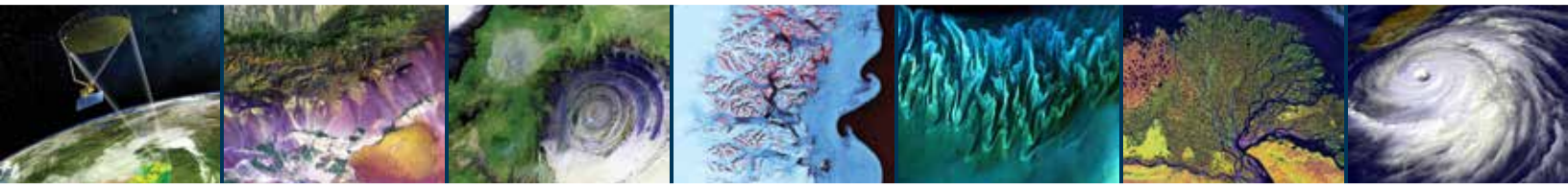
National Aeronautics and Space Administration

Measuring Socioeconomic Impacts of Earth Observations



A Primer

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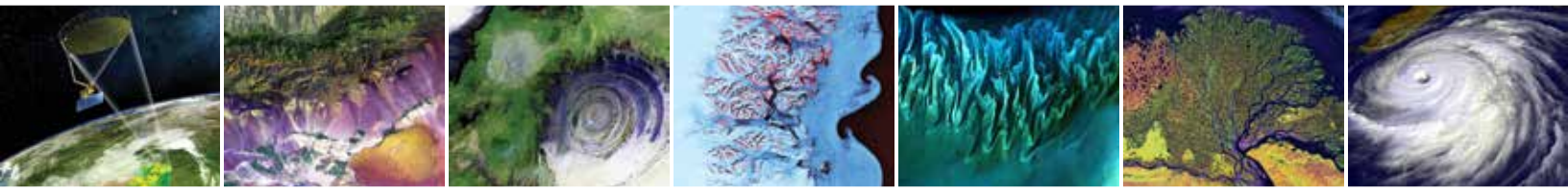

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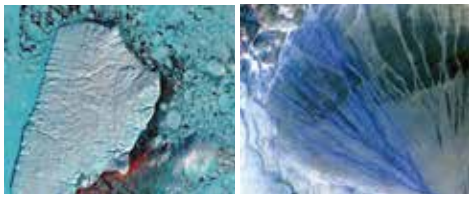
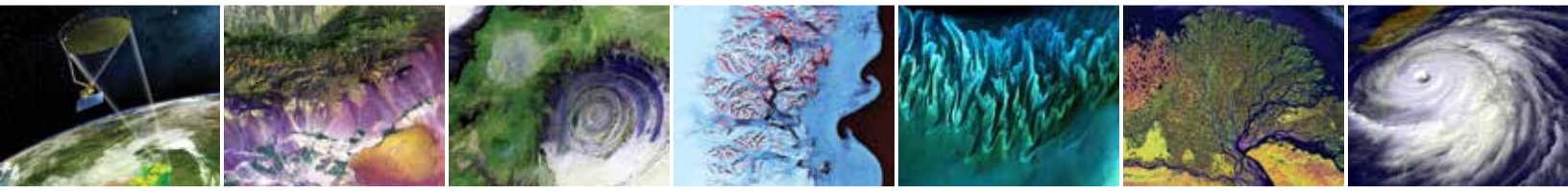




1. Introduction

Public and private organizations have used Earth observations for decades to benefit society. For example, weather agencies use space-based meteorological observations to increase the accuracy and timeliness of weather forecasts. As a result, the public is able to make more timely preparations for severe weather, thereby saving lives and reducing property damage. These benefits are examples of socioeconomic impacts from the use of Earth observations.

In times of limited public and private budgets, managers and decision makers may look at ways to quantify the socioeconomic benefits of projects and programs they are considering. For example, when deciding whether to support new or ongoing funding for a project, budgeting authorities may compare the socioeconomic benefits of the project with the costs required to develop and maintain it. Accurate and credible estimates of these benefits help authorities make informed decisions about how to allocate scarce resources among projects and programs.

Members of the Earth observations community have historically been quite effective at qualitatively describing the socioeconomic benefits of their projects. However, without more consistent and rigorous quantitative benefit estimates, members of the community are at a disadvantage when their projects are evaluated against competing priorities.

Techniques for quantifying socioeconomic benefits exist for many types of projects. Related techniques also quantify negative "benefits," such as risks incurred during project operations. Positive and negative benefits together are often referred to as "impacts," and the application of these techniques is referred to as ***socioeconomic impact analysis***. Socioeconomic impact analyses provide decision makers with an objective, defensible basis to

- evaluate Earth observations project impacts in the community;
- communicate the value of Earth observations to key stakeholders, including the public and government authorities;
- support efforts to defend Earth observations research budgets against competing priorities; and
- respond to budgeting inquiries concerning the value of projects and programs.

The purpose of this Primer is to inform the Earth observations community and project teams about the language, key principles, techniques, and applications of socioeconomic impact analyses and to provide suggestions on best practices for analyses of Earth observations projects. With this Primer as a resource, community members can be more effective in communicating the value of

their projects in discussions with academic colleagues in economics, business, resource management, environmental, and public policy departments; policy makers and their staffs; the private sector on partnership opportunities; and government agencies. The Primer is part of a series of efforts to stimulate discussion and research within the community about how to better use and improve these techniques in an Earth observations context.

Table 1 summarizes the impact assessment approaches described in this Primer, along with some related analyses and techniques that are addressed in relevant sections.

The remainder of the document focuses on five topics:

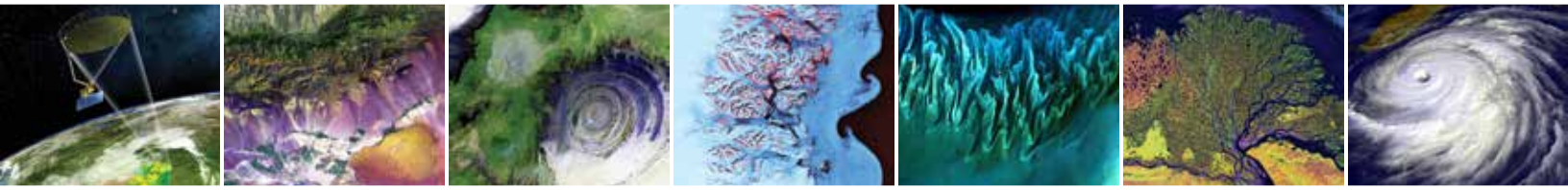
- Section 2 provides an overview of socioeconomic impact analysis.
- Section 3 describes specific steps of impact analysis techniques.
- Section 4 provides two examples of applying the techniques to an Earth observations project.
- Section 5 describes two specific techniques: Cost-Benefit Analysis and Cost-Effectiveness Analysis.
- Section 6 describes key terms and concepts in more depth.

