PROCESS FOR SELECTING INDICATORS AND DATA AND FILLING INFORMATION GAPS

Final Report

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Final Report

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PROCESS FOR SELECTING INDICATORS AND DATA AND FILLING INFORMATION GAPS

INTRODUCTION

The purpose of this document is to present a process for selecting indicators and data sets that can be used to measure the current status of the environment and to show patterns or trends in that status. This proposed process is directed primarily to technical managers within EPA who have responsibility for the specification and quantification of indicators.

DEFINITION OF ENVIRONMENTAL INDICATOR

Many definitions of environmental and environmentally related indicators appear in the literature, most of which can be encompassed by the following definition[1]:

> An environmental indicator is an environmental or environmentally-related variable or estimate, or an aggregation of such variables into an index, that is used in some decision-making context:
>
> - To show patterns or trends (changes) in the state of the environment (the focus of this report),
> - To show patterns or trends in the human activities that affect, or are affected by, the state of the environment,
> - To show relationships among environmental variables, or
> - To show relationships between human activities and the state of the environment.

This definition of environmental indicators is purposely very broad to reflect the diversity of assessment and reporting contexts in which the term is used. Thus, the definition includes both measured or observed variables, i.e., representative indicators; as well as composite indicators (indices), that aggregate a number of variables into a single quantity. Representative indicators are measures selected on the basis of expert opinion or statistical methods to reflect the behavior of one or more variables. Furthermore, a representative indicator can be either a direct measure of an environmental or environmentally-related attribute of interest (e.g., chemical concentrations in effluents, as used in compliance monitoring), or a surrogate measure (e.g., use of indicator species as surrogate measures of ecosystem integrity), or a more ecologically-realistic indicator of ecosystem integrity (e.g., community level measures of biological condition relative to natural expectations such as the Index of Biotic Integrity). Note that the above definition of an environmental indicator also includes environmentally-related data (e.g., demographic data, indicators of human health status), as well as strictly environmental data.

[1]Ingrid Schulze, ESID Draft *Conceptual Approaches to the Development and Use of Environmental Indicators and Statistics for Decision-Making*, April, 1994.

FRAMEWORKS FOR DEVELOPING INDICATORS

Many different conceptual frameworks or models of human-environment interactions can be proposed as bases for the selection, organization, and use of indicators in different policy contexts. Because the relationships between human activities and the environment are extremely complex, there is no unique framework that generates sets of indicators for every purpose, and further, no one framework can generate a unique set of indicators.

The Organization for Economic Co-operation and Development (OECD) uses a Pressure-State-Response (PSR) framework[2] as the basis for organizing its reports on the State of the Environment and environmental performance reviews. In the basic PSR framework (see Figure 1), human activities exert pressures on the environment (such as pollution loadings and land use changes), which induce changes in the state of the environment (such as ambient levels of pollutants and habitat diversity). Society responds to these changes through environmental and economic policies (such as programs to reduce impacts to the environment). The latter form a feedback loop to pressures through human activities. The OECD has used this PSR framework to develop the core set of indicators now being used in the OECD country reviews.

An elaboration of the OECD PSR framework is being developed by EPA as the basis for developing a system of environmental statistics and indicators, combining it with principles and techniques from environmental assessment and emerging ecosystem approaches to decision-making for environmental management and development[3]. This enhanced conceptual framework adds a category for impacts of environmental change on human health and welfare and distinguishes between proximate (direct) pressures and underlying (driving or motivating) pressures. It also seeks to link the PSR framework explicitly to society's environmental values, goals and priorities. Finally, it aims for the incorporation of spatially referenced (geographic) information, organized on the basis of ecologically defined land units; the adoption of sustainability targets; and the multiscaled use of information.

Within the basic PSR framework, three broad types of indicators can be distinguished:

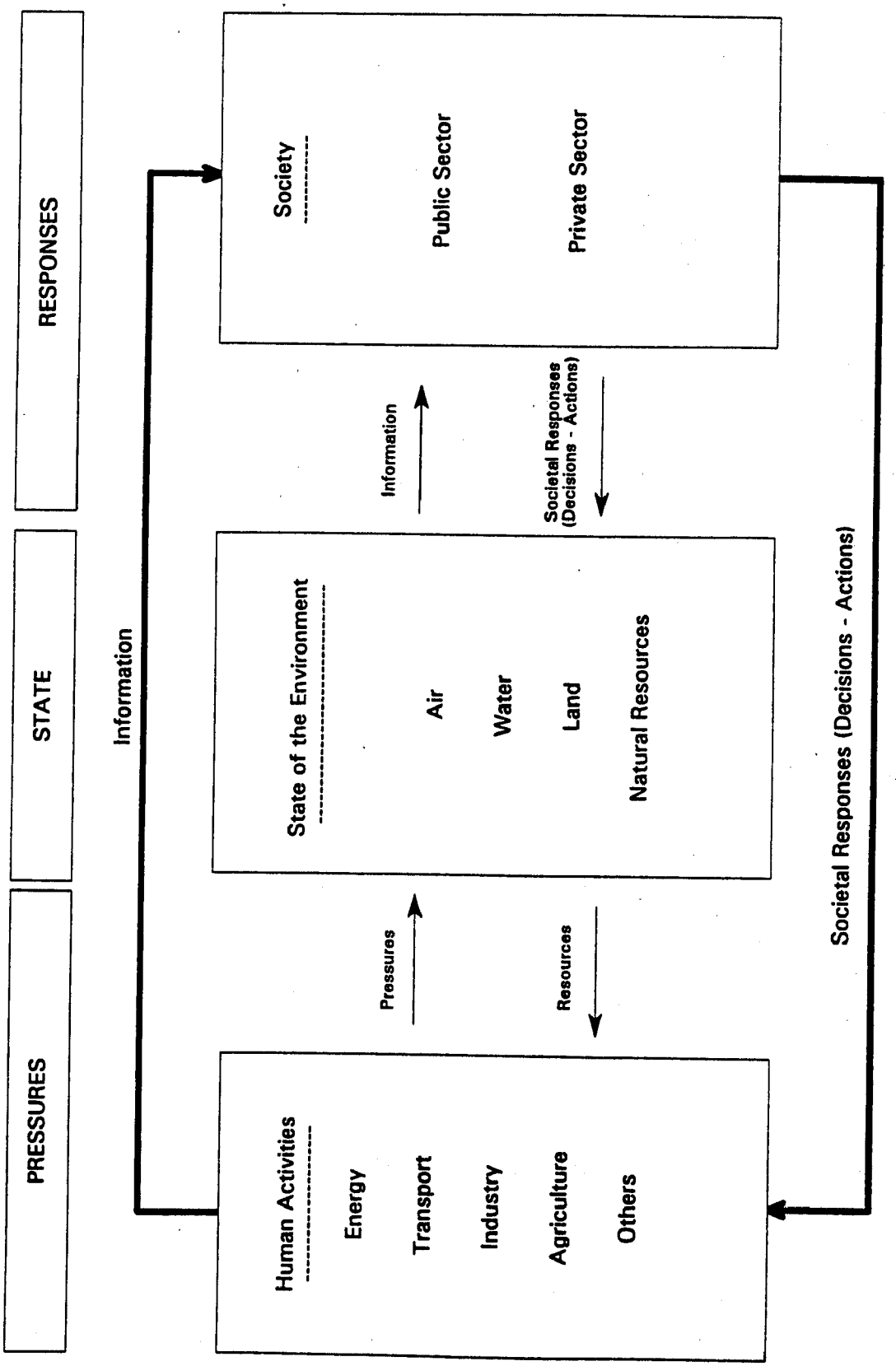
- **Indicators of environmental pressures** describe the pressures that human activities exert on the environment, including the quality and quantity of natural resources. Indicators of environmental pressures can be divided into indicators of proximate pressures (pressures directly exerted on the environment, normally expressed in terms of emissions or consumption of natural resources) and indicators of indirect pressures (background indicators reflecting human activities that lead to proximate environmental pressures).

- **Indicators of the State of the Environment** relate to the quality of the environment and the quality and quantity of natural resources. As such, they reflect the ultimate objective of environmental policy making. Indicators of environmental conditions should measure the state of the environment and changes in that state over time, rather than the pressures on it. In practice, however, the distinction between pressures on the environment and the resultant conditions can be ambiguous and the direct measurement of environmental conditions can be difficult or very costly. Therefore, the measurement of environmental

[2]This PSR discussion is adapted from *OECD Core Set of Indicators for Environmental Performance Reviews* Environmental Monograph No. 83 (1993).

[3]Ingrid Schulze, ESID Draft *Conceptual Approaches to the Development and Use of Environmental Indicators and Statistics for Decision-Making*, April, 1994.

Figure 1: OECD Pressure-State-Response Framework



* Adapted from "OECD Core Set of Indicators for Environmental Performance Reviews", Environmental Monograph No. 83 (1993)

pressures is often used as a substitute for the measurement of environmental conditions.

