances. These data can be weighted by the number of persons at each distance (that is, the number of persons exposed to each estimated concentration) to obtain population-weighted average exposures for each site where chemical is emitted.

As mentioned earlier, specific methods for applying exposure modeling to the TRI database are discussed separately and will not be expanded on here. However, it should be noted that generic exposure modeling to rank exposure potential is used by a number of other scoring/ranking systems. For example, Appendix B of the Risk Screening Guide presents results of generic air modeling to assist readers in the evaluation of air releases. OTS' TSCA pre-screening of TRI chemicals used generic air and water exposure modeling to place chemicals in categories of low, medium and high concern. Furthermore, generic air modeling was used by OAQPS to identify high risk chemicals as part of defining offsets credits for early emissions reductions of hazardous air pollutants. Other scoring methods using generic modeling approaches include the California Air Toxics Hot Spots program and OAQPS' Source Category Ranking System.

Step 6. For each chemical-facility combination, express the exposure estimate as a fraction of the maximum exposure observed to obtain an exposure index. Normalizing the exposure values allows us to combine the exposure ranks with the toxicity rankings in later steps. Otherwise, we would be combining ranks with dissimilar scales. The exposure index is then combined with the toxicity rank to derive the medium-specific index. The final index is the sum of the media-specific indices.

(A modification to this approach would be to use the RfDs and q_1^*s in concert with the exposure models to estimate cancer cases and/or number of individuals above the RfD. The "cases" could then be scaled by the maximum number of "cases" observed at each facility to obtain a unique subindex for each chemical-facility combination by exposure pathway. The index for the chemical would be the sum of the subindices across all facilities. The overall index would be the sum of the chemical indices.)

An example demonstrating Option 2 for the sample data set is found in **Figure 2.**

Advantages - The use of location-dependent exposure indices allows the index to reflect changes in where chemicals are released, as well as changes in volume. Normalizing toxicity ranks allows the use of structure-activity relationships to fill in data gaps; if a particular toxicity value is not known, the chemical can still be assigned a rank relative to the highest value in the category.

Disadvantages - The lack of toxicity data for many of the TRI chemicals would hinder this approach. This approach presents some programming challenges for performing multiple chemical, multiple site analyses. This option has the same difficulties as Option 1 in assigning appropriate sensible weighting factors to different elements. Furthermore, the option relies on normalizing the ranks based on a "reference chemical" which has the maximum value in the ranking category. A danger in this approach is the possibility that the underlying data (toxicity or physicochemical information) may change over time. Since all other chemical ranks are keyed to the values for this chemical, a change in the reference chemical would change the entire index. Therefore, rather than selecting the chemical with the maximum value, we may want to select as the reference chemical a well-known, well-characterized chemical for which underlying data is unlikely to change. Using this approach, the reference chemical rank would still be 1, while chemicals with values greater than the reference chemical would be assigned ranks proportionally greater than 1.

Figure 2. Example Calculation for Option 2 Ranking System

Step 1. Using inverse of RfD value and actual q* values, rank chemicals within each selected toxicity evaluation criteria.

For this and subsequent steps, ranks are ordered low to high.

Chemical	Cancer (q*)	Chronic Toxicity Other Than Cancer (1/RfD)		
		Liver	Neurologic	Reproductive
A	10	10		
B	0.001		5	
C	1			50
D	0.03	20		
E (metal)	5		200	
F (metal)	45			1000

Step 1a. Since the raw toxicity ranks are on different scales, express the rank in each category as a fraction of the maximum rank observed in that category. The maximum rank is 1.

Chemical	Cancer	Chronic Toxicity Other Than Cancer		
		Liver	Neurologic	Reproductive
A	2.2E-01	0.5		
B	2.2E-05		0.025	
C	2.2E-02			0.05
D	6.7E-04	1		
E (metal)	1.1E-01		1	
F (metal)	1.0E+00			1

Step 2. Within each of these categories, assign severity and weight of evidence rank to each chemical.

Step 2.a. As in Option 1, we use weights from 1 to 3 to rank the relative severity of chronic effects.

Chemical	Chronic Toxicity Other Than Cancer		
	Liver	Neurologic	Reproductive
A	1		
B		3	
C			2
D	3		
E (metal)		1	
F (metal)			1

Step 2.b. We use weights from 1 to 3 for assigning carcinogens by their weight of evidence classification.

Chemical	Cancer (WOE)
A	2
B	2
C	2
D	3
E (metal)	1
F (metal)	2

Step 3. Determine severity weights for each toxicity category.

This step is also the same as Option 1. For the purposes of this example, the relative weights are:

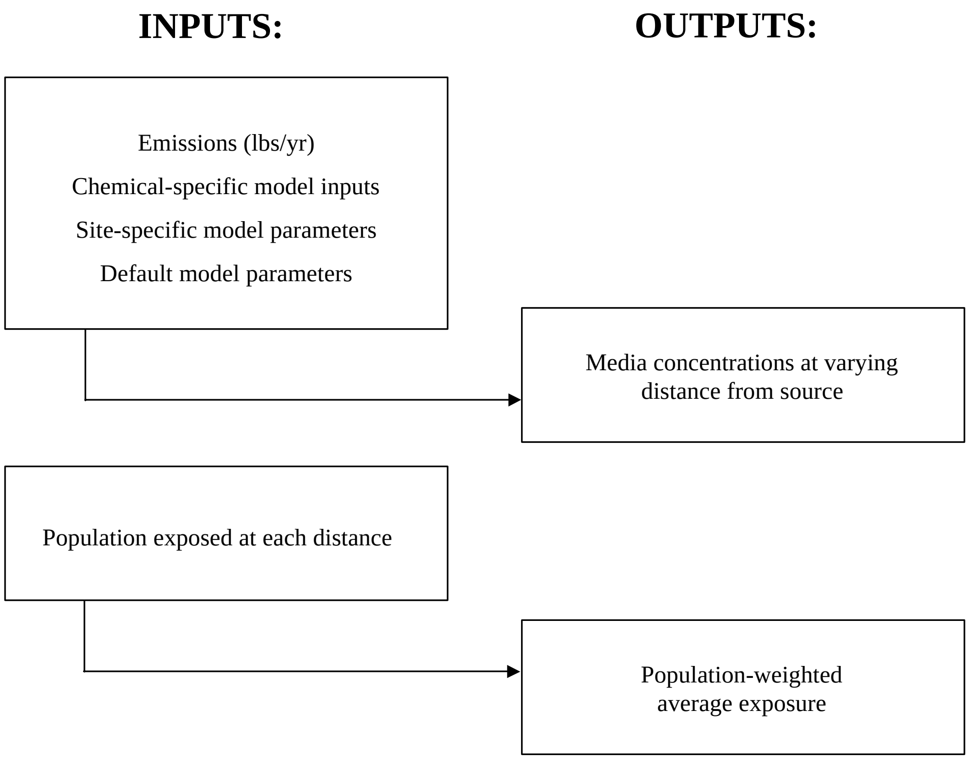
Cancer	10
Reproductive Effects	7
Neurological Effects	5
Other Chronic Effects	2

Step 4. Derive categorical toxicity rank by multiplying toxicity rank, severity rank and category rank. To get overall rank, average the chemical's rank in each category.