A series of appendices provide supplementary information:

- Appendix A gives a list of references.
- Appendix B provides two examples of a value of information approach.
- Appendix C, which is an aid for researchers in the United States, describes regulatory and statutory drivers in the United States for conducting a common type of socioeconomic impact analysis.
- Appendix D provides a list of acronyms.

Table 1. Socioeconomic Impact Assessment Methods

Approach	Focus	Considerations	Sections
Impact Assessment			
Time-Series/ Statistical Analysis	Comparing historical trends before and after project completion	Retrospective; based primarily on objective data; therefore data-intensive and dependent upon availability of data	3.1, 3.6, 4.1
Expert Opinion	Using expert judgment or prior analyses to estimate project impacts	Can be retrospective or prospective; feasible in situations with limited data, but based on subjective or proxy data	3.1, 3.6, 4.2
Value of Information	Analyzing decisions under uncertainty with and without information from project	Usually prospective; requires availability and cooperation of decision maker; mix of subjective and objective basis	3.1, 3.6, App. B
Cost-Based Assessment			
Benefit-Cost Analysis	Comparing monetized impacts with financial costs of project	Allows financial comparison of projects with different objectives; requires both impact and cost analyses; monetizing impacts can be difficult and controversial	5.1
Cost-Effectiveness Analysis	Comparing costs of achieving desired impacts	Allows financial comparison of projects with similar objectives; requires both impact and cost analyses; does not require monetizing impacts	5.2
Impact Monetization			
Market Valuation	Using prices paid in open markets for goods and services related to project impacts	Objective; requires market data; applicable only if markets exist for goods and services related to the project impact	3.7
Standards-Based Valuation	Using standardized prices from government or industry for project impacts in lieu of market data	Can be controversial, depending on standardizing source; simplifies monetization process; available for only a limited number of impacts	3.7
Benefits Transfer from Prior Research	Adapting existing studies to monetize impacts similar to those from the project	Can be controversial, depending on relative similarity of project benefits to those in prior research	3.7
Stated Preferences Valuation	Using surveys, augmented by analysis, to estimate stakeholders' willingness to pay for project impacts (e.g., conjoint analysis)	Tendency for biased responses by stakeholders who are only conceptually spending money for the impacts; requires survey development and analysis	3.7
Revealed Preferences Valuation	Using stakeholder behavior to estimate willingness to pay for project impacts (e.g., travel cost analysis, hedonic analysis)	Based on actual behavior rather than conceptual surveys; relationship between priced item and project impact may be indirect and thus controversial	3.7



2. Assessing Socioeconomic Impacts

This section provides an overview of socioeconomic impact analysis. It defines key terms, presents the common steps and flow used in all approaches, and describes how each step is performed.

2.1 Key Terms

Like other scientific disciplines, socioeconomic impact analysis has its own unique language. Terms such as "costs," "benefits," and "discounting" have specific meanings in impact analysis. An understanding of the terms and lexicon can support Earth observations researchers in effectively communicating with stakeholders and social science colleagues. Some of the key terms used in impact analysis include the following:

Socioeconomic—Concerning the use of resources belonging to a group of people.

Positive benefit—Anything perceived to be a good change in an individual or group's life. Example: Reduced deaths due to improved hurricane forecasting.

Negative benefit—Anything perceived to be a bad change in an individual or group's life. Example: Reduced privacy due to improved space-based surveillance.

Impact—A positive or negative benefit.

Tangible impact—A directly quantifiable impact. Example: Reduced timber losses due to more timely detection of wildfires.

Intangible impact—An impact that is difficult to quantify directly. Example: Happiness due to lower old-growth forest destruction from wildfires.

Monetized impact—An impact that has been converted into the equivalent amount of money. This usually represents the maximum amount of money that a person or group would be willing to pay to obtain or avoid the impact.

Baseline—A reference case, assuming no changes in historical trends, that can be compared to actual outcomes or impacts to measure changes due to both project outputs and confounding factors.

Proxy—A tangible quantity used to infer information about a related intangible impact. Example: Contributions to charities that work for species preservation might be a proxy for happiness due to biodiversity.

Confounding factor—Any action or effect, other than the primary factor (such as an Earth observations project) being analyzed, that might change the value of an impact metric. Example: Political change might be a confounding factor in an analysis of the impact of Earth observations in reducing the spread of a disease in a developing country.

Cost—An expenditure of effort or resources required to obtain an outcome; usually expressed as a monetary value.

Discount rate—Preference for money today compared with money at a later date, expressed as a percentage per time period. Example: If a private decision maker has a personal discount rate of 10 percent per year, they are equally satisfied with receiving $100 today or $110 one year from now.

Net Present Value (NPV)—The sum of a series of payments over time, expressed in terms of a single equivalent payment received today. Mathematically, it is expressed as

$$NPV(p) = \sum_{t=0}^{\infty} \frac{p_t}{(1+r)^t}$$

where p is a series of payments made at time periods t=0, 1,…, and r is a discount rate.

Retrospective impact analysis—A review of impacts already realized.

Prospective impact analysis—A forecast of impacts that may be obtained in the future.

These terms are sufficient for an initial overview of the socioeconomic impact analysis framework. Related terms are described in more detail in section 5 below.

2.2 Common Framework and Flow

Socioeconomic impact analysis is an approach to specify and quantify the economic, social, environmental, and other impacts or value that accrue to society as a result of an action. For example, a socioeconomic impact analysis might measure if a policy action achieves an intended decrease in deaths from a disease or an increase in biodiversity. In the Earth observations context, the actions analyzed are directly influenced by the information or decision systems provided by a project or program.

Analysts quantify impacts by observing or estimating metrics of value if a project is completed successfully and comparing them with observations or estimates of the same metrics assuming the project had not been undertaken or completed successfully. To perform such an analysis, data on the metrics are collected for periods before and, if available, after project implementation. A baseline projection is then developed to estimate the same metrics in the absence of the project. This baseline projection is compared with actual data or projections of the metric for the period after project completion. The difference between the two, corrected for causative and randomness factors, is the total impact estimate.

Conceptually:

Impact metrics after completion of the project **–** ***Impact metrics in baseline projection*** **=** ***Impacts attributable to the project***

This approach is analogous to the controlled-experiment approach used in physical sciences, with the project providing the test case and the baseline the control case. A key difference is that, in a socioeconomic impact analysis, only one set of actual observations can be made; the other set must be estimated. For a given time period, a baseline can be measured in the absence of the project, or the impact metric can be measured with the project completed, but the two cases cannot be observed together. To determine the impact of an executed project, therefore, one must estimate the baseline. To determine the impact of a proposed project, one must estimate the metrics expected after the project. Many of the modeling and statistical approaches used in the physical sciences, such as time-series analysis and multivariate regression, are available to social scientists to make estimates of the unobserved baseline case and projected post-project case.[1]

The steps analysts typically perform in completing such an analysis are shown in figure 1. First, analysts choose an approach appropriate to the maturity of the project and availability of data. For example, for a mature weather-satellite project, a retrospective approach might be appropriate since the project has been completed successfully, and time-series methods might be selected initially due to the availability and reliability of project data.