- **Indicators of societal responses** relate to individual and collective actions to mitigate, adapt to, or prevent human-induced damage to the environment and to halt or reverse environmental damage already inflicted. Societal responses also include actions for the preservation and the conservation of the environment and natural resources.

EPA's Office of Water uses a six-level continuum of environmental indicators (see Figure 2) to organize indicators. Indicators range from direct measurements of environmental conditions to those that relate to agency and state activities. The six types of indicators along the continuum are:

■ Health and ecological effects	(State)
■ Uptake or body burden	(State)
■ Ambient levels	(State)
■ Emission or discharge quantities	(Pressure)
■ Actions by sources	(Response)
■ Agency and state activities	(Response)

The right-hand column shows the correspondence between the continuum and the OECD PSR framework.

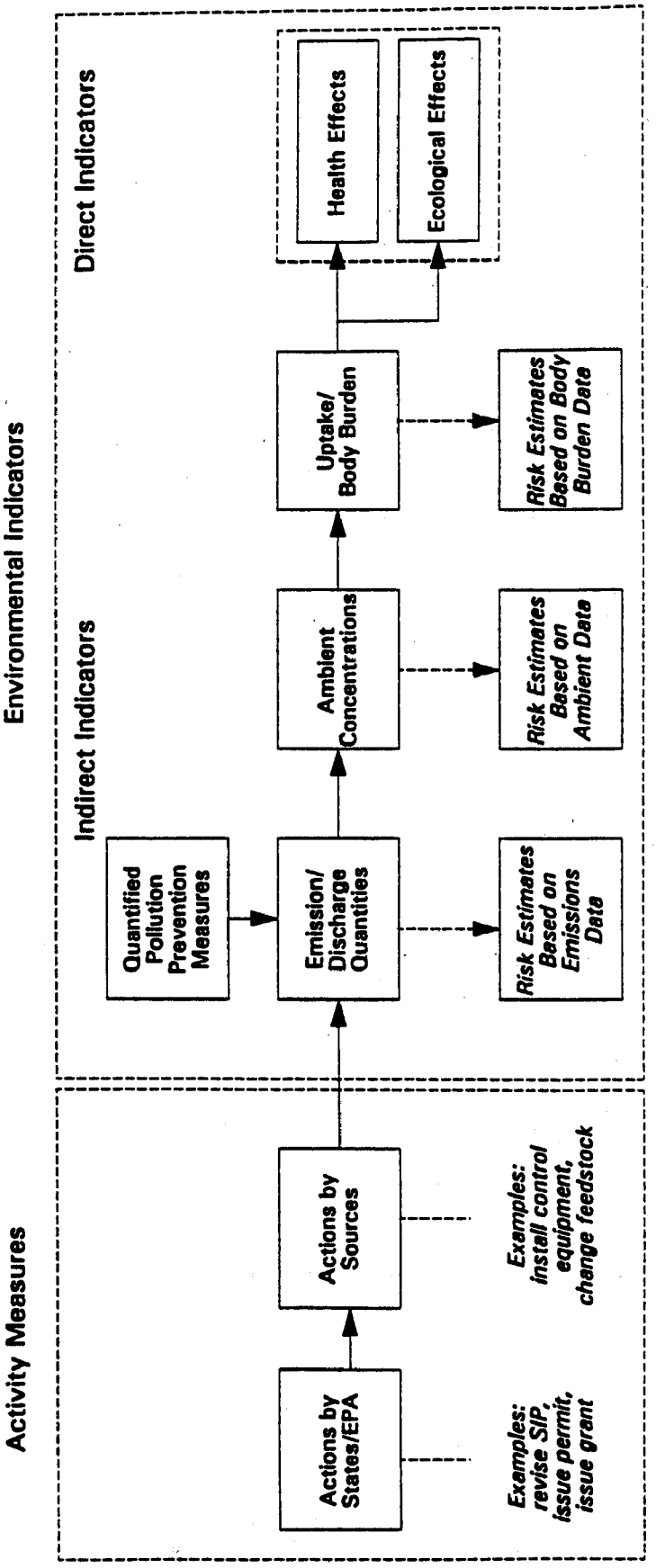
GENERAL COMMENTS ON THE PROCESS OF SELECTING ENVIRONMENTAL INDICATORS

In developing indicators, EPA has come to recognize that environmental indicators need to be explicitly linked to expressions of society's environmental values, goals and priorities. Indicators are measurable quantities that can be related directly or indirectly (via qualitative or quantitative models, e.g., via indices) to society's environmental values or concerns. For the State of the Environment, this implies linking indicators to the specific attributes of ecosystems, human health and welfare that society values (collectively termed *valued environmental attributes*[4]). Indicators of societal pressures and/or responses need to be selected, among other things, on the basis of (current understanding of) risks to valued attributes.