Chemical	Cancer (a)	Chronic Toxicity Other Than Cancer (b)			OVERALL AVERAGE (a+b)/2
		Liver	Neurologic	Reproductive	
A	2E-1 * 2 * 10 = 4	0.5 * 1 * 2 = 1			2.7
B	2E-5 * 2 * 10 = 4E-4		0.025* 3* 5=4E-1		0.2
C	2E-2 * 2 * 10 = 4E-1			0.05 * 2 * 7 = 7E-1	0.6
D	7E-4 * 3 * 10 = 2E-2	1 * 3 * 2 = 6			3.0
E (metal)	1E-1 * 1 * 10 = 1		1 * 1 * 5 = 5		3.1
F (metal)	1 * 2 * 10 = 20			1 * 1 * 7 = 7	13.5

Step 5. Derive rank for each exposure pathway using modelling approach.

For this step, we use computer programs to estimate population-weighted average in each medium, for each chemical at each facility. The steps are as follows:



For the purposes of this example, we assume that these models yield the following results:

FOR AIR:

Facility	Chemical	Emissions (lbs/yr)	Pop. Exposed (no. people)	Population-Weighted Average Exposure (calculated with model)
Facility 1	A	1000	3000	5.0E-04
Facility 3	A	2000	2000	3.3E-03
Facility 1	B	2000	3000	9.0E-03
Facility 1	C	2000	3000	2.0E-03
Facility 2	C	3000	1000	3.3E-03
Facility 3	C	4000	2000	8.0E-03
Facility 2	D	4000	1000	3.3E-02
Facility 3	D	6000	2000	2.0E-02
Facility 1	E	4000	3000	2.0E-02
Facility 3	E	1000	2000	1.7E-02
Facility 2	F	10000	1000	1.7E-01

FOR WATER:

Facility	Chemical	Emissions (lbs/yr)	Pop. Exposed (no. people)	Population-Weighted Average Exposure (calculated with model)
Facility 1	A	6000	500	3.5E-02
Facility 3	A	4000	2000	9.4E-03
Facility 1	B	4000	500	1.2E-02
Facility 1	C	1000	500	2.9E-04
Facility 2	C	1000	6000	7.1E-04
Facility 3	C	2000	2000	4.7E-04
Facility 2	D	5000	6000	2.8E-02
Facility 3	D	10000	2000	4.7E-04
Facility 1	E	3000	500	1.8E-04
Facility 3	E	6000	2000	7.1E-03
Facility 2	F	2000	6000	7.1E-02

Step 5a. Take the exposures as a fraction of the maximum in order to get exposure indices for the chemicals.

FOR AIR:

Facility	Chemical	Exposure Index
Facility 1	A	3.0E-03
Facility 3	A	2.0E-02
Facility 1	B	5.4E-02
Facility 1	C	1.2E-02
Facility 2	C	2.0E-02
Facility 3	C	4.8E-02
Facility 2	D	2.0E-01
Facility 3	D	1.2E-01
Facility 1	E	1.2E-01
Facility 3	E	1.0E-01
Facility 2	F	1.0E+00

FOR WATER:

Facility	Chemical	Exposure Index
Facility 1	A	5.0E-01
Facility 3	A	1.3E-01
Facility 1	B	1.7E-01
Facility 1	C	4.2E-03
Facility 2	C	1.0E-02
Facility 3	C	6.7E-03
Facility 2	D	4.0E-01
Facility 3	D	6.7E-03
Facility 1	E	2.5E-03
Facility 3	E	1.0E-01
Facility 2	F	1.0E+00

Step 6. To derive media-specific indices, multiply toxicity ranks and exposure indices. To derive final index, add media-specific indices.

Facility	Chemical	Air Exposure Index (from Step 5a) (a)	Toxicity Rank (from Step 4) (b)	AIR INDEX c=(a*b)
Facility 1	A	3.0E-03	2.7	8.10E-03
Facility 3	A	2.0E-02	2.7	2.72E+00
Facility 1	B	5.4E-02	0.2	2.54E-01
Facility 1	C	1.2E-02	0.6	6.12E-01
Facility 2	C	2.0E-02	0.6	6.20E-01
Facility 3	C	4.8E-02	0.6	6.48E-01
Facility 2	D	2.0E-01	3	3.20E+00
Facility 3	D	1.2E-01	3	3.12E+00
Facility 1	E	1.2E-01	3.1	3.22E+00
Facility 3	E	1.0E-01	3.1	3.20E+00
Facility 2	F	1.0E+00	13.5	1.45E+01
TOTAL:				32.1

Facility	Chemical	Water Exposure Index (from Step 5a) (a)	Toxicity Rank (from Step 4) (b)	WATER INDEX c=(a*b)
Facility 1	A	5.0E-01	2.7	1.35E+00
Facility 3	A	1.3E-01	2.7	2.83E+00
Facility 1	B	1.7E-01	0.2	3.67E-01
Facility 1	C	4.2E-03	0.6	6.04E-01
Facility 2	C	1.0E-02	0.6	6.10E-01
Facility 3	C	6.7E-03	0.6	6.07E-01
Facility 2	D	4.0E-01	3	3.40E+00
Facility 3	D	6.7E-03	3	3.01E+00
Facility 1	E	2.5E-03	3.1	3.10E+00
Facility 3	E	1.0E-01	3.1	3.20E+00
Facility 2	F	1.0E+00	13.5	1.45E+01
TOTAL:				33.6

Facility	Chemical	AIR INDEX (a)	WATER INDEX (b)	OVERALL INDEX c=(a+b)
Facility 1	A	8.10E-03	1.35E+00	1.4
Facility 3	A	2.72E+00	2.83E+00	5.6
Facility 1	B	2.54E-01	3.67E-01	0.6
Facility 1	C	6.12E-01	6.04E-01	1.2
Facility 2	C	6.20E-01	6.10E-01	1.2
Facility 3	C	6.48E-01	6.07E-01	1.3
Facility 2	D	3.20E+00	3.40E+00	6.6
Facility 3	D	3.12E+00	3.01E+00	6.1
Facility 1	E	3.22E+00	3.10E+00	6.3
Facility 3	E	3.20E+00	3.20E+00	6.4
Facility 2	F	1.45E+01	1.45E+01	29.0
TOTAL:		32.1	33.6	65.7

3.3 Option 3

Step 1. From among the various toxicity categories, choose the category which yields the lowest dose. This is the limiting dose. This decision rule was used in the ranking of chemicals for inclusion as priority pollutants under the Clean Water Act.

Step 2. Establish criteria for placing chemicals in categories of low, medium, and high toxicity based on the limiting dose, and classify chemicals based on these criteria. A number of scoring systems have provided criteria that could be used to place chemicals in categories of low, medium, and high concern. The human and environmental toxicity categories into which chemicals were divided and the criteria used to place chemicals in these categories for each scoring system were summarized in Exhibits 1 and 2 of this Appendix.