Analysts then specify well-defined, relevant metrics to capture the desired impacts. These impacts can be physical or financial, tangible or intangible. Additional work is done to develop proxies to analyze the intangible impacts. In our weather-satellite example, one metric might be daily hospital admissions in a given region for injuries due to extreme weather events; this is physical and tangible. Financial metrics are specified for physical metrics that will be monetized later in the analysis. In our example, analysts might decide to monetize hospital admissions for weather-related injuries by estimating the average total cost per admission for such injuries. The financial metric might be the NPV of the cost savings.

Analysts then identify explicitly the expected relationship between the project and the impacts. This might be derived from theory or, for completed projects, by examining the impact data recorded after project completion. In our example, theory suggests that improved weather forecasting reduces the average daily admissions during severe weather events.

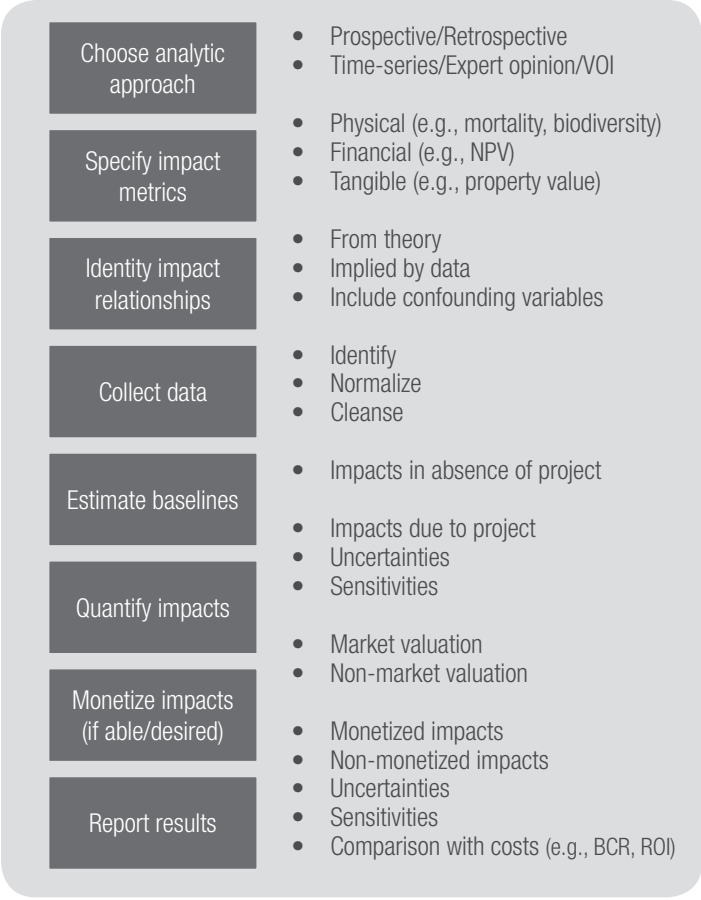


Figure 1. Socioeconomic Impact Analysis Flow

1. In certain cases, a baseline can be estimated by comparing two similar regions, one in which the project outputs are being used and the other in which they are not. If this can be arranged and the differences between the regions are minor, a near-baseline and post-project case can, in fact, both be observed.

Data relevant to the selected metrics or proxies are identified, collected, and conditioned through normalization and cleansing. In our example, daily hospital admissions data and weather data for the region may be required. If the admissions data do not explicitly identify weather-related injuries, then the opinion of subject-matter experts might be required in order to transform the data into a form suitable to model project impacts.

The data available for analysis may be incomplete and suffer from series breaks, tradeoffs between detail and accuracy, time lags, revisions, and missing values. As the elements of the impact analysis come together, the effects of these data issues become more evident and analysts will use compensating techniques where possible to mitigate the effects. In our example, any missing values might be imputed by applying weights to existing data points based upon relevant characteristics of existing points and assumed characteristics of the missing points.

Analysts use historical data to create a baseline projection in the absence of the project, usually through time-series modeling or expert opinion elicited during data collection. In our example, a time-series model of seasonally adjusted admissions during extreme weather events would be developed using data from periods prior to the project's completion.

It is important during this phase to identify factors other than the project that might affect the metrics. This allows for appropriate isolation of project impacts within the data. For example, weather-related hospital admissions in the region might have been reduced by a separate, unrelated program that increased local emergency response staff. Efforts that do not account for such "confounding variables" likely misstate the impact of the project being analyzed.

Analysts then use the data they collect to calibrate the impact model and to derive the actual or estimated metrics for periods after the project is successfully completed. These metrics, corrected for confounding variables, are compared with the baseline projections to estimate the impact of the project. Uncertainty measures are derived for estimates based on statistical approaches or are reported for estimates based on expert opinion. At this point, analysts often derive the sensitivity of results to uncertain variables and assumptions.

Where possible, impacts are translated into common terms and consolidated into a single net measure. Money is often used as a common metric of benefit. In our example, the analysts decided to monetize the admissions impacts by using NPV of hospitalization costs.

While economists have a range of methods to monetize impacts in the absence of objective market prices, these methods can be controversial. For example, the monetary value of saving a life and preventing a species from becoming extinct are both examples that can be difficult or considered inappropriate to monetize. Thus, analysts often choose to present some impact metrics in non-monetized form, allowing decision makers to perform their own internal aggregation and evaluation of the impacts.

Analysts then report the results of the impact analysis, focusing on information to clarify the value of the project. In addition to details about the methodology used and assumptions, the analyst's report should also describe the monetized impacts, the non-monetized impacts, measures of uncertainty in the findings, and any sensitivities of the results to uncertain variables or assumptions. During the final report development, analysts may also extend the analysis to include a comparison of project impacts with project costs.

In summary, the general flow for socioeconomic analysis is as follows:

1. Choose an analytic approach.

2. Specify metrics.

3. Identify impact relationships.

4. Collect and condition data.

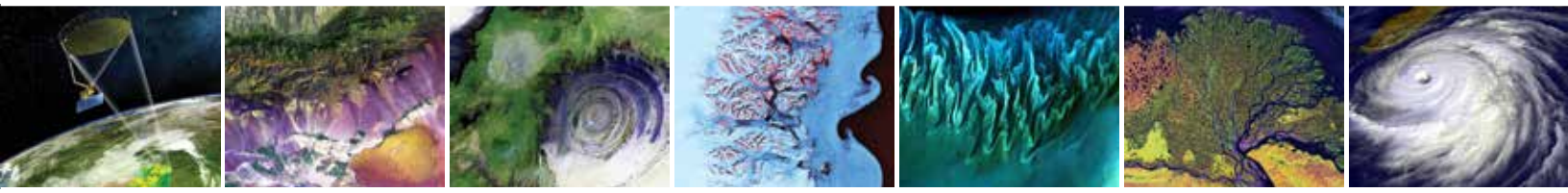
5. Estimate baselines.