Different approaches can be used to select environmental indicators. On the one hand, indicators for a particular application can be selected on an ad hoc basis from existing indicators that are already in use. Such an approach can yield many meaningful and informative indicators; however, it also limits the range of possible indicators to those that have been previously developed for other purposes. An alternative

[4]Examples of valued environmental attributes include species diversity, wetland hydrologic function, drinking water quality, climate stability, productivity of fisheries, as defined for particular geographic areas (preferably ecologically-based land units). These issues are discussed further in: Ingrid Schulze, ESID Draft *Conceptual Approaches to the Development and Use of Environmental Indicators and Statistics for Decision-making.*

Figure 2: Continuum of Environmental Indicators



approach is to base indicator selection on (qualitative or quantitative) conceptual model(s) of the issue(s) or problem(s) at hand, regardless of current data availability. This approach uses a systematic process in which indicator selection is based on postulated cause-effect linkages between valued environmental attributes and the societal and natural factors that potentially affect these attributes.[5] While the latter approach may expose gaps in existing data, it allows society's environmental values and current scientific understanding of environmental linkages to drive indicator selection. The identification of such data gaps can drive EPA's indicator research.

CRITERIA FOR SELECTING INDICATORS FOR ASSESSING ENVIRONMENTAL STATUS AND TRENDS

In selecting environmental indicators, it is important to have clear selection criteria. Previously developed criteria are available from several sources including the Environmental Monitoring and Assessment Program (EMAP), the International Joint Commission for the Great Lakes (IJC), and Intergovernmental Task Force on Water Quality Monitoring (ITFM). The choice of selection criteria depends in part on the intended use for the indicators. (Note that some indicator selection criteria may be mutually exclusive.) The list of criteria suggested here, in Table 1, has been adapted from other sources (primarily the ITFM criteria).

The selection criteria are grouped based on considerations of validity, interpretability, timeliness, understandability, and cost considerations. These considerations include the following:

- Indicators should be valid measures of the attributes of interest. Validity is defined here as a close qualitative or quantitative linkage between the attribute actually of interest (e.g., "biological integrity") and the measurable quantity represented by the indicator. Three factors listed in Table 1 contribute to a close logical link between an indicator and the attributes of societal concern or value. First, indicators that respond at the appropriate spatial and temporal scales are more likely to be valid measures of an attribute of concern. Second, if the purpose of an indicator is to assess environmental status and trends, indicators that respond to cumulative effects of multiple stressors will be more representative of overall ecosystem condition than those that are responsive to only a few stressors. Third, indicators that are highly correlated with other measures (of an specified attribute) will tend to be representative of the environmental attribute or system being measured. Finally, indicators must be sensitive enough to measure changes over a reasonable time but not so sensitive that they fluctuate substantially between time periods. The signal-to-noise ratio for an indicator is in part determined by the data used to measure the indicator. Expert knowledge and peer review can be used to assess the sensitivity of different indicators.

- Indicators should be interpretable in terms of the end point in the assessment process. They should be able to distinguish unacceptable from acceptable environmental conditions.

[5] For discussions on this type of approach, see for example *Managing Troubled Waters: The Role of Regional Marine* Environmental Monitoring (National Academy Press, 1990) and the *Indicator Development Strategy for the Environmental Monitoring and Assessment Program*, U.S. Environmental Protection Agency, 1991.

Table 1: Criteria for Selecting Indicators

Criterion	Explanation
Validity	
*Social and Environmental Relevance	Scientific theory links the indicator to society's environmental values, goals and concerns.
Appropriate Scale	The indicator responds to changes on an appropriate geographic (e.g., national or regional) and temporal (e.g., yearly) scale.
Integrates Effects/ Exposures	The indicator integrates effects or exposure over time an space and responds to the cumulative effects of multiple stressors. It is broadly applicable to many stressors and sites.
Representative	Changes in the indicator are highly correlated with other measures of the attributes of interest.
Signal-to-Noise Ratio	The indicator is able to distinguish meaningful differences in environmental conditions with an acceptable degree of resolution.
Interpretability	
* Interpretable	There is a reference condition or benchmark against which to measure changes and trends. The indicator can distinguish acceptable conditions in a scientifically defensible way.
Comparability	Can be compared to existing and past measures of conditions to define trends and variation.
Timeliness	
Timely/Anticipatory	The indicator provides early warning of changes.
Understandability	
* Understandable	Indicator is, or can be transformed into a format that is understandable to the target audience.
Perceived Relevance to the User	The measured quantity or an index constructed therefrom is seen by the audience as being important or relevant to their lives.
Cost Effectiveness	
Cost Effectiveness	Information is available or can be obtained with reasonable cost and effort. Provides maximum information per unit effort.
Minimal Environmental Impact	Sampling produces minimal environmental impact.