Step 3. To assess exposure potential, use photolysis rate, solubility, and bioconcentration factor for the inhalation, drinking water, and fish ingestion exposure pathways, respectively to place chemicals in categories of low, medium, and high for exposure potential. Classify chemicals based on these criteria. As with the toxicity ranking, a number of scoring systems have provided criteria that could be used to place chemicals in categories of low, medium, and high exposure potential. The exposure potential categories into which chemicals were divided and the criteria used to place chemicals in these categories for each scoring system were summarized in Exhibit 3 of this Appendix.

Step 4. Construct human hazard and exposure potential matrices for each medium of concern; assign chemicals to each cell according to their toxicity and medium-specific classifications. An example of such a matrix is given in ORD's "Simplified Approach for Screening and Categorizing Toxic Chemicals." A toxicity/exposure matrix was also used in the University of Michigan's application of the Hazard Ranking System to the prioritization of organic compounds at hazardous waste sites.

Step 5. Assign weights to the low, medium and high categories for exposure potential and toxicity. In our example, the rank for each cell in the matrix is the product of the toxicity weight and the exposure weight for the row and column that define the cell. The ORD simplified approach to classifying toxic chemicals provides an example of values assigned to matrix cells. OTS's TSCA pre-screening of TRI chemicals also presents an exposure/toxicity matrix, but assigns ranks of low, medium, or high to each cell, rather than numerical weights.

Step 6. Individual chemical-facility indices are derived for each medium by multiplying the rank for the cell in which the chemical falls, the population exposed via that medium, and the emissions to that medium.

Step 7. The overall index is the sum of the media-specific indices across all chemicals and across all facilities. An example demonstrating Option 3 for the sample data set is found in **Figure 3.**

Advantages - This method avoids combining toxicity categories. It provides a simple but informative rank for each chemical based on a two-way classification scheme. The final index weightings are explicit and understandable.

Disadvantages - This approach assumes that all of the toxicity categories are of equal importance. In this approach, chemicals do not get specific exposure-toxicity ranks; only the categories to which they belong are ranked. The use of three broad categories within the scoring elements does not allow fine-scale differentiation among values for chemicals within a scoring element. This particular flaw would prevent us from distinguishing changes in chemicals with very high toxicities from changes in "border" chemicals with marginally high toxicities. Options to address this problem include (a) eliminating "border" chemicals from the index calculation; and (b) performing more explicit analysis on the "border" chemicals to evaluate how different the index would be if they switched into different categories.

Figure 3. Example Calculation for Option 3 Ranking System

Step 1. From among the toxicity criteria of interest, choose the lowest dose for each chemical among all the categories. This is the limiting dose.

Chemical	Cancer	Chronic Toxicity Other Than Cancer			LIMITING DOSE
	Risk-specific Dose at 1E-4 Risk Level (mg/kg-day) (1E-4/q*)	Liver	Neurologic	Reproductive	
		RfD (mg/kg-day)	RfD (mg/kg-day)	RfD (mg/kg-day)	(mg/kg-day)
A	1E-05	1E-01			1E-05
B	1E-01		2E-01		1E-01
C	1E-04			2E-02	1E-04
D	3E-03	5E-02			3E-03
E	2E-05		5E-03		2E-05
F	2E-06			1E-03	2E-06

Step 2. Place chemicals into high, medium, and low categories.

For this step, we need to develop criteria for what constitutes a high, medium, or low toxicity. For the purposes of this example, we assign the following values to these categories:

Category	Range
High	Dose < 1E-4
Medium	1E-4 < Dose < 1E-2
Low	1E-2 < Dose

Using these criteria, we classify the chemicals:

Chemical	Limiting Dose (mg/kg-day)	Toxicity Category
A	1E-05	High
B	1E-01	Low
C	1E-04	Medium
D	3E-03	Medium
E	2E-05	High
F	2E-06	High

Step 3. Based on salient physicochemical properties, assign chemicals to high, medium, and low exposure potential categories.

For this step, we must establish media-specific criteria for assigning chemicals to high, medium, and low categories.

For the purposes of this example, we make the following assignments:

Exposure Medium	Criterion		
	Low	Medium	High
Air	photolysis < 1E-7	1E-6 < photolysis < 1E-4	1E-4 < photolysis
Drinking Water	solubility < 10	10 < solubility < 500	500 < solubility
Fish	BCF < 50	50 < BCF < 500	500 < BCF

Using these criteria, we classify the chemicals:

Chemical	Air	Drinking Water	Fish
A	High	High	Low
B	Low	High	Medium
C	High	Low	Medium
D	Medium	Low	High
E	Low	Low	Low
F	Low	Medium	Low

Step 4. Using the exposure and toxicity ranks, create a toxicity-exposure matrix for each medium.

Toxicity-Exposure Matrix

Toxicity	Air Exposure			Drinking Water Exposure			Fish Ingestion Exposure		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Low	B					B		B	
Medium		D	C	C	D			C	D
High	E,F		A	E	F	A	A,E,F		

Step 5. Assign values to each cell in the matrix.

For this step, ranks are assigned the following values:

Category	Exposure Rank	Toxicity Rank
High	0.4	5
Medium	0.2	3
Low	0.1	1

The value for the cell is the product of the toxicity times the exposure rank.

Toxicity-Exposure Matrix Values

Toxicity	Air Exposure			Drinking Water Exposure			Fish Ingestion Exposure		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Low	0.1					0.4		0.2	
Medium		0.6	1.2	0.3	0.6			0.6	1.2
High	0.5		2	0.5	1	2	0.5		

Step 6. Combine facility-specific emissions and population data to obtain media-specific chemical scores.

EMISSION-EXPOSURE SCORES

FOR AIR:

Facility	Chemical	Air Emissions (lb/yr)	Population Exposed Via Air	Matrix Value	Air Score
1	A	1000	3000	2	6.0E+06
	B	2000	3000	0.1	6.0E+05
	C	2000	3000	1.2	7.2E+06
	E	4000	3000	0.5	6.0E+06
2	C	3000	1000	1.2	3.6E+06
	D	4000	1000	0.6	2.4E+06
	F	10000	1000	0.5	5.0E+06
3	A	2000	2000	2	8.0E+06
	C	4000	2000	1.2	9.6E+06
	D	6000	2000	0.6	7.2E+06
	E	1000	2000	0.5	1.0E+06
	TOTAL:				5.7E+07

FOR WATER:

Facility	Chemical	Water Emissions (lb/yr)	Population Exposed Via Water	Drinking Water Matrix Value	Fish Matrix Value	Average Matrix Value	Water Score
1	A	6000	500	2	0.5	1.3	3.8E+06
	B	4000	500	0.4	0.2	0.3	6.0E+05
	C	1000	500	0.3	0.6	0.5	2.3E+05
	E	3000	500	0.5	0.5	0.5	7.5E+05
2	C	1000	6000	0.3	0.6	0.5	2.7E+06
	D	5000	6000	0.6	1.2	0.9	2.7E+07
	F	2000	6000	1	0.5	0.8	9.0E+06
3	A	4000	2000	2	0.5	1.3	1.0E+07
	C	2000	2000	0.3	0.6	0.5	1.8E+06
	D	10000	2000	0.6	1.2	0.9	1.8E+07
	E	6000	2000	0.5	0.5	0.5	6.0E+06
	TOTAL:						8.0E+07

Step 7. Combine the media-specific ranks to obtain overall rank.