6. Quantify impacts.

7. Monetize impacts (if appropriate).

8. Report results.

Each of these activities is described in more detail below.



3. Performing Socioeconomic Impact Analyses

3.1 Choose an Analytic Approach

Socioeconomic impact analyses of Earth observations projects are either **retrospective** or **prospective**. Retrospective analyses estimate impacts already realized, whereas prospective analyses estimate impacts to be realized in the future. Common approaches used within these two classes of studies are grouped conceptually into three categories: time-series and statistical methods, expert opinion (or counterfactual estimation) methods, and value of information methods. Hybrid combinations of these categories may be applied as well.

Time-series and statistical methods use historical information to establish trends in impact metrics and check for statistically significant changes in those trends after a project's completion. Analysts use physical and social science theory to specify a model relating the value of the metric in a given time period to the value in previous periods. The model may include explanatory variables for confounding factors. The model is then calibrated using historical data from time periods prior to project completion. The calibrated model provides baseline projections into time periods subsequent to program completion. Analysts perform mathematical tests to determine if the difference between baseline projections and actual, observed values is statistically significant.

Expert opinion methods, also referred to as **counterfactual estimation methods**,[2] use the professional judgment of subject matter experts to develop estimates of data not otherwise available. Analysts use these approaches to obtain estimates of impacts directly or obtain estimates of other missing data relevant to impact analysis, such as proxies and confounding variables. The estimates usually include some measure of the experts' uncertainty, such as high and low ranges for 50 percent or 90 percent confidence.

The **Delphi method** is an example of a commonly used expert opinion method. It is a structured approach to obtain consensus among multiple experts on the value of a metric. Each expert is asked for a best estimate of the metric value. Analysts then create a list of the estimates, without the associated sources' names, and redistribute the list to the experts. The experts are then asked for a best estimate a second time, taking into consideration the estimates provided by their colleagues. The process continues until a consensus value is reached.

Another commonly used expert opinion approach uses **logical decision models**. In this approach, theory and the literature take the place of the expert input. A quantitative model of the expected effect of decisions on the impact metrics is obtained from physical and economic theory, along

2. While the term "counterfactual estimation" is used to refer specifically to expert opinion methods, the common framework described in section 2.2 requires the comparison of a baseline case and an after-project case, only one of which can actually occur. In this sense, all of the approaches described have a "counterfactual" element to them. To avoid any confusion, in this document we will use the term "counterfactual" only when referring to expert opinion techniques and will use "baseline" to refer to a projection of historical data that ignores project impacts.

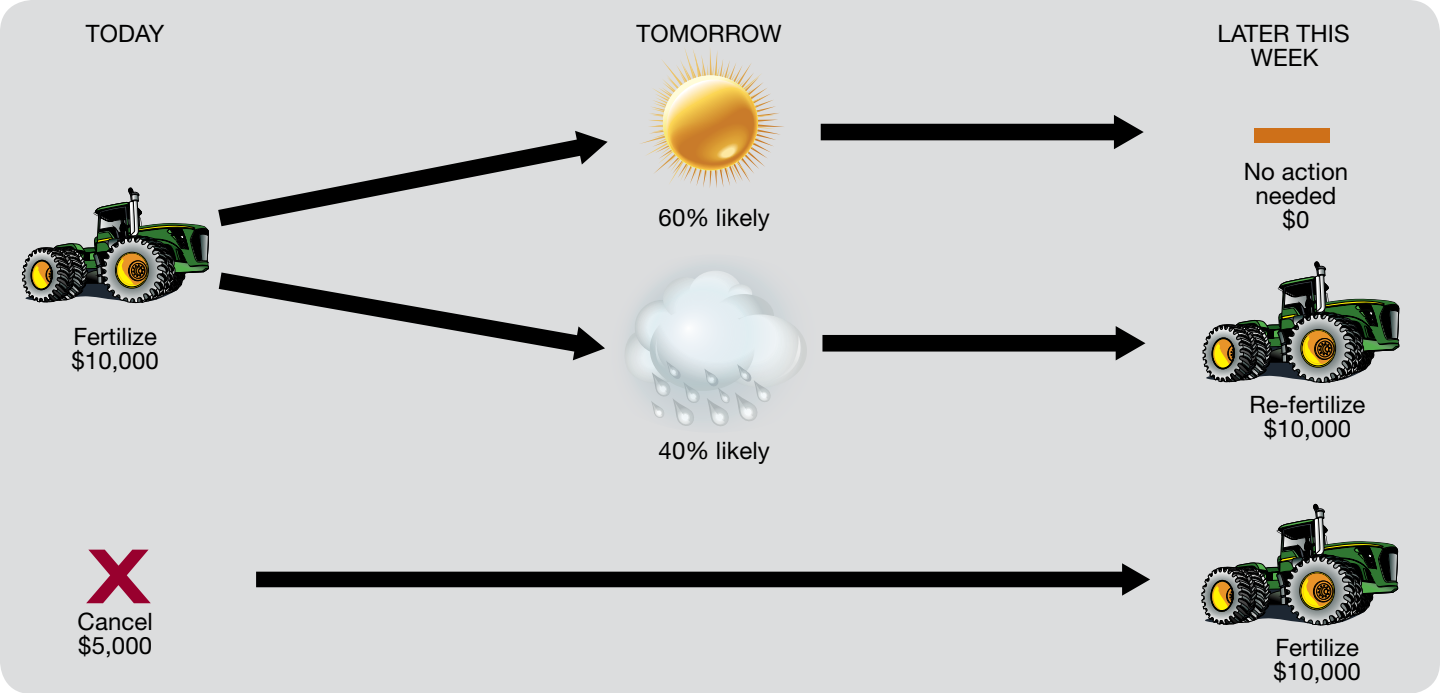


Figure 2. Farmer's Decision (without Earth Observations)

with model parameters from existing literature. Any missing parameters are obtained by Delphi or other direct elicitation methods. A decision-making model is then used to predict how a rational decision maker would react to the outputs of the project under analysis. These reactions are applied to the theoretical impact model to estimate impacts likely to be obtained through best use of the project's outputs.[3]

Earth observations projects almost always provide information as their primary output. If decision makers who are the primary users of the project's output are available to assist, then **value of information (VOI)** methods can be used. VOI methods, which are primarily prospective, measure how new information changes a decision maker's prior beliefs about uncertainties, and the value the decision maker would derive from the resulting change. (One could describe it is as a "with/without" analysis that explores the avoided cost or "but-for" loss-avoided estimates.)

