5. Selecting Sustainability Indicators

"Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)" (Meadows, 1998). Whether in the context of government policy making or business decision making, indicators are essential for characterizing current conditions, evaluating management options that may be proposed, tracking the outcomes of actions taken, and assessing progress towards overall goals. The selection of indicators effectively determines the "lens" through which one views the system, and is therefore extremely important in influencing human decisions and judgments.

As discussed in Section 4, there are a wide variety of sustainability indicators used by different organizations in the U.S. and around the world. Depending upon the perspectives of various stakeholder groups and interested parties, the preferred indicators may be quite different. In addition, different indicators are needed at different spatial scales—from national-level reporting and tracking of progress to local, place-based or program-based investigation. This section addresses the selection of indicators in connection with two major EPA needs—the Report on the Environment, and focused planning or decision making.

5.1. Indicators for National Reporting

One objective of the Sustainability Indicators project was to select a small number of sustainability indicators for EPA's 2012 ROE. The ROE has strict guidelines for the choice of indicators, and requires a careful statement of rationale as well as supporting data and methodology. The ROE defines an indicator is defined as a numerical value derived from **actual measurements** of a pressure, state or ambient condition, exposure, or human health or ecological condition, over a specified geographic domain, whose trends over time represent or draw attention to underlying trends in the condition of the environment or human health (USEPA, 2008). The major categories of indicators reported in the 2008 ROE are discussed in Section 4.

Consistent with the Green Book recommendations, it is possible to augment the current ROE indicators to represent fundamental trends in sustainability. The simplest way to achieve this is to build upon existing indicators of pressures on the environment and human health that are already included in ROE. For example, one important goal for moving toward sustainability in a developed economy is to avoid adverse health and ecological impacts by reducing emissions of pollutants in the face of population and economic growth. To capture this trend, airborne emissions can be normalized by population size or annual economic output to create a 2-D indicator. An example of such an indicator is "greenhouse gas emissions per capita" or "greenhouse gas emissions per $ of gross domestic product". The normalizing factors are readily available from demographic and economic statistics maintained by other agencies. Rather than measuring an absolute condition, these indicators are measures of **intensity**, and reflect the rate at which pollutants are being generated in order to support the needs of the U.S. economy.

Airborne emission rates may be seen as an indirect measure of resource consumption, since they generally correlate with the rate of energy consumption and industrial activity. However, it is possible to reduce emission rates simply by pollution prevention and control technology, which does not necessarily lower the rate at which scarce resources are depleted or degraded. Another desirable option is to increase energy efficiency, thereby reducing the amount of energy (and corresponding impacts) required to deliver the same output (e.g., goods, services, electricity and transportation). Additional important goals for moving toward global sustainability are to reduce the rate at which non-renewable resources are consumed and to assure that consumption of renewable resources does not exceed their rates of natural regeneration (OECD, 2001). Accordingly, this project has investigated several additional indicators for national-scale reporting, reflecting the resource intensity for water, energy and materials.

- **Fresh water** is a critical, finite resource, and both the quality and availability of U.S. water sources are being stressed due to agricultural, urban, and industrial uses. An informative choice of sustainability indicator for water resources would be the use of water with respect to economic output (e.g., gross domestic product (GDP): **water use per unit of GDP**. Water use measures the amount of water withdrawn from the environment minus the amount discharged back into water bodies. This is an important consideration because some industrial sectors (e.g., electric power generation) return large quantities of treated water to the environment, while other sectors (e.g., agriculture) do not. Additionally, this water intensity indicator could be interpreted in the context of water scarcity to enable an assessment of sustainability. However, data to support this indicator as described above are currently not available. Every 5 years the US Geological Survey reports data on total water withdrawals compiled at the county level for industrial sectors. While current data constrains us to total water withdrawal intensities and limits interpretations with respect to sustainability, trends in water withdrawals per capita and per GDP can provide useful information on water withdrawal efficiencies by industrial sector or geographic region.