Facility	Chemical	Air Score	Water Score	Overall Score
1	A	6.0E+06	3.8E+06	9.8E+06
	B	6.0E+05	6.0E+05	1.2E+06
	C	7.2E+06	2.3E+05	7.4E+06
	E	6.0E+06	7.5E+05	6.7E+06
2	C	3.6E+06	2.7E+06	6.3E+06
	D	2.4E+06	2.7E+07	2.9E+07
	F	5.0E+06	9.0E+06	1.4E+07
3	A	8.0E+06	1.0E+07	1.8E+07
	C	9.6E+06	1.8E+06	1.1E+07
	D	7.2E+06	1.8E+07	2.5E+07
	E	1.0E+06	6.0E+06	7.0E+06
	TOTAL:	5.7E+07	8.0E+07	1.4E+08

Part C.

Options for Indicator Computation and Normalization

Table of Contents

1. Introduction

The options described in this Appendix were considered early in the development of the Risk-Screening Environmental Indicators model, and are retained here to indicate possible options for computation and normalization of the Indicator. As noted in the body of this methodology document, the Section 2.1 below ("Simple Sum of the Component Scores") describes how Indicator Elements are combined to calculate the overall Indicator. The model can also model a core set of chemicals (those that have been on the TRI list through all years of reporting). Tracking core chemicals is a method of normalizing much like the normalization option "Creation of a Separate Indicator" (Section 3.2) described below.

2. Options for Indicator Computation

The Indicator will be calculated by combining the individual scores of the TRI chemical-facility-media components. Each component's value is related to a chemical's risk to either human health or the environment (depending on the Indicator). The value is calculated based on measures of the volume of release from a facility, the chemical's toxicity, and the potential exposed population for the media of release.

This Appendix discusses the two leading methodologies considered for calculating the Indicator. The method of calculation will influence the ways we can adjust the Indicator and how the Indicator will change in response to the adjustments as facilities and chemicals are added over time.

2.1 Simple Sum of the Component Scores

In this method, each component score makes a contribution proportional to its size. Simply, it is the total "risk" resulting from all chemical-facility-media releases.

$$I = S_1 + S_2 + S_3 + \ldots + S_n$$

where:

I = Indicator
S = facility-chemical-medium-specific subindicator

It should be noted that subscores for particular chemicals, industries, and regions can also be calculated for Indicator diagnostics.

2.2 Simple Sum Normalized to a Base Year

Like the simple sum method, this method represents each component score proportionately.

$$I = \frac{(S_1 + S_2 + S_3 + \ldots + S_n)_{\textit{present year}}}{(S_1 + S_2 + S_3 + \ldots + S_n)_{\textit{base year}}} \cdot 100\%$$

Its primary advantage is that it is a dimensionless ratio that tracks progress over time and continuously looks back at the beginning of the Indicator record. A score of 60 indicates that the overall chemical-facility-media risk has been reduced by 40 percent since the Indicator began. Hence, each individual score has meaning, as does the change from year to year.

2.3 Other Methods of Calculation

We considered alternative means of calculating the Indicator. Some of these included the arithmetic mean of the component scores, the geometric mean of the scores, and the least-square difference of the scores. Although each of these methods generates a score that will fluctuate as the individual components of the risk, the methods do not produce readily interpretable results.

For the greatest sensitivity in the actual Indicator score, as well as for the greatest ease in calculation and interpretation, we recommend that the chemical-facility-media scores simply be added and then adjusted to a manageable level.

3. Normalizing the Indicator

This section discusses options considered for modifying the Indicator to accommodate the addition of SIC codes and chemicals for TRI reporting purposes. We discuss how the failure to report chemical release data as well as data errors can affect the calculation of the Indicator. We also present an example to illustrate both the necessity of designing a method of normalization and the implications of the methods presented here.

As discussed previously, the Indicator should be designed to accommodate an increase in the number of components of the TRI. This increase can occur through any of three mechanisms: an addition of chemicals to the TRI list, an increase in the number of facilities by enhancing the SIC code list, and an increase in facility compliance with existing reporting requirements. Each of these scenarios enhances the accuracy of the report because they supply missing information. However, this addition changes the scope of the Indicator (from a small subset to a larger subset), thereby limiting the effectiveness of comparison between current and past values.

The addition or deletion of chemicals from the TRI roster will occur as EPA responds to petitions or initiates its own action through the chemical listing or delisting process. The deletion of chemicals will presumably have a minor effect since such chemicals would be deleted due to their low risk; by definition these chemicals will make only a minimal contribution to the Indicator. Deletion will most likely occur in batches every few years. The addition of SIC codes will likely follow investigations of the TRI chemicals revealing other industries that emit the listed chemicals. Compliance could also increase in the future. In 1989, the Office of Toxic Substances studied compliance with TRI reporting requirements. The study found that the compliance rate was 81.7 percent in the first year of reporting. Follow up studies have not been done to determine the improvement in compliance with Section 313. However, the OTS study stated that under full compliance, the estimated number of respondents would be over 29,000. In later years of reporting, the number of reporting facilities has not approached that figure, despite a lowering of reporting thresholds.

The fundamental problem in maintaining a single, continuous Indicator is that there is no way to differentiate between fluctuations due to changes in actual environmental risk and those due to changes in the chemical or facility roster. Therefore, to maintain the integrity of the Indicator when chemicals are added to the roster, each major addition to the Indicator should be accompanied by some kind of adjustment. Methodologies for accommodating the addition of chemical-facility-media components are presented below along with discussions of their impact on the accuracy of the Indicator. First, we present a hypothetical example of Indicator values over a five year period and then articulate a number of options for normalizing the index.

<u>Example:</u>

The calculation of the Indicator begins in 1988, and we select the Simple Sum method of calculating the Indicator. For the first 5 years the Indicator scores are as follows:

Year	**Indicator Score**
1988	1,000
1989	950
1990	850
1991	800
1992	775

In 1993, the Agency adds another 200 chemicals to the TRI list as well as five SIC codes. The 1993 score of the original set of TRI chemicals and SIC codes is 750, meaning that the risks associated with those chemicals and facilities have decreased. The score for the additional set of chemicals and facilities is 500.

3.1 Do Nothing

The Do-Nothing scenario is important to examine since the benefits of lost continuity may outweigh the disadvantages and the effort required to work around them. For this method, the score will rise when components are added and will no longer describe the environmental progress as compared to the previous roster. In our example, the Indicator score will read 775 in 1992 and 1,250 in 1993. It will be impossible to recalculate the previous years' scores with the new chemicals because release data will not be available. Thus, information on progress since the initial roster will be lost.

The Do-Nothing scenario could be viewed as a more accurate representation of the "complete picture" of environmental risk. If, for example, the Indicator score for the universe of **all** chemicals and **all** facilities were actually 4,000, and this initial TRI setup provides a score of 1,000, then the subsequent addition of components to the TRI will fill in the additional 3,000 points for which no information exists. Yet for the public to understand the severity of a change, increases in the Indicator score from new chemicals ought to occur on the same scale as that of the original set. As discussed earlier, the public will perceive the Indicator score presented with the first set of TRI chemicals and facilities as representing the risk associated with all chemicals and facilities. The public will believe that the new score of 1250 means that the risk-related impacts posed to them have risen by 475 points; they have not increased at all, they are just better represented. An increase in the number of components should not actually increase the risk-related impacts but should redistribute the individual contributions to the total score of risk-related impacts.