Since VOI approaches are quite different from analytic methods typically used in physical sciences, a simplified numerical example of VOI for Earth observations data may be instructive. Consider a farmer, who wants to know whether to fertilize his field today or if he should to wait until later in the week (see figure 2).

Applying fertilizer on any day costs $10,000, and cancelling and rescheduling will result in a penalty of $5,000 from the fertilizing contractor. With the current information available, the farmer believes there is a 40-percent chance of rain tomorrow. If he fertilizes today and it rains tomorrow, the rain will wash away the fertilizer, forcing him to purchase a $10,000 repeat application. If he waits until later in the week, it will cost him $5,000 to reschedule the application, plus the $10,000 cost of the treatment. He believes that some Earth observations information, which he does not currently possess, will tell him for certain whether or not it will rain tomorrow.

3. In section 3.3, a "project logic model" is developed to assist in identifying impact relationships. The "logical decision models" described here are similar to, but distinct from, project logic models. A project logic model is primarily qualitative, describing the functional connections that flow from project initiation to final impacts; no numerical estimates are explicitly derived. In contrast, the logical decision model described here is quantitative; this allows the analyst to quantify impacts based on decision-maker inputs and to identify the optimal choice that a rational decision maker would take if given the project outputs.

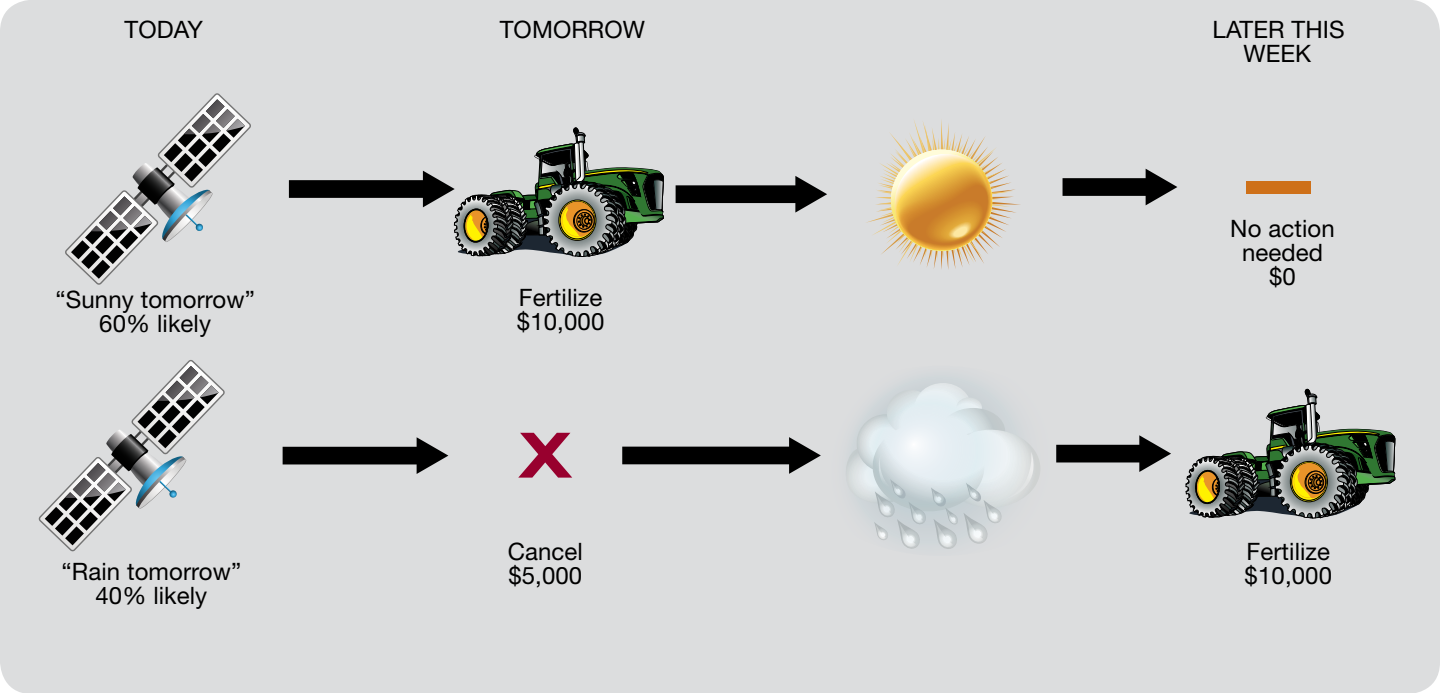


Figure 3. Farmer's Decision (with Earth Observations)

Under a common assumption about risk tolerance, a "risk-adjusted" cost for an uncertain set of outcomes is calculated by multiplying each potential outcome's cost by its probability of occurring. Using this approach, the farmer's risk-adjusted cost for choosing to fertilize today is [$10,000 + (60% × $0) + (40% × $10,000)] = $14,000, where the first term is the direct cost of fertilizing today and the other two terms are the risk-adjusted costs of subsequent actions: do nothing if it is sunny tomorrow, or refertilize if it rains tomorrow. His costs for choosing to reschedule and fertilize later in the week would be $5,000 + $10,000 = $15,000, where the first term is the cancellation penalty paid to the contractor and the second term is the direct cost of fertilizing later in the week. So, given his current state of information, the farmer will chose to fertilize today, at a risk-adjusted cost of $14,000.

The farmer then considers obtaining the Earth observations information (see figure 3).

If he does obtain the information and it indicates the weather will be sunny tomorrow, the farmer will fertilize today, at a cost of $10,000. If the data indicate the weather will be rainy tomorrow, the farmer will reschedule the fertilization, at a total cost of $15,000, including the penalty. Since he thinks it is 60 percent likely that the Earth observations will predict sunny weather and 40 percent likely that the observations will predict rain, his risk-adjusted cost for acting on the data is [(60% × $10,000) + (40% × $15,000)] = $12,000, which is lower than the $14,000 risk-adjusted cost that he would incur if he acted without the data. The farmer should be willing to pay for the data at any price up to the difference between his expected costs without and with the data. The difference, ($14,000 – $12,000) = $2,000, is therefore the farmer's **Expected Value of Perfect Information (EVPI)** on tomorrow's weather. A more detailed example of a VOI approach is given in appendix B.