- **Energy** is a critical resource for economic growth and human well-being. However, there is growing concern over shrinking fossil resources, rising energy costs, and adverse impacts of certain energy generation technologies. The U.S. has achieved significant advances in energy efficiency and more opportunities exist to reduce energy demand and shift to renewable sources. Therefore, a useful sustainability indicator is the following measure of energy intensity: **energy use per unit of GDP**. Again, energy intensity can be measured on a national level and can be disaggregated across different energy use sectors.

- **Material** flow is an important aspect of sustainability because increasing material consumption requires a greater demand on resources (water, energy, minerals, land, etc.) and larger quantities of pollutants and wastes. In the U.S., over 90% of the materials that are extracted from the environment, transported, and processed are eventually discharged as waste or atmospheric emissions. To achieve sustainability it is necessary to break this pattern by "decoupling" material consumption from value creation. A suitable indicator of progress in material use reduction is material intensity, but it is difficult to gather reliable data on a national scale regarding actual material consumption over the life cycles of all products and services. Instead, a surrogate indicator for which reliable data are available is waste intensity, which can be measured as follows: **solid waste per unit of GDP**. Conservation of mass implies that the lower the amount of waste generated, the lower the overall material flow through the economy. This approach is consistent with the "sustainable materials management" initiative being conducted by EPA's Office of Resource Conservation and Recovery.

Although it appears that these intensity indicators only account for environmental and economic aspects, it is clear that core resources (e.g., energy, material and water) have a significant and measurable impact on people (hence, the social pillar), both individually and collectively. The goal of developing and recommending sustainability indicators for the ROE was to enhance the coverage past its core focus on the environment. Ongoing work on the ROE includes investigating the feasibility and relevance of these indicators and possibly expanding the use of intensity indicators by developing per capita measures (e.g., municipal solid waste per capita) to augment the view of sustainability and further highlight the impact of human activity. Subsequent editions of the ROE intend to increase the development, tracking and use of sustainability indicators.

5.2. Indicators for Focused Investigation

To accelerate successful adoption of the Sustainability Framework, the Green Book (NRC, 2011) recommends that EPA pursue a set of place-based and program-based pilot projects to develop sustainability expertise, encourage cultural change, and demonstrate value for stakeholders. Such projects will typically involve collaborations both within and outside EPA, making it critical to select a comprehensive set of goals and indicators that reflect stakeholder aspirations for shared value.

Generally speaking, in the context of decision making, a portfolio of indicators will be needed to represent the breadth of environmental and socioeconomic issues associated with sustainability. Typical categories of sustainability indicators that may be relevant to various stakeholder groups are illustrated in Figure 7. Note that in order to fully capture the dimensions of sustainability, environmental footprint reduction indicators need to be accompanied by stakeholder value creation. Table 3 further illustrates various categories of sustainability indicators that have been used by international organizations to characterize conditions in different countries and cities around the world.

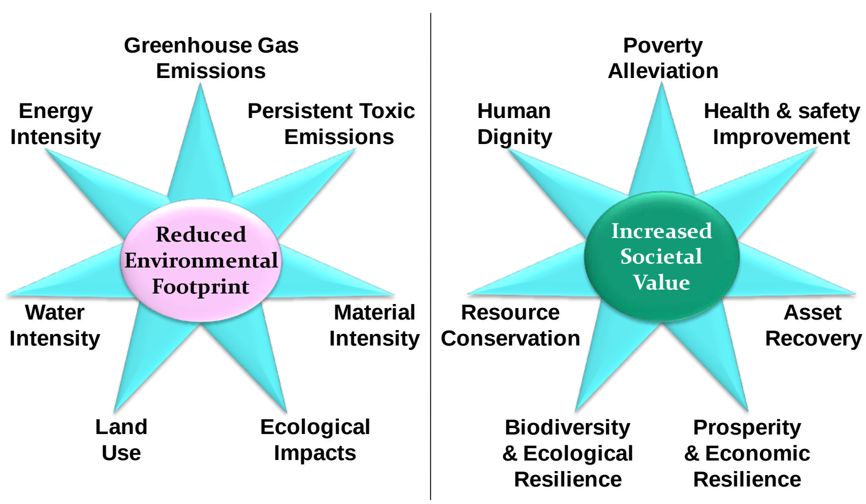

Figure 6 – Typical categories of sustainability indicators

Based on generally accepted performance measurement principles, an overarching criterion in the selection of indicators is "materiality," i.e., their relevance to the problem or issue under consideration. The following is a list of selection criteria that can be used to choose sustainability performance indicators (Fiksel, 2009). The set of indicators should be:

- **Relevant** to the interests of the intended audiences, reflecting important opportunities for enhancement of social and environmental conditions as well as economic prosperity.
- **Meaningful** to the intended audiences in terms of clarity, comprehensibility and transparency.
- **Objective** in terms of measurement techniques and verifiability, while allowing for regional, cultural and socio-economic differences.
- **Effective** for supporting benchmarking and monitoring over time, as well as decision-making about how to improve performance.
- **Comprehensive** in providing an overall evaluation of progress with respect to sustainability goals.
- **Consistent** across different sites or communities, using appropriate normalization and other methods to account for their inherent diversity.
- **Practical** in allowing cost-effective, non-burdensome implementation and building on existing data collection where possible.

In addition, the Green Book (NRC, 2011) states that indicators should have the following attributes:

- **Actionable**, so that practical steps can be taken to address contributing factors.
- **Transferable** and **scalable**, so that they are adaptable at regional, state, or local levels.
- **Intergenerational**, reflecting fair distribution of costs and benefits among different generations.
- **Durable**, so that they have long-term relevance.

While every indicator need not satisfy all of these criteria, a credible portfolio of sustainability indicators should have the above characteristics. The most effective performance measurement programs are those that focus upon a small number of quantifiable key performance indicators (KPIs) covering the most important aspects of sustainability for the specific problem at hand.

Table 3 – Examples of Sustainability Indicators Used Worldwide

Poverty
- Unemployment rate
- Poverty index
- Population living below poverty line

Population Stability
- Population growth rate trend
- Population density

Human Health
- Average life expectancy
- Access to safe drinking water
- Access to basic Sanitation
- Infant mortality rate

Living Conditions
- Urban population growth rate
- Floor area per capita
- Housing cost

Coastal Protection
- Population growth
- Fisheries yield
- Algae index

Agricultural Conditions
- Pesticide use rate
- Fertilizer use rate
- Arable land per capita
- Irrigation % of arable land

Ecosystem Stability
- Threatened species
- Annual rainfall

Atmospheric Impacts
- Greenhouse gas emissions
- Sulfur oxide emissions
- Nitrogen oxides emissions
- Ozone depleting emissions

Generation
- Municipal waste
- Hazardous waste
- Radioactive waste
- Land occupied by waste

Consumption
- Forest area change
- Annual energy consumption
- Mineral reserves
- Fossil fuel reserves
- Material intensity
- Groundwater reserves

Economic Growth
- GNP
- National debt/GNP
- Average income
- Capital imports
- Foreign investment

Accessibility
- Telephone lines per capita
- Information access

Sources:
United Nations, *Indicators of Sustainable Development*
World Bank, *World Development Indicators*

5.3. Integrated Indicator: Index

Many organizations have developed integrated indicators that combine multiple indicators into a single index as a common "currency". Examples include the Human Development Index used by the U.N., the Environmental Quality Index and the Genuine Savings Index mentioned earlier. While an index is convenient for purposes of communication and tracking, it reduces transparency by collapsing a variety of substantive information into a single index. Thus, it is difficult for a user or stakeholder to interpret the value of increasing the index or its underlying indicators by a certain amount. While reporting such aggregate indices, it is generally advisable to also present the information that comprises the index, and to make it available to interested parties. Many researchers have performed sustainability studies using multiple indices (e.g., Wilson et al., 2007; Nourry, 2008; Pulselli et al., 2008; Tiezzi and Bastianoni, 2008; Hopton et al., 2010). Such data can be presented as a spider diagram for visual inspection, but further aggregating these composite into a single overall index invites similar transparency concerns. Researchers around the world, including within ORD are wrestling with methods of identifying underlying drivers of behavior reflected in indices. Methods under investigation include principal components analysis (PCA), system dynamics models and correlation tests (Vyas and Kumaranayake, 2006; USEPA, 2010; Primpas et al., 2010; Eason and Cabezas, 2012; Gonzalez-Mejia et al., 2012).