*** Indicates critical criteria**

- Timely indicators that anticipate future changes in the environment are preferred over those that are not anticipatory. To the extent that an indicator does not anticipate future conditions, the indicator with the least time lag would be preferred. The time lag depends on both characteristics of the indicator and the time lag between the data collection and when the data is available to calculate the indicator.

- Indicators should be understandable by the public and perceived as relevant. Understandability is in part a characteristic of the indicator and in part a function of how the indicator is presented. EPA may need to educate the public on the importance of some indicators. If possible, indicators should be "attention grabbers" in that they communicate to the audience why an attribute or value is important, e.g., information on the number of fish is generally more interesting to the public than data on macroinvertebrates in the food chain. Keeping data presentations simple, graphic, and consistent will help. When there is uncertainty as to how an indicator will be understood, the use of focus groups may help EPA to understand how the public perceives the indicator and to provide guidance on improvements to the indicator.

- Finally, indicators should be cost effective relative to alternatives, and to the effort and expertise to collect the data, if required, and monitor the indicator over time.

CRITERIA FOR SELECTING EXISTING DATA SETS TO QUANTIFY INDICATORS

Table 2 sets forth proposed criteria for evaluating the usefulness of an existing data set to assess environmental conditions and trends in a particular geographic area.

Critical criteria for selecting data sets would include the availability of data on the selected parameters, appropriate temporal and spatial coverage, documented quality, and accessibility. Because changes in the data collection procedures might affect the technical credibility, the magnitude of the estimation error (and the associated sample size) and the cost, another critical criterion for consideration of a data set is that minimal standards of technical credibility, estimation precision, and cost can be achieved by either the present data collection procedures or reasonable modifications.

It is likely that either the sampling procedures or laboratory analysis procedures will change over the time that a data source is used to quantify an indicator and monitor progress. These changes will result from advances in technology and changes in budgets and uses of the data sets over time. The effect of these changes can be minimized by using (1) measurements for which changes in technology are likely to improve the precision but not affect the measurement bias and (2) procedures for which the measurement bias is relatively insensitive to the magnitude of the collection effort. To the extent that this cannot be achieved, a comparability study can be used to compare the indicator before and after the change. The value of both the original and revised indicator can be used for some time to provide information on how the two indicator compare. This same procedure can be used if a entirely new data set is used for the revised indicator.

Table 2: Criteria for Selecting Existing Data Sets to Quantify Indicators

Criterion	Explanation
* Availability of Data	Data set provides measurements of the parameter(s) or variable(s) specified in the indicator.
* Appropriate Temporal Coverage	At a minimum, information should be available for the present and for future years. In addition, temporal coverage within reporting cycles (usually annually) may have gaps but should not exclude data that will significantly affect the indicator.
* Appropriate Spatial Coverage	Information should be available on a national (regional) basis for a national (regional) program, or, if the information is compiled from local or regional data, the information will need to be aggregated using scientifically and statistically valid procedures.
Documented Quality	The information should be of known quality, i.e., there should be (1) documented QA/QC procedures for the collection, analysis and presentation of data, (2) documentation of any deviations from the procedures, and (3) quantitative information on both sampling and non-sampling errors.
* Accessibility	The information should be retrievable and analyzable using existing data retrieval and analysis procedures. EPA would not be prohibited from using the data due to confidentiality concerns, etc.
Technical Credibility	The procedures used to manage and analyze the data should follow accepted professional practices. In addition, the sample and data collection procedures should not be inconsistent with the use of the data as a measure of the indicator, as judged by technical experts in the field who are familiar with the data. The calculated bias in the indicator should be insensitive to the magnitude of the data collection effort and to political pressures. In general, this criterion will eliminate self-reported data from consideration.
Acceptable Estimation Error	The precision and bias of the indicator should be acceptable given the desired precision specified by the program.
Acceptable Cost	Cost of data collection, management, and analysis are within programmatic guidelines.