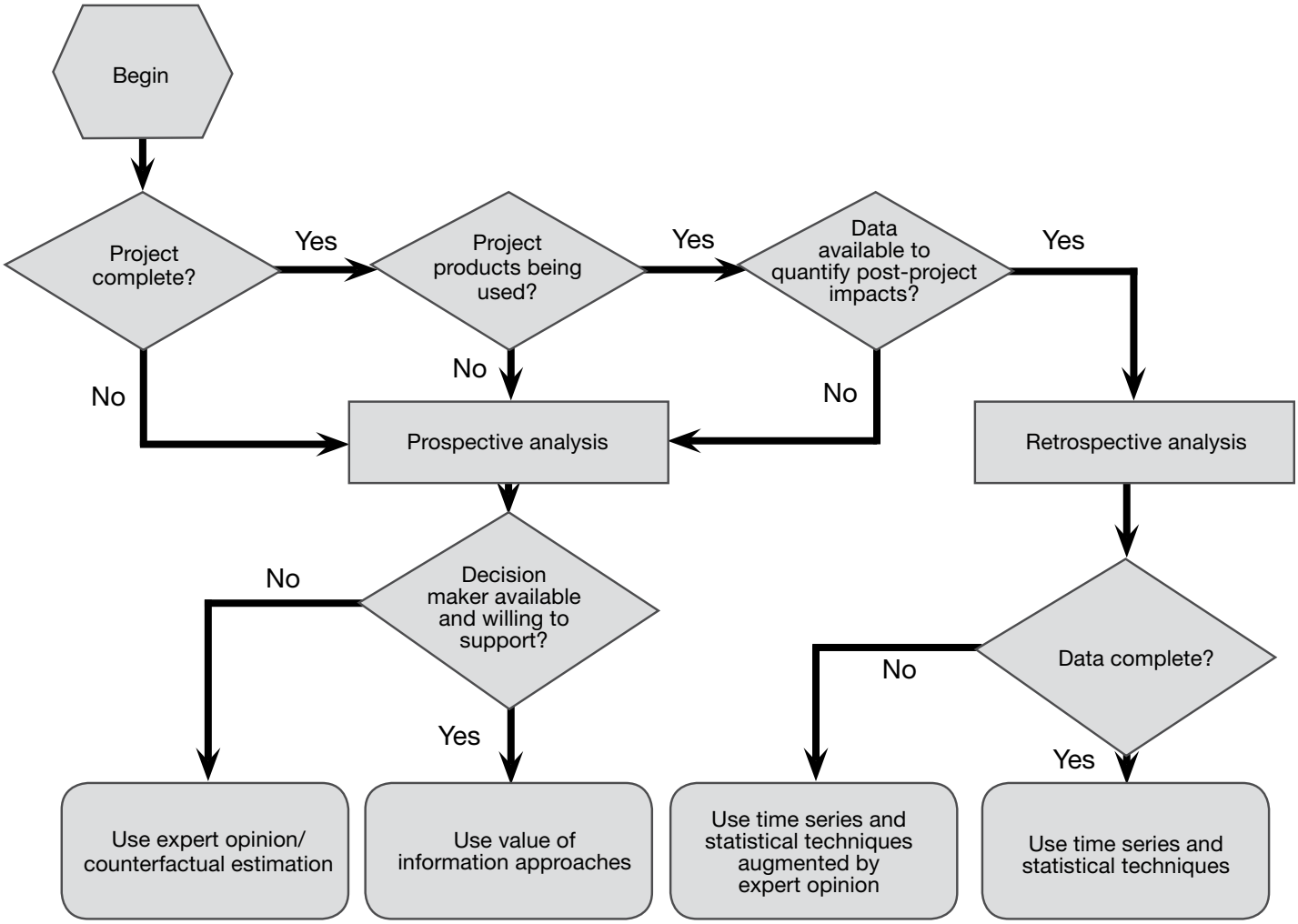


Figure 4. Flowchart for Choosing an Impact Assessment Approach

Figure 4 provides a high-level flowchart for choosing which category of approach—statistical, expert opinion, VOI, or some combination—might be appropriate for a particular problem.

If the project is complete, data products from the projects are used by decision makers, and initial inquiries suggest historical data are available to quantify project impacts, then the analysis will likely be retrospective. The choice of approach category will depend on the completeness of the data, including data on potentially confounding factors. For retrospective analyses, full datasets allow for rigorous objective analysis using time-series and statistical techniques. If, as is common, some data are missing or incomplete, analysts often use expert opinion/counterfactual information approaches to augment the statistical approach. For prospective analyses, the availability of the decision maker who will use the data enables analysts to use VOI approaches. In the absence of access to decision makers, prospective analyses usually revert to expert opinion approaches. Where available, theoretical models of impacts allow analysts to provide more structure to the problem and more precisely specify the questions asked of the experts.

3.2 Specify Metrics

A key step to estimating socioeconomic benefits is to establish concrete, measurable metrics to quantify the desired end-state impacts.

In specifying the relevant metrics, it is important to identify **final benefits** rather than intermediate means. For example, for a project to improve tracking of a disease vector, one might initially propose the desired impact to be improved tracking models. However, better models are not an end in themselves, but rather a means to enable improved vector-control policies and operations. Further, the operations are not an end in themselves, but a means to reduce disease morbidity and mortality. Reduced morbidity and mortality may be ends in themselves or may be means to another end, such as improved productivity and economic growth in a poverty-stricken region. The key is to identify the ultimate benefits to individuals, groups, or society rather than focus on intermediate means to achieve those benefits. A useful question to clarify this is, "If I could change this one quantity, and absolutely nothing else changed, would I achieve a desired result?"

Analysts should be expansive when thinking about the range of final benefits that might result from a project. Desired benefits can include economic, environmental, social, policy, or other desired outcomes.

3.3 Identify Impact Relationships

To link a project's impacts to the final benefits, analysts develop a clear **project logic model**. A project logic model depicts the functional connections from project initiation to the desired impacts. It is a series of relationships to illustrate what the project is expected to accomplish if implemented as designed. In its simplest form, a logic model is a representation that shows logical relationships between these factors:

- ***Baseline:*** The conditions that existed prior to the project
- ***Inputs:*** The resources that go into the project
- ***Outputs:*** The products provided directly from the project
- ***Outcomes:*** The changes directly enabled by or resulting from the outputs
- ***Impacts:*** The anticipated positive or negative benefits resulting from the outcomes
- ***Assumptions:*** The assumptions that underlie the model
- ***Confounding Factors:*** Other factors that might include or confound the outcomes

Figure 5 illustrates the project logic model that describes the theory of how the inputs (the project resources) lead to a series of positive outcomes. Analysts often develop the logic model as part of project planning and design. Using this method, analysts establish a series of hypotheses about what is expected to occur, which they test against observed data after the project is complete. In developing a project logic model, analysts should consider the process described below.

- ***Step 1—Identify the Baseline:*** Analysts characterize the existing baseline as it is relevant to the project and the expected impacts identified previously (described in section 3.2). This effort is a qualitative characterization; quantitatively developing a baseline forecast is a later step, described in section 3.5.