Further, scientists are studying and testing methods based on fundamental properties of systems (e.g., thermodynamic and information-theoretic approaches) to develop a new generation of sustainability indices. Examples of these approaches include Fisher Information (Mayer et al., 2007), exergy (Dincer and Rosen, 2007; Baral and Bakshi, 2010), and emergy (Odum, 1994). These composite indicators can be used alone or in combination with other indicators. Emerging indices offer powerful scientific tools for sustainability assessment and are the subject of ongoing research. However, since the focus of this document is on the selection and implementation of commonly used, transparent, and meaningful sustainability indicators, a detailed review of indices is not included in this report.

6. Implementing the Use of Sustainability Indicators

Following the guidance of the Green Book (NRC, 2011), it is assumed that EPA will begin to implement a Sustainability Assessment and Management (SAM) process as depicted in Figure 8. The important features of the process include the following:

- **Comprehensive and systems-based**: Analysis of alternative options should include an integrated evaluation of the social, environmental, and economic consequences.
- **Selective application**: The level and depth of analysis should match with the scale and magnitude of potential consequences for the decision at hand.
- **Intergenerational**: The long-term consequences of alternatives should be evaluated in addition to the more immediate consequences.
- **Stakeholder collaboration**: Stakeholders should be involved throughout the process.

Sustainability indicators play a critical role in the SAM process, from the initial establishment of goals to the ultimate evaluation of outcomes. Ideally, the indicators used in the EPA sustainability assessment and management process will be consistent with the indicators in the Report on the Environment, thus providing linkages between broad national indicators (e.g., GHG emissions per capita) and focused local or regional assessments (e.g., annual energy use per urban household).