*** Indicates critical criteria**

PROCESS FOR SELECTING INDICATORS AND DATA

The proposed process for selecting indicators and data and filling information gaps consists of the following four basic steps:

Step 1. Identify And Recommend Possible Indicators For Reporting

Step 2. Inventory Existing National Data Sets

Step 3. Identify and Recommend Information/Data for Selecting Indicators

Step 4. Fill Information Gaps

These four steps are discussed in more detail below. Characteristics of how these four steps interrelate is provided in Figure 3.

Step 1: Identify and Recommend Indicators for Reporting Status and Trends

Step 1a: Identify possible indicators. Compile two lists of candidate environmental indicators. The first list includes indicators developed on the basis of conceptual models specific to the issue of concern, without any consideration for the availability of data. The second list includes currently used indicators. In many cases these indicators are meaningful and informative summaries constructed from available data. Many indicators will appear on both lists.

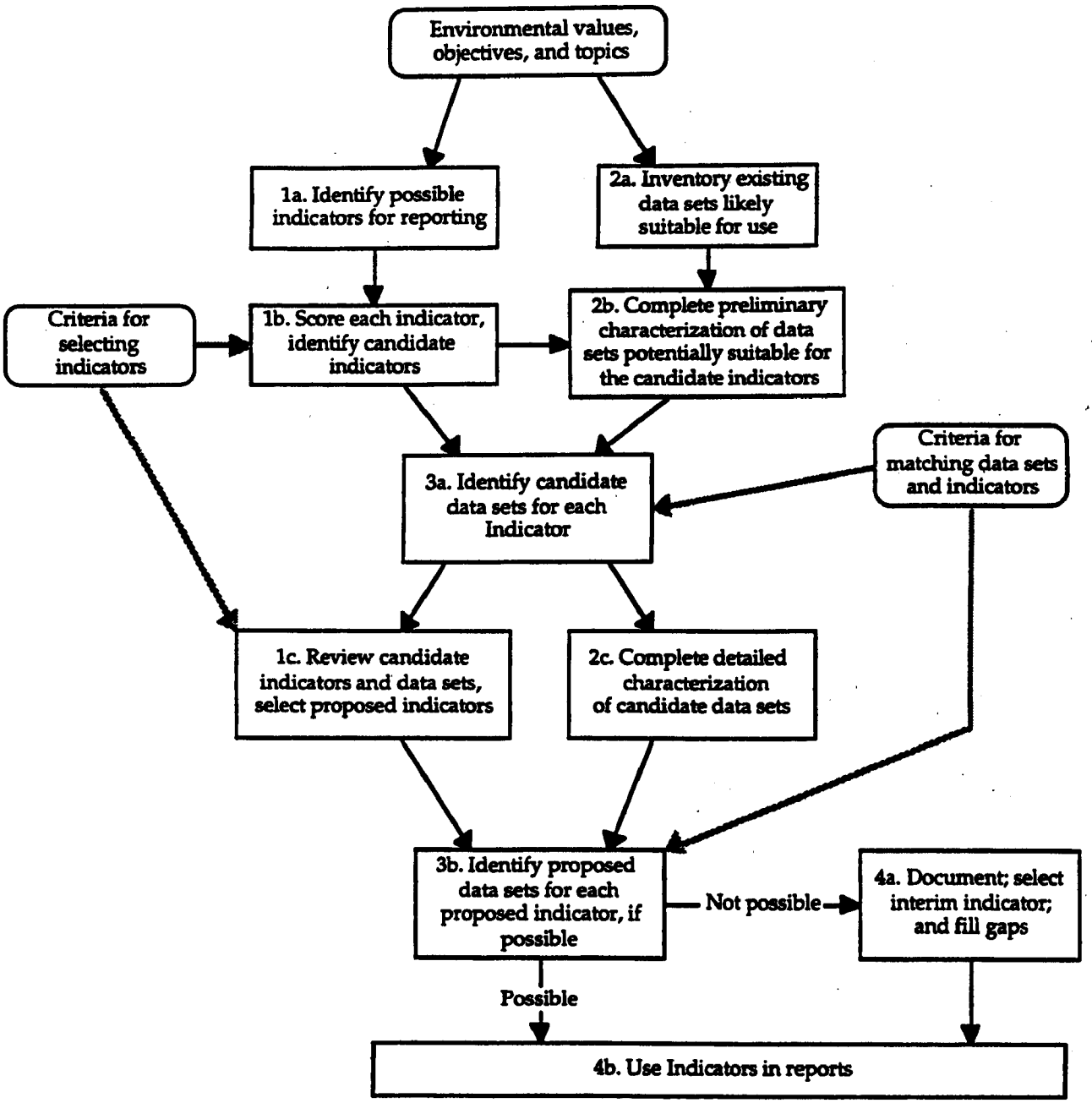
Step 1b: Score each indicator, using the criteria in Table 1, to identify candidate indicators. Review each indicator in the two lists and select a range of possible indicators for further consideration. Indicators will be rejected if they do not satisfy all of the critical criteria shown in Table 1. Of the remaining indicators, use a combination of peer review, literature review, and expert knowledge to select the candidate indicators for further consideration. The availability of data would be used as a criterion only for selecting between otherwise similar indicators.