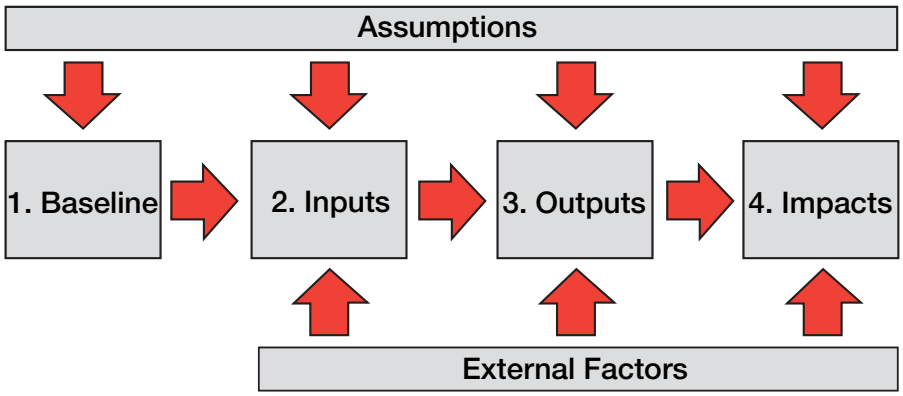


Figure 5. Basic Representation of a Project Logic Model

- ***Step 2—Identify the Resource Inputs:*** Analysts identify all the resource inputs that go into the project. These include the project costs and any other resources that are invested in the project (e.g., resources from partner organizations that are cooperating in the project).
- ***Step 3—Identify the Outputs:*** Analysts specify the products or other concrete outputs created or modified as a result of the project. In Earth observations projects, outputs could be the information products or application methods provided directly by the project.
- ***Step 4—Identify the Outcomes:*** Analysts identify the direct changes caused or enabled by the outputs. For example, the outcomes might be the improved decisions enabled by the use of Earth observations.
- ***Step 5—Identify the Impacts:*** Analysts describe how the project outcomes enable or contribute to impacts of interest, identified as described in section 3.2. Impacts could be the socioeconomic benefits associated with the improved decisions.

  For example, a team could develop a project that is intended to improve aviation weather forecasts, such that the parts of storms that are particularly dangerous for aircraft can be localized. The logic of the project is that the immediate project output (improved data on storms) will lead to outcomes (a reduction in flight delays and unnecessary deviations in airplane routes to avoid storms) that will lead to impacts of interest (less delay time for passengers, greater safety, and lower fuel costs for airlines).

- ***Step 6—Identify Key Assumptions and Review Confounding Factors:*** Analysts identify any key assumptions and review the confounding factors for completeness.

3.4 Collect and Condition Data

Once analysts identify final benefits in measurable, observable benefits metrics and complete the logic model, they identify and collect data to establish the baseline and project-related changes for each metric.

Often the relevant information will consist of time-series data. For example, in a disease-vector project, the baseline might be historical data on infections and deaths for a particular region of interest. Factors to consider when deciding what data to use include the following:

- Availability
- Cost
- Completeness
- Format and practicality of use for analysis

If data on the specific metrics are not practically available, analysts can identify related proxy metrics. In the disease-vector example, if infection rates are not available, then some other, correlated metric may be used, such as inpatient admissions for the disease or expenditures on treatments for disease-specific symptoms.

In determining data needs, analysts should identify factors, other than the project interventions, that could influence the final benefits metrics. These other "confounding factors" should be addressed and controlled for in the analysis so their effects can be isolated from those of the project. For example, in the disease-vector case, analysts might identify factors other than disease-vector tracking that would affect morbidity and mortality and seek

Stakeholder Involvement Is Key

Analysts should strive to keep end-user stakeholders involved and informed throughout the impact analysis process. Stakeholders can help identify and refine impacts, convert these impacts into metrics, and help identify data sources and any problems with those data sources. In addition, involving stakeholders can build support for the project, help disseminate results, and report impacts broadly.

out potential sources for historical data on these factors. Vaccination rates may be one of these confounding factors. If historical data on vaccination are available, analysts can use standard statistical techniques to isolate the effect of vaccination from both the historical baseline data and any post-project measurements.

Project teams may wish to consider ways to adjust their project design to make isolating the desired impacts easier to measure. These might include measures to more easily collect relevant data both before and after the project is complete. In some cases, data sources do not change during the course of the project; in the disease-vector example, the morbidity and mortality data source may be the same government agency or non-governmental organization (NGO) both before and after the project is complete. But in other cases, the experimental design can be adjusted slightly to gather the relevant data directly, rather than going through an intermediary. Judicious project design can help develop more rapid and reliable impact analyses for the project.

In summary, analysts identify relevant historical data to develop baselines, identify data that are expected to show changes from baseline projections due to project interventions, seek opportunities to isolate the impacts from other confounding factors, and consider experimental designs that facilitate collection of data during and after the project. Figure 6 illustrates aspects of data gathering.

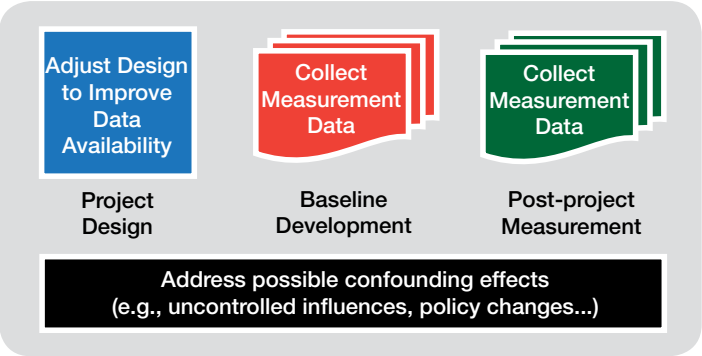


Figure 6. Data-Gathering Tasks

In conducting an analysis using socioeconomic data, analysts may encounter several common issues to mitigate:

- ***Series Breaks:*** Socioeconomic data often suffer from changes in the way data are defined, classified, or collected from one time period to another. These changes result in series breaks and are a byproduct of attempts to improve data. For example, if a Government statistical bureau adopts a more accurate method for calculating labor force, the new data are not necessarily comparable with the old. Analysts should be careful to avoid series breaks in data used for socioeconomic analyses and develop appropriate workarounds and adjustments if necessary.
- ***Detail/Accuracy Tradeoff:*** Socioeconomic data are often statistical estimates based on a population sample. Usually sampling, rather than a full count, is carried out to save time and money. Most providers of socioeconomic data supply confidence intervals for sample-based data series. Analysts should ensure they have properly addressed the uncertainty in the data used.
- ***Time Lags:*** A major challenge is obtaining timely socioeconomic data. The process of collecting, collating, analyzing, and disseminating socioeconomic data is time consuming. Data agencies often release national data as a first priority, with detailed subnational and regional data published later. As a result, analysts are likely to encounter considerable time lags in obtaining data for socioeconomic analyses. The timeliness problem is even greater with the publication of biophysical data (e.g., crop yields) and international data, which typically lags at least a year behind observations. Analysts should determine when data are likely to be available and schedule analyses accordingly.
- ***Revisions:*** Another challenge is the tension between timeliness and revisions in analyzing socioeconomic data. For some data series, government agencies produce rapid estimates of socioeconomic data. Using information gathered easily and quickly, such as partial information from a sample, agencies often generate an initial estimate in the shortest possible time. Later, as more

complete information becomes available, the agencies revise the earlier estimates. Analysts should be mindful of such revisions and modify their analysis, when appropriate, to use the most current data available.[4]