3.2 Creation of a Separate Indicator

Chemicals could be added to the TRI roster one or two at a time each year or in a large number once every five years. If the latter occurs exclusively, we could establish an Indicator consisting solely of the new chemicals and allow the scores of the old Indicator to continue as before. In our example, the Indicator would be reported as two scores: in 1993 it would be 750 for the original set of TRI chemicals and facilities and 500 for the new set of chemicals and facilities. This approach has two advantages. First, this system could accurately track the progress of the original roster as well as the new roster. Second, the Indicator for each roster could be compared and the program could establish priority for alleviating environmental problems associated with the new or old list.

The primary disadvantage of two Indicators is the loss of a single instrument. Chemicals and SIC codes will be added to the TRI more than once, and each time another four indices (human health and environmental risk; chronic and acute effects) will be needed. Each of these indices is also compared at regional, state and local levels. Maintaining a number of Indicators will create public confusion, as people try to keep track of each separate Indicator change from the previous year. A second disadvantage follows from the Do-Nothing scenario: if people add these scores together to get the "total" score, they will perceive an increase in overall risk-related impacts. Finally, if TRI chemicals are added continuously in small amounts, this method will be extraordinarily difficult to implement as new indices are created each year.

3.3 Ratio Adjustment

The ratio adjustment method is used with the Dow Jones Industrial Average, the Producer Price Index, the Consumer Price Index, and the New York Stock Exchange Composite Index. The underlying components of each of these indices are updated periodically to reflect fundamental shifts in what is being measured. For example, this year the Dow substituted three service sector stocks for three industrial stocks to reflect the U.S. economy's shift toward the service sector. The Producer Price Index and Consumer Price Index revise their basket of goods decennially to reflect the caprice of consumer taste. The NYSE Composite Index, which encompasses every stock on the New York Stock Exchange, is revised every time companies start up, merge, or fail.

The adjustment is straightforward. On the first day that the revised components are employed, the index is calculated twice, once based on the old components and again based on the revised components. Thereafter, the ratio between these two index values is used to adjust the index as it is calculated from the revised components:

$$I = I_{revised\ components} \cdot \frac{I_{old,\ last\ day}}{I_{new,\ first\ day}}$$

In our example, the old system yielded a score of 750 and the new system yields a score of 1,250. To scale down the new score to maintain continuity, we multiply the new score by (750/1,250) = 0.6. All subsequent scores (1994, 1995, and so on) will also be calculated in the same manner and then multiplied by 0.6, until another addition requires the determination of another adjustment factor.

One disadvantage of this method is the loss of information concerning the original set of chemicals and facilities in the presentation of one Indicator that integrates all scores. Even if the Indicator publishes the scores associated with each set of chemicals, the scale will have changed, prohibiting direct comparison. (Compare this to the method where original and supplemental indices are both tracked.)

Another disadvantage is the misrepresentation of the behavior of the new set of chemicals and facilities. The Indicator is distinct from the Dow in a way that affects the applicability of this system. The Dow uses a few stocks to model the entire market and assumes that the behavior of these stocks reflects the general behavior of all stocks. This implies that substitution of one stock for another in the Dow fits conceptually with its purpose. The Indicator seeks to reflect the levels of risk to human health and the environment by including a subset of the universe of all chemicals and facilities. The behavior of risks posed by all chemicals and facilities cannot be said to match the behavior of the set of TRI chemicals and facilities. The inclusion in TRI focuses a facility's attention upon particular chemicals and presumably results in changes of releases of TRI chemicals by TRI facilities. By fitting the combined score of new and old TRI chemicals and facilities to the score of the old, we inherently assume that the new have experienced reductions in risk identical to the old. In truth, we have no way of knowing the past pattern of releases for new additions. Emissions may have not changed at all since these chemicals have not yet been targeted by TRI; on the other hand, emissions may have been reduced more than emissions of old TRI chemicals because the new chemicals may have already been regulated by certain EPA programs or by states, or companies may have reduced emissions voluntarily.

3.4 Normalization to a Base Level

This method reflects the Do-Nothing approach except for taking necessary adjustments for the use of normalization. Instead of using the score resulting from a base year, base levels could be used, defined as the sum of the component scores at the first year that each list is added to the Indicator. For example, upon the first addition to the TRI (combining the initial roster, list 1, and the addition, list 2), the Indicator could be calculated as follows:

$$I = \frac{(S_1 + S_2 + \ldots + S_m + \ldots + S_n)_{present\ year}}{(S_1 + S_2 + \ldots + S_m)_{first\ year\ of\ list\ 1} + (S_{m+1} + \ldots + S_n)_{first\ year\ of\ list\ 2}}$$

where:

S = Each chemical-facility-media component score,
n = Total number of TRI chemicals,
m = Number of TRI chemicals in the first list, and
$m\text{-}n$ = Number of chemicals added to the roster.

Following the example, the score for 1988 would be (1,000/1,000)*100 = 100. The following scores would be (950/1,000) = 95, (850/1,000) = 85, (800/1,000) = 80, and (775/1,000) = 77.5. In 1993, the score would be calculated as follows:

$$\frac{750 + 500}{1000 + 500} = 83.3$$

While this score represents an increase, it is not as drastic as using the Simple Sum method, and it can be explained to the public as resulting from the addition of TRI chemicals and facilities to the Indicator. This equation can also be used to indicate relative percentages of the two different sets of chemicals and facilities (750/1,500 = 50 for the original and 500/1,500 = 33.3 for the new). However, as with ratio adjustment, the original set cannot be said to have improved by (77.5 - 50) = 27.5 points.

3.5 Variations on the Previous Methods

Improvements in the way in which the smaller TRI chemical universe models the larger one would lead to more meaningful comparisons between the old and new indices. One way to improve this modeling ability is to employ data on the new chemicals for the period predating their addition to TRI. If we had the release data, we could calculate exactly how inaccurate the small TRI chemical universe was as a model and adjust it accordingly. Although these data will not exist except as part of a state inventory, we could approximate them through the correlation of releases of other chemicals. For example, if a facility reports the release of a chemical because of its addition to the TRI, it is very likely that the chemical had been released at that level all along. A rough approximation would be to look at changes in releases from that facility and then correlate the release of the new chemical in back years.

Yet another possibility is to combine more than one of the above examples. For example, it may be appropriate to maintain one "primary" Indicator score while also maintaining "subscores" for each of the sets of TRI chemicals (i.e., the original set and each additional set). The main score could be calculated using the simple sum and normalized with the ratio adjustment each time an additional set of chemicals is added. The subscores could be calculated for each set of TRI chemicals using the normalization to a base year; each of these subscores could be maintained separately. In our example, after the addition of chemicals, the main Indicator score would be 750 while the subscores would be (750/1,000) = 75 and (500/500) = 100. As in the discussion of the creation of separate indices, this combination depends upon the addition of TRI chemicals in large groups every number of years. If routine additions occur, the main Indicator could be calculated as above and only one subscore, that of the original set of chemicals, could be maintained.