Make a preliminary determination (using the descriptions of each indicator and the short forms for each data set) of which data sets are useful for each indicator. (See Step 3a below.) This will provide additional information for each indicator on what data may be available.

Step 1c: Review the specific attributes to which indicators should related, the data supporting the indicators, the criteria for selecting indicators, and the data available for each indicator in the geographic area of interest (as a secondary criterion) to select proposed indicators. The process will use a combination of peer review, literature review, and expert knowledge to select the proposed indicators.

The process of making a preliminary choice, gathering more information, and making a more refined choice of indicators is iterative. Additional iterations may be necessary to refine the selection of indicators and to incorporate new information as it is gathered.

Figure 3: Process for Selecting Indicators and Data and Filling Gaps



Step 2: Inventory and Describe Existing Data Sets that may be Suitable for Quantifying Indicators

This step consists of (1) an ongoing inventory of existing data held by EPA, other federal agencies, and other groups that may be suitable for use in reporting on environmental conditions and trends and (2) summarizing information about the data sets to facilitate the use of appropriate data sets to measure the selected indicators. This step is broken into three substeps shown in Figure 3 and described below.

Step 2a: Inventory existing data sets for their potential suitability for quantifying the candidate indicators. Prepare an assessment of existing data sources potentially available for reporting. Continually revise the assessment as new information is gathered through discussions with other federal agencies, non-government organizations, etc.

Step 2b: Complete a preliminary characterization of data sets potentially suitable for measuring the candidate indicators. After the candidate indicators have been selected, conduct a preliminary assessment of each data set that might potentially be used to assess one of the candidate indicators. To do this, prepare a "short form" to screen each data set. The "short form" will summarize the most important information needed to decide if a data set is potentially appropriate for a selected indicator. A draft short form appears in Appendix A.

Step 2c: Complete a detailed characterization of candidate data sets. After an initial selection of data sets that might be appropriate for the preliminary selection of indicators (see step 3a), do a more extensive examination for each data set that might be useful for the candidate indicators. For example, a form provides additional details beyond that provided by the short form if it can be used to determine if a data set (1) provides adequate data for a selected indicator or (2) provides data that, if augmented or modified, can be made adequate.

Step 3: Identify and Recommend Information/Data for Selected Indicators

Once the indicators to be used in reporting assessing environmental conditions and trends have been selected, the next step is to select the information/data to be used to quantify the indicators. This requires examining existing data collection and analysis programs to determine if appropriate information are or will be available. To the extent that characteristics of the data collection procedures affect the evaluation of the criteria for selecting indicators -- validity, interpretability, sensitivity, timeliness, understandability, and cost effectiveness -- the program should evaluate these criteria in light of the proposed data set.

The process will be accomplished in the following two steps:

Step 3a: Identify candidate data sets for each indicator. Use the information from the short form, published EPA documentation, and other sources to identify data sets that might be appropriate for use with each indicator. Several data sets might be appropriate for use with an indicator. If several data sets could be used, all would be considered unless one or more were clearly inferior to the others (i.e. being similar on most criteria but clearly worse on some). Additional information would be collected on all data sets that were being considered for any of the candidate indicators (step 2c). In some cases it may not be possible to identify any data that might be appropriate.

Step 3b: Identify proposed data sets for each indicator, if possible. Use additional information to identify data sets that are either appropriate for use with each indicator or, if not, could be made acceptable with additional data collection or changes in procedures. If several data sets are appropriate

for use with an indicator, the best one would generally be chosen. In some cases it might not be possible to identify any data that are appropriate. For those indicators where the available data are either inadequate and can be improved or are not available, a data gap exists.

Step 4: Fill Information Gaps

For indicators that lack adequate data:

(1) Document the data gap.