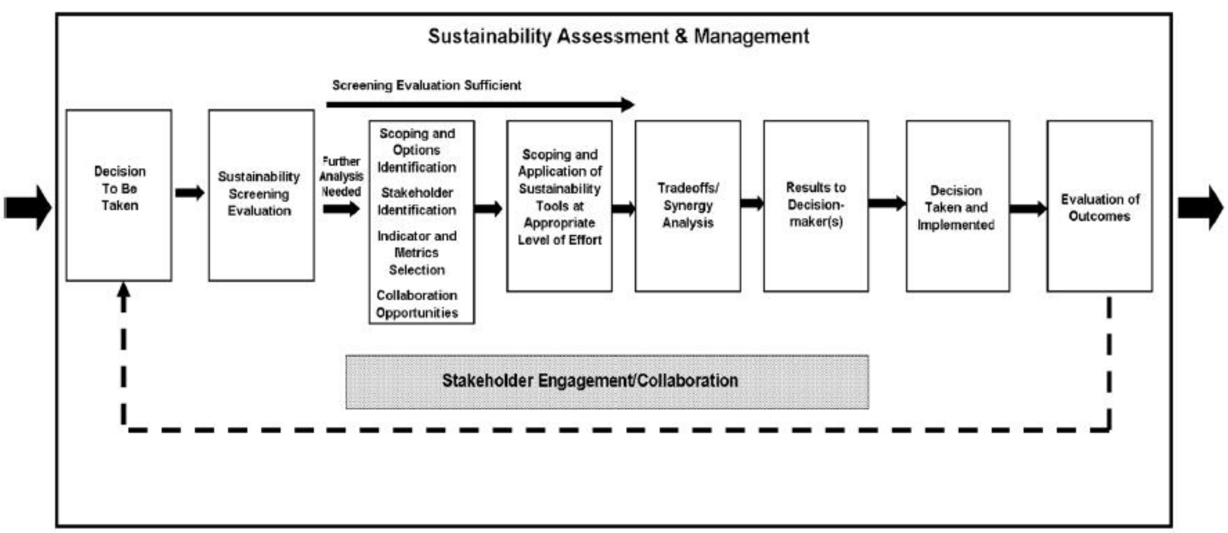

Figure 7 – The Sustainability Assessment and Management Process

Similar to SAM, the following is a five-step guideline for implementing the use of sustainability indicators in the context of applied research projects that are intended to support policy or decision-making. These steps are illustrated using a pilot project that is currently being conducted by ORD on mitigation of excessive nutrients (i.e., nitrogen and phosphorus compounds) in New England waterways, in collaboration with EPA Region 1. This is a place-based study focused on the Narragansett Bay and its watershed, with a broad scope that includes social, economic, and environmental issues.

Step 1 - Problem Definition, Scoping and Planning

Problem definition is a critical activity in the SAM process because it determines the scope and boundaries of the system to be considered, and explicitly identifies the relevant stakeholder interests. Systems thinking is needed because an overly narrow problem formulation may omit important unintended consequences. Therefore, definition of sustainability goals should address all the important environmental, economic, and social aspects that might be affected by a system intervention. In the Narragansett example, the overall goal is to reduce nutrient impairment while supporting regional economic growth and community well being.

Step 2 - Identification and Selection of Relevant Indicators

As discussed in Section 5.2, a portfolio of sustainability indicators should be chosen to address the goals of the research as well as the interests of different stakeholder groups. For the nutrient study, the triple value framework (see Section 3.4) was selected to represent the overall system, and ten primary "key" indicators were chosen covering each of the three major subsystems—industries, communities, and environmental resources. As shown in Figure 9, the Narragansett Bay project involved identifying and modeling the causal linkages among these indicators. During the course of the project, a variety of additional indicators were identified for purposes of modeling the system behavior.