3.6 Start Over

The last system that may be used is to announce the beginning of a new Indicator. Once every 5 years the Agency could integrate all of the additions to and deletions from TRI that had occurred since the beginning of the previous Indicator. EPA could announce that to better characterize the risks to the environment posed by chemical releases, certain chemicals have been deleted or added based upon TRI criteria and that a new Indicator, calculated in the same manner at the same scale, has been created. It is also quite possible that experience with the Indicator may suggest a new mode of calculation by the time more chemicals and facilities are ready to be added.

Part D.

Considerations for Including Underground Injection in the Risk-Related Chronic Human Health Indicator

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1. Background Information on Underground Injection

Underground injection refers to the placement of fluids into permeable rock strata in the subsurface environment using wells. Disposal of industrial wastes through the use of underground injection began in the 1930's. This practice is based on simple hydrogeological principles and has been considered a useful method of isolating wastes from the accessible environment by placing them into deep formations where they will remain for millions of years.

EPA classifies five types of underground injection wells. These are:

Classification	**Definition**[4]	**1992 Inventory**[5]
Class I	wells that inject municipal or industrial waste water (including hazardous waste) below the lowermost underground sources of drinking water (USDW)[6]	517 active wells (170 hazardous)
Class II	wells that inject fluids related to oil and gas production, including saltwater disposal, enhanced oil recovery and liquid hydrocarbon storage	177,047 active wells
Class III	wells that inject fluids for the extraction of minerals	35,668 active wells
Class IV	wells that inject hazardous waste into or above a USDW (these wells have been banned)	409 abandoned wells
Class V	wells that do not fit into any of the above categories, including industrial dry wells and aquifer remediation wells	190,443 active wells

The Underground Injection Control (UIC) program was established in 1974 to protect USDWs from contamination due to underground injection practices and is administered under the Safe Drinking Water Act (SDWA). Many types of underground injection, however, are also defined as a form of hazardous waste land disposal and thus are subject to the land disposal restrictions imposed by the Hazardous and Solid Waste Amendments of 1984 (HSWA). The HSWA banned

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[4] Definitions taken from *U.S. EPA Fact Sheet: Underground Injection Control,* Office of Drinking Water.

[5] Underground Injection Control Program, *Injection Well Inventory, 1992*, Office of Ground Water and Drinking Water.

[6] A USDW is defined as an aquifer that is currently serving as a public drinking water supply, or those that have the potential to serve as a public drinking water supply, and have less than 10,000 mg/L total dissolved solids.

all injections into Class I Hazardous Waste (Class 1H) wells. However, EPA may allow injections to continue if it determines that the prohibition is not required to protect human heath and the environment.

Pursuant to HSWA requirements, in 1985 EPA conducted an inventory of Class I facilities and summarized their results in the *Report to Congress on Underground Injection*[7]. In 1986, EPA evaluated reported failures and incidents of non-compliance using data gathered in Report to Congress and studies conducted by Engineering Enterprises[8], and the Underground Injection Practices Council (UIPC), an independent coalition of industry, government, and consulting professionals. From these reports, EPA concluded that "most USDWs are adequately separated from injection zones and that contamination of USDWs from injection operations is insignificant."[9] When contamination incidents did occur, the problems were the result of improper well design and construction, or poor operation standards and/or monitoring requirements. EPA believes that these failures would not have occurred under better management standards. To further protect USDW from potential underground injection failures, in July of 1988 EPA promulgated more stringent technical requirements for Class 1H wells. These regulations are published in 40 CFR parts 124, 144, 145, 146, and 148, and are summarized below.

Most of the 1988 regulations stipulate safe practices for operating Class 1H wells that will prevent contamination of USDWs. Before a Class 1H well can begin operations, however, the operator must prove to EPA that the injection operations will not endanger human health and the environment by submitting a "no-migration" petition demonstrating that the waste will not migrate from the injection zone for as long as it remains hazardous. Well operators that do not submit petitions must either treat to remove the banned substances or cease injection of the waste. The "no-migration" petitions are comprehensive, typically several volumes long and containing thousands of pages of technical data. Petitions are required to address every technical aspect of well siting, construction, operation, and a detailed analysis of the injected waste streams. EPA has established a rigorous Class 1H petition review process; approximately 2,000 hours are spent on each petition review. Prior to the approval of any petition, EPA reviews the construction, operation, compliance history, and closure plans for the well. In addition, the Agency evaluates the chemical compatibility of the waste with the materials of the well construction, and the injection and confining zone rocks and fluids. Information for the Area of Review (AOR) is studied to ensure that no migration could occur through unplugged or improperly completed wells which penetrate the confining zone.

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[7] U.S. EPA 1985. *Report to Congress on Injection of Hazardous Waste.* Office of Drinking Water. EPA 570/9-85-003.

[8] *Class I Hazardous Waste Well Failure Study Prepared for U.S. Environmental Protection Agency.* Prepared by Engineering Enterprises, Inc., Geraghty & Miller, Inc., and Ken E. Davis Associates, September, 1986.

[9] U.S. EPA, Office of Drinking Water (1986). Class I Hazardous Waste Injection Wells Evaluation of Non-compliance Incidents.

The Class 1H operating requirements were designed to control underground injection contamination pathways. The following summary of the technical requirements has been taken directly from the EPA's Office of Ground Water and Drinking Water publication, *Analysis of the Effects of EPA Restriction on the Deep Injection of Hazardous Waste.*[10]

The controls to prevent well failure include:

- The well materials must be compatible with wastes they are likely to contact and operators are required to conduct corrosion monitoring.

- The wells must be adequately cased and cemented to protect USDWs and isolate the injection zone.

- The long string casing, injection tubing, and annular seal must be pressure-tested at least annually, and whenever there is a well workover. The bottom-hole cement must be tested annually by a radioactive tracer survey (RTS). Also, a test for fluid movement along the bore hole must be conducted at least once every five years using a noise, temperature, or other EPA-approved logging method. Finally, for certain Class I wells, casing inspection logs must be maintained. These logs are predictive tools to assess developing weaknesses in the well's casing.

- The operator must install and use continuous recording devices to monitor the waste injection pressure, flow rate and pressure. He must also install and use an automatic alarm and shut-down system designed to alert the operator and shut-in the well when pressures, flow rates, or other parameters exceed the allowable limits.

- If loss of mechanical integrity is found during an automatic shutdown or during routine MIT, the operator must notify the EPA, cease injecting fluids, and preform the well workover and remediation plan specified by the director.

Controls to prevent fluid migration up improperly plugged wells that penetrate the confining zone include:

- The operator must identify all wells within a two-mile radius of the well bore. In some cases a larger area of review (AOR) may be required if pressure analysis shows that the injection well has a greater radius of influence.

- All wells on the AOR must be examined to determine whether they are adequately completed or plugged, or that there is no potential for fluid movement.

- A description of each well and any records of its plugging or completion must be submitted to EPA. A remediation plan must be submitted for wells that EPA determines

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[10] U.S. EPA 1991. *Analysis of the Effects of EPA Restrictions on the Deep Injection of Hazardous Waste.* Office of Ground Water and Drinking Water. EPA 570/9-91-031.

are improperly plugged, completed, or abandoned, or for which plugging or completion information is inadequate. The plan must consist of steps or modifications that will be taken to ensure that fluids will not move up the wells. The plan is a condition of the operating permit.