(2) Review existing indicators and data to see if some can be used as interim indicators to at least provide some information on conditions and trends.

(3) Develop strategies for filling information gaps, including improvements to existing programs in data collection, data analyses, and information management. Developing strategies includes determining if data can be made available by modifying existing data management and analysis procedures. For example, this could include the reanalysis of existing data or the integration and harmonization of two or more separate data sets.

a. If the information can be made available by changes in existing data management or data analysis procedures, develop a strategy for making the needed changes.

b. If the information cannot be made available by changes to existing data management or data analysis procedures, determine if there are validated test methods, statistical methods, etc. at the levels of precision and bias required:

For each indicator with validated methods, identify the type of data required (including statistical design) and design a data collection and analysis program. If feasible, implement the program.

For each indicator without validated methods, set up a process to develop these. If needed, set priorities for developing these methods. Once appropriate methods are developed, identify the type of data required (including statistical design and data analysis) and design a data collection and analysis program. If feasible, implement the program.

APPENDIX A

DRAFT SHORT FORM FOR SCREENING CANDIDATE DATA SETS

Data Set Screening ("Short") Form

Data Set Acronym/Short Name: **Date Completed:** ____ / ____ / ____

1. Background and Summary Information

1.1 Full Name of Data Set:

1.2 Sponsoring Agency:

1.3 Contact person: Name:

Address:

Telephone:

1.4 Brief summary of data set and the reasons for collecting this data:

1.5 References for additional information

2. Target Population and Identification of Sampling Units

2.1 Describe the target population / sampling frame:

2.2 Describe the sampling units:

2.3 How were the sampling units covered by the data base selected? (check one)

[ ] Probability Based Sampling: **Briefly describe the sample design:**

[ ] Census

[ ] Other: **Specify:**

2.4 Overall response rate: _ _ %

2.5 What is the geographic coverage of the data in the data set? (check one)

[ ] National

[ ] Regional: **Specify:**

[ ] State: **Specify:**

[ ] Other: **Specify:**

2.6 What time period (years) does the data set cover? From 19 _ _ to 19 _ _ .

2.7 Is the data collection on-going? Yes [ ] No [ ]

2.8 Frequency with which the survey or data collection effort is repeated:

3. Information Recorded In The Data File

3.1 For which of the following types of samples (including questionnaires) are measurements/data recorded in the data set? (Check all that apply) Describe the samples collected and the measurements obtained.

	Sample type	Sample description:	Measurements obtained:
[ ]	Water		
[ ]	Soil		
[ ]	Air		
[ ]	Food		
[ ]	Bulk chemical		
[ ]	Human tissue or fluid		
[ ]	Questionnaire (diary, observation form)		

4. Documentation of Data Collection Procedures

4.1 Did the following data collection activities have written procedures (including the use of accepted standard methods) and were the procedures documented through a QA/QC program review?

Sample/data collection activities	Written procedures	QA/QC review	Not applicable
Environmental sampling:	[ ]	[ ]	[ ]
Biological sampling:	[ ]	[ ]	[ ]
Field measurements:	[ ]	[ ]	[ ]
Laboratory preparation and analysis:	[ ]	[ ]	[ ]
Interview/questionnaire/field notes:	[ ]	[ ]	[ ]
Data Entry, editing, and verification:	[ ]	[ ]	[ ]

5. Summary Assessment of Data Quality

5.1 For key summary statistics derived from the data, describe the statistic and the associated confidence interval or measure of precision:

5.2 Give a general assessment of the data quality. Include comments, issues, or usage guidance relevant to using this data, including any potential biases or limitations in the data:

6. Description of the Available Data File

6.1 Availability of data:

Non-aggregated data		Summary Statistics	
[ ]	Public use. **Give cost:**	[ ]	Public use. **Give cost:**
[ ]	Restricted use: **Specify:**	[ ]	Restricted use: **Specify:**
[ ]	Confidential (not available for public use)	[ ]	Confidential (not available for public use)

6.2 In what form are data available? Mark all that apply.

Non-aggregated data		Summary Statistics	
[ ]	Hard copy (for example, Computer printouts, Files or log books, Reports, Microfilm)	[ ]	Hard copy (for example, Computer printouts, Files or log books, Reports, Microfilm)
[ ]	Machine readable form (for example: Tape, Diskette, On-line, CD-ROM)	[ ]	Machine readable form (for example: Tape, Diskette, On-line, CD-ROM)

6.3 Describe available summary statistics:

6.4 On average, how long is the time from field measurement, sample collection, and interviewing until data is available to the public?