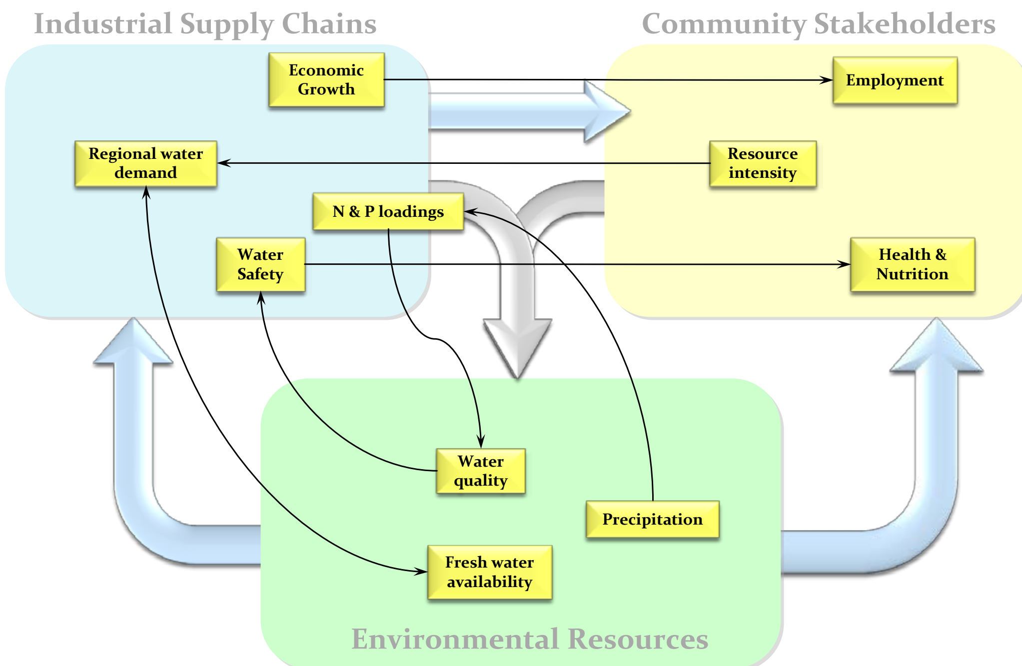

Figure 8 – Selected Key indicators for Mitigation of Nutrient Impairment

Step 3 - Specification of appropriate spatial scale and units of measure

To implement the use of an indicator, it is necessary to define the scope or scale of measurement (e.g., single water body vs. watershed-scale vs. regional or national scale) as well as the physical or monetary units (i.e., metrics) to be utilized. For example, "water demand" can be quantified in terms of the following specific metric: millions of gallons of water consumed annually within the watershed. It is important to distinguish between **absolute** measures and **relative** metrics, which are normalized with respect to another quantity. Examples of relative metrics are time-based indicators, e.g., percent increase in water demand from 2010 to 2020, and "intensity" measures, e.g., water demand per capita" (see Section 5.1). Although stakeholder groups often advocate the use of absolute measures, these may lead to inappropriate comparisons whereas relative indicators are generally less biased by differences in system characteristics. For example, the largest facilities in a region will typically be the largest consumers of water, even though their water intensity may be significantly lower than others.

Step 4 - Data collection and quality assurance procedures

Once the indicators and measurement approaches have been determined, data must be collected from primary or secondary sources. Typically a baseline set of data will be established in a given year for purposes of future comparison. As in any research effort, care must be taken to assure the quality, accuracy, reliability, comparability of the data. It is also useful, where possible, to identify the sources of uncertainty and to establish uncertainty bounds. Since indicators will typically be tracked over a long period of time, provisions must be made for data archiving, maintenance and retrieval.

Step 5 - Communication and reporting

Indicators are valuable tools for purposes of problem analysis, reporting of progress, evaluation of outcomes and assessment of performance. Through successive iterations of the SAM process, sustainability indicators can be used repeatedly to support decision-making and stakeholder communication. The availability of quantitative measures lends credibility to any type of communication exercise. However, care must be used to assure that indicators are used appropriately, bias is avoided, uncertainty is communicated and transparency is emphasized. If an aggregated index is used, the components and weighting factors that comprise the index should be available and understandable.

Implementing the above process across EPA's multiple activities will pose challenges in terms of coordination and consistency of interpretation. Establishing uniform guidelines, procedures, and tools for the use of sustainability indicators will not only facilitate coordination, but will also enhance EPA's long-run credibility and provide leadership to stakeholders in the business community and civil society.

7. Conclusions

Incorporation of sustainability concepts into the EPA policy and decision making process will require the adoption of sustainability indicators for purposes of problem definition, goal setting, measurement of progress, evaluation of performance, communication with stakeholders, and public reporting. In particular, to effectively support sustainability initiatives in Program and Regional offices, coordination of ORD research programs will be facilitated by the adoption of a common framework for sustainability indicators. This document provides guidelines for the definition, selection, and implementation of sustainability indicators that are consistent with EPA's mission. The approach presented here is an effort to provide a comprehensive and flexible toolkit for tracking of sustainability progress at multiple scales across the full spectrum of EPA activities.

Sustainability indicators are a powerful tool for focusing attention on important environmental, economic, and social trends that provide signals of change. However, indicators can potentially be manipulated to convey biased messages, and therefore the selection of indicators for public policy purposes should be approached with the utmost effort to assure objectivity, transparency, and stakeholder consensus. It is in EPA's interest to develop an ongoing repository of sustainability indicators that are meaningful, verifiable, defensible, and relevant to stakeholder audiences. The database developed under this project can provide a starting point for such a repository.

The guidelines and tools provided through this work should be helpful as EPA moves forward with implementation of the Green Book recommendations. Selection and implementation of sustainability indicators should be coordinated across various Agency activities, including high-level, national-scale reporting through the Report on the Environment, programmatic activities including policy development and rule-making, and focused, place-based projects involving collaboration and decision-making.