Controls to prevent fluid migration through faults or fractured confining strata include:

- Wells must be completed such that the injection zone which receives the waste is confined above and below by an impermeable confining zone.

- Injection pressure must be controlled so that new fractures are not created or propagated in the injection zone or the confining strata.

- The confining zone must be laterally continuous and free of faults and transmissive fractures.

- The waste must be chemically compatible with the confining zone, so that dissolution of the confining zone rock does not allow waste to migrate out of the injection zone.

- The operator must conduct an annual pressure transient test to measure any changes in reservoir characteristics and pressure increases in the reservoir over time.

Controls to prevent lateral displacement of fluids include:

- The injection zone must have sufficient permeability, porosity, thickness, and areal extent to prevent fluid movement into USDWs.

- Information must be provided by the operator on faults, the continuity of injection and confining zones, and the proximity of USDWs to the injection well.

2. Human Health Risk Analysis

The fundamental problem with analyzing the human health risks from current underground injection practices is that well-maintained and well-operated facilities in theory pose little or no human health risks since the potential for exposure is removed. In fact, a letter from the UIPC urged EPA not to consider injection into deep wells as a "release" to the environment for this reason.[11] In fact, there are only a few documented cases of well failures where underground sources of drinking water have been contaminated. For example, EPA and state regulatory agencies have identified two cases where injected wastes contaminated USDWs, and one case where an injection well was suspected of causing contamination of an USDW. All three cases occurred prior to the implementation of a State or Federal UIC program. EPA has also identified eight cases where leakage from Class 1H wells entered non-USDW formations and two cases of surface contamination due to blowouts.

Both cases of known USDW contamination from Class 1H injection wells occurred prior to the existence of the UIC program. Both wells failed due to the same problem; they were constructed without a tubing and packer and without a surface casing set to protect the area's USDWs. Corrosion of the long string casing (the only layer of protection for these wells) allowed the unobserved leakage of wastes into USDWs. The UIC regulations currently in effect would never have allowed this method of completion for Class 1H wells. UIC regulations require three redundant layers of protection: a surface casing set and cemented through all USDWs, a cemented long-string casing, and a tubing with a packer (or an equivalent). These three levels of protection and the requirement for continuous annulus pressure (mechanical integrity) monitoring would make these cases of contamination impossible today.

In another incident, Class 1H injection wells operated by Hammermill Paper were suspected as the cause of USDW contamination near Erie, PA in 1972. It was suspected, but never proven, that the increase in injection zone pressure attributable to the Hammermill wells caused injected waste or formation fluid to migrate up an unplugged well into an USDW, five miles from the injection site. The current UIC regulations require that the pressure effects of an injection well be thoroughly examined. Also, in an area where injection pressures are found to be sufficient to cause migration to an USDW, the operator is required to identify and evaluate all artificial penetrations of the confining zone. Furthermore, the Land Disposal Restrictions regulations require a detailed analysis of the fate and transport of the injected waste, and an evaluation of its potential for confinement in the injection zone for 10,000 years. Given the relatively shallow injection zone of the Hammermill wells, it is highly unlikely that the petitions for these wells would have been approved under the current UIC program.

Hazardous waste leakage out of the injection zone into non-USDWs also occurred in the past. Eight facilities between 1975 and 1984 reported such incidents. Most of these failures occurred prior to the implementation of UIC programs and were relatively minor leaks in the area immediately adjacent to the well bore. All incidents were caused by tubing and casing corrosion.

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[11] Letter from L. Wilcher to R. Thomas Segall, President of Underground Injection Practices Council, September 30, 1991.

The most notable of these cases involved the unobserved deterioration of the long-string casing in wells without packers at the Chemical Waste Management site in Vickery, Ohio in 1983. This type of failure is easily detected with continuous annulus pressure monitoring. However, the Chem Waste wells were designed in such a manner that it was not possible to conduct this type of continuous monitoring. Current UIC regulations require either a packer or a system that allows comparable protection and a capability for continuous monitoring of mechanical integrity. In all eight cases where leakage into non-permitted zones occurred, the current UIC program's construction, monitoring, and MIT requirements would have either prevented the failure or detected its occupancy in time to prevent significant leakage.

In addition, there have been two cases of well blowouts which resulted in soil contamination at the surface. Both of these cases were caused by the buildup of carbon monoxide (CO), gas that was generated in the injection zone due to the incompatibility of the injected waste with the formation. The two blowouts occurred before the implementation of a UIC program in the states where the incidents occurred. Current UIC regulations require that an operator demonstrate the compatibility of the waste with the materials of well construction and with the injection formation. The regulations also require the operator to demonstrate the capability for emergency shut-in, case of well failure or in response to conditions such as those encountered in these two examples.

An analysis of potential health risks from the failure of a Class 1H injection well would have to involve a calculation of both the probability of a failure event occurring and the level of exposure should the failure occur. As has been illustrated from an explanation of past well failures, the probability for such events to occur while the Class 1H injection facilities are under the management of an UIC program are extremely small. In fact, the UIC program controls are so protective, that if the program is operating properly, these risks are most certainly negligible. However, because some TRI wastes are not regulated under RCRA as hazardous wastes, some TRI facilities that release waste fluids through underground injection are not Class 1H. In addition, some TRI facilities may be operating underground injection wells that are classified as Class V. Thus, these "RCRA-non-Haz Waste" TRI facilities as well as any TRI Class V wells are not subject to the stringent UIC requirements outlined above and may pose some risk of human exposure due to failure.

3. Evaluating Underground Injection in the RSEI Model

In addition to simply tracking the number of pounds that are handled by underground injection, the current Risk-Screening Environmental Indicators model also has the ability to multiply underground injection releases by the toxicity weighting factor for the chemical released. However, this (pounds * toxicity) measure should be interpreted carefully. If underground injection represents a safer way of handling toxic chemicals than other releases, then an increase in a pounds-times-toxicity weight Indicator may actually represent a decrease in overall health and environmental impacts if toxic chemicals are being moved to underground injection from environmental media with higher potential for impacts.

A possibility for future modeling might be to try to include exposure potential for underground injection in the Indicator. Beginning with the 1996 reporting year, facilities must report whether releases to underground injection are placed in Class I facilities or in Class II-Class V facilities. Some modeling has been performed for Class I underground injection failures for different geographical settings and for different failure scenarios where a ratio between the injected concentration and the concentration in the drinking water aquifer were obtained. These ratios could be applied to the TRI releases to Class I facilities to estimate aquifer concentrations, and subsequently surrogate doses through drinking water. The probability of failure could be estimated from the failure rates reported in the UIPC report and a consideration of current practices. However, exposure potential for other types of facilities would remain unknown.

Part E.

Additional Exposure Scenarios

Table of Contents

1. Introduction

It has been suggested that the Indicator method be expanded to include additional exposure scenarios. These scenarios result from either the direct exposure to TRI chemicals or exposure to an indirect effect of the chemicals. A primary example of another direct exposure not currently incorporated into the Indicator method is the deposition of airborne chemicals into other pathways, such as groundwater. The most renown examples of indirect exposures include the greenhouse effect, acid rain, the ozone "hole," and smog.

Since each of these scenarios poses a level of risk to human health and the environment, it would seem necessary to include them in an Indicator which measures risk. However, the complexity of and uncertainty in modeling these scenarios makes direct insertion into the Indicator extremely difficult. The following endpoints are discussed for their potential inclusion into the Indicator, the creation of a separate Indicator for the endpoint, or difficulties in accomplishing either.

2. Global Warming

Some of the TRI chemicals are considered "greenhouse gases." These chemicals, when released into the atmosphere, can absorb infra-red radiation which the earth emits as it establishes radiative equilibrium with the solar system. The potential result of this "effect" is the increase of the average temperature of the earth's surface, an increase which could lead to higher sea levels, droughts, floods, and climate changes.

The quantification of these risks is a hotly contested topic in academic, political and industrial circles. The temperature rise has been predicted to be anywhere between zero and eight degrees Celsius. The direction of the climate change resulting from the accumulation of greenhouse gases can be offset by natural occurrences such as volcanic eruptions or the appearance of El Niño, a circulating body of abnormally warm water in the Pacific Ocean. Since the results of the buildup of greenhouse gases have not been, and quite possibly cannot be, quantified, it is impossible to assign a greenhouse effect risk to the unit emission of a greenhouse gas. Thus the greenhouse effect cannot effectively be incorporated into the Indicator.

This is not to say that the release of greenhouse gases, and their relative threat, cannot be traced with a separate Indicator. In attempting to quantify the climate change potential associated with gaseous emissions, greenhouse gases have been weighted relative to their capacity to absorb infra-red radiation and their half-life in the atmosphere. These weights have been normalized to CO_2, the greenhouse gas greatest in both presence in the atmosphere and rate of addition to the atmosphere. The other major greenhouse gases are listed below:

Trace Gas	**Lifetime (years)**	**Global Warming Potential (Integration Time Horizon)**		
		20 years	**10 years**	**50 years**
Carbon Dioxide	(120)	1	1	1
Methane	10	63	21	9
Nitrous Oxide	150	270	290	190
CFC-11*	60	4500	3500	1500
CFC-12*	130	7100	7300	4500
HCFC-22	15	4100	1500	510
CFC-113*	90	4500	4200	2100
CCl_4*	50	1900	1300	460
CH_3CCl_3	6	350	100	34
CF_3Br	110	5800	5800	3200
CO	<1	7	3	2

*TRI chemical
Source: IPCC, 1990.

The emissions of greenhouse gases can be reported by their relative weight of contribution to the greenhouse effect and reported in a simple Indicator.

3. Acid Rain

Acid rain results from the deposition of sulfur- and nitrogen- containing compounds, particularly sulfur dioxide and nitrous oxides, into clouds. The sulfur and nitrogen react with the water to form sulfuric and nitric acid which then accompany water during precipitation, leading to corrosion of structures and reductions in the pH of soils and water. Some researchers have attributed the elimination of habitat in different parts of the world to acid rain, particularly in areas where coal provides the primary energy source for combustion processes.

Like the greenhouse effect, it is extremely difficult to determine the effect caused by the unit emission of an "acid rain" chemical. The amount of sulfur and nitrogen which may combine to form an acid depends upon equilibrium concentrations in the area of concern. Although the acidity of sulfuric acid and nitric acid may be compared directly by their respective pH at a given concentration, and although the number of sulfur or nitrogen atoms present in a compound may determine the ability of a chemical to contribute to the creation of these acids, site-specific conditions will determine the quantity and concentration of the acids.

Like the risks associated with global warming, the risks posed to human health and the environment have not been quantified in terms of individual toxic risks. Some work has been done on health conditions and respiratory problems. However, most work concerning acid rain has focused on population-based economic risks, a different perspective than the one used to determine the Indicator. The health effects seem to have been precursors to determining factors such as days lost at work and other economic inputs.

4. Stratospheric Ozone Depletion

The depletion of the stratospheric ozone layer results from the reaction of chlorine and fluorine atoms in chlorofluorocarbons with ozone, breaking the ozone down into diatomic oxygen and oxygenated compounds. Since ozone absorbs incoming ultraviolet radiation, the deterioration of the ozone layer is resulting in dramatic increases in environmental exposure to UV radiation. This high-energy end of the spectrum has been shown to cause cataracts, suppress the immune system and induce cancer in humans. It has also been shown to adversely affect plant and animal life. Thus the risks to humans could lie anywhere from actual health hazards to loss of agriculture.

A major project at EPA, in conjunction with ICF, focused on determining the risks associated with CFCs and their alternatives in order to formulate policy options. The model tracks emissions into the atmosphere, models the reduction in the ozone layer, and calculates risks and damage associated with skin cancer, cataracts, aquatic impacts, crop loss, immunosuppression, and even a qualitative assessment to the food chain (starting with oceanic plankton). The model is complicated but could be used to determine risks associated with the emissions of CFCs.

A weighting scheme has been developed to determine the effectiveness of different CFCs at depleting the ozone layer. These weights are detailed below:

Substance	Domestic 1986 Use (millions kg)	Weight	Weighted Production
CFC-11*	91.3	1	91.3
CFC-12*	146.2	1	146.2
CFC-113*	71.1	0.8	56.9
CFC-114*	4.1	1	4.1
CFC-115*	4.61	0.6	2.8

*TRI Chemicals: Chlorinated Fluorocarbons are a category in the TRI.
Source: U.S. EPA, 1987.

A separate Indicator could be managed for ozone depletion through the use of these weights.

5. Tropospheric Ozone

The creation of tropospheric (low atmosphere) ozone, results from the reaction of a radical oxygen atom with an oxygen molecule. This maverick oxygen atom is produced when ultraviolet radiation in sunlight breaks apart a nitrogen dioxide atom into nitrous oxide and oxygen. Under normal circumstances, the ozone will react with the nitrous oxide in order to reform the nitrogen dioxide and the diatomic oxygen, the preferred state of being. However, the presence of volatile organic compounds (VOCs) in the air prevent this elimination of ozone by reacting with the nitrous oxide, creating nitrogen dioxide before the molecule can react with ozone. Thus it is the presence of both NO_x and VOCs which lead to the formation of ozone in the troposphere.

The presence of ozone in the troposphere poses human health and environmental risks since it is this level of the atmosphere in which we live. Ozone causes respiratory ailments, particularly in the older and younger populations, and is an eye irritant.

The difficulty with pinning down the effects of emissions of either nitrous oxides or VOCs is their dependence upon one another for the creation and destruction of ozone. Rural and urban areas will have different impacts from increased or decreased emissions of VOCs. Some work has been done in modeling ozone formation at ORD, and these models can be consulted.

6. Particle Deposition

Particle deposition differs from the volatilization pathway currently analyzed in the Indicator by tracing airborne emissions through exposure scenarios other than inhalation. Particles can land on clouds and precipitate, entering water bodies and exposing populations through drinking water. Particle deposition can also produce risks to wildlife through direct ingestion.

Many models have been developed at ORD to determine the exposure posed by particle deposition. The office would need to be contacted in order to consider the exposure scenarios which these cover.