- ***Missing Values:*** Frequently, socioeconomic datasets can have missing values. For example, international data covering a range of countries are often incomplete due to differences in data collection, periodicity, and varying levels of detail between countries. There are various techniques to deal with such data gaps, including regression or time-series analysis, mean or median values, or the removal of specific years from analysis. However, some regions, countries, or areas may need to be excluded from analysis due to missing values. For example, in the case of a recent analysis of using Earth observations to reduce cases of malaria in sub-Saharan Africa, large data gaps forced a more narrow focus on just one country.

3.5 Estimate Baselines

After collecting sufficient data, analysts develop a baseline model for estimating the metrics of interest in the absence of the Earth observations project interventions.

In time-series analysis, this is done by developing a mathematical model for estimating the value as a function of past values and external factors. In our disease-vector example, the analysts may observe that current operations and policies produce a slow but steady decline in infection rates. For example, the data may suggest a linear decrease over time, with a functional form of

$$infections(t) = a - b(t - t_0),$$

or an exponential decrease, with form

$$infections(t) = a x^{b(t - t_0)}.$$

The analysts would then use historical data to find best estimates for the model parameters, in this case a and b.

In expert opinion and VOI analysis, analysts estimate baselines by querying experts or decision makers. Often the analysts have a theoretically defensible model of baseline trends, which they calibrate using expert or decision-maker input. If no defensible model exists, the analysts may ask experts or decision makers to provide estimated values directly.

3.6 Quantify Impacts

Quantifying project impacts can be challenging. If analysts follow the procedure described in section 3.2, they will have identified the impacts expected from the project. Analysts will attempt to measure and quantify the impacts using the approach chosen in section 3.1. In statistical approaches, the impacts may be relatively easy to derive from data or they may require complex modeling or statistical analysis. In some cases, analysts must use expert opinion methods, VOI approaches, or some combination.

4. Note that these revisions can also create problems when comparing baselines and forecasts; projections based on initial data releases might suggest very different results compared to a final, revised version of the data. See section 3.5.

For example, consider a project to improve water resources management through the use of remote sensing data to produce seasonal climate forecasts. The intended output is an improved hydrologic forecast system for water management decisions related to releasing water for irrigation. The final result could be increased or more stable crop yields. Thus, assuming the logic chain associated with the project is followed, there should be an increase or stabilization in crop yields in the region resulting from more effective use of the information made available because the project was completed successfully.

To measure the net impact, analysts compare baseline projections to actual or projected impacts after project completion. If statistical approaches are used, analysts should determine if differences are statistically significant. Continuing the example above, analysts would use time-series data from a number of years prior to the project to estimate the expected variation in crop yields as a baseline and use statistical methods to determine if the observed impacts following project completion are statistically significant.

A common issue with assessing project impacts is that of "agency"—how, or even if, decision makers actually use the information to make decisions that result in the desired impacts. Earth observations projects generally provide new or improved information to support decisions. Although the project may improve available information for decision makers, the target users ("agents") may not use the information effectively, such that some or all of the anticipated benefits are not achieved. Alternatively, the improved information may be used in a manner unanticipated by the project team, which may also result in unanticipated impacts. Analysts should verify whether and how the project output information is actually used after the project. The impact analysis report should include statements about whether or not the products were used and if they were used in a manner other than anticipated.

3.7 Monetize Impacts (if appropriate)

The impacts measured in the previous section may be expressed in a wide variety of units, such as deaths avoided, tons of maize grown, or hectares of wildfires avoided. To compare impacts between projects or against project costs, analysts often turn these physical impacts into a common unit, usually that of money. For example, the average annual price of maize and forestry products at a particular sales point is used to change bushels of maize and acres of avoided wildfire into an equivalent monetary impact.

Not all benefits can be converted into monetary terms. Thus, some "benefit outcomes" are tangible but not monetized. If only tangible benefits are available, the impact analysis team may report these benefits as a final result or may consider combining them with costs as part of a cost-effectiveness analysis.

There is a broad selection of methods available from the economics literature to convert tangible benefits into monetary costs. For example, the United States Department of Transportation (U.S. DOT) has established a standard value per minute of time lost waiting in traffic congestion. There are numerous ways to value human health impacts, such as costs of productive time lost, cost of healthcare, and avoided loss of future earnings. Analysts may consider one or more of the following approaches to quantify project impacts:

- ***Market Values:*** There may be a "market value" for the impact quantities under study. That is, people may have bought or sold items that are used to quantify impacts. For example, if the impacts are increased agricultural yields, the prices paid for the agricultural products in relevant markets (such as local retail purchases or international commodities markets) can be used to place a market value on the increased yields.
- ***Government or International Agency Standard Monetary Equivalents:*** Some governments and international agencies have established standard monetary values for impact quantities under analysis. The U.S. DOT cost per minute for traffic congestion is an example of this. As another example, some governments have developed a "value of a statistical life" to monetize mortality data.
- ***Industry and Non-Governmental Organization Standard Monetary Equivalents:*** Some industries and non-governmental organizations have established standard monetary values for the unit under analysis. For example, there are often industry wage rate and standard costs for common operations that can be used.
- ***Monetary Equivalence Estimates from the Literature:*** Socioeconomic impact analysis is a mature discipline. Previous analytic work has been done on many impacts of interest to develop reasonable conversion methods from physical to monetary terms. This work can be mined to develop simple conversion factors or methods. Some of these methods may include non-use approaches, which are discussed below. The adaption of existing studies to monetize similar, but not identical, benefits in new studies is known as **benefits transfer**.

Generally, market valuation methods are considered preferable to other monetization methods because they represent actual transactions involving real monetary allocations. If a relevant market value is not readily assessable, standard monetary equivalents are a next-best solution, with the choice between multiple sources based upon the analyst's judgment of the applicability and credibility of the source.

In the event no straightforward monetary valuation is available and monetized tangible outcomes are still desired, more complex non-use analytic methods may be used. There are many such methods, which are usually divided into two categories:

- ***Stated Preference:*** Using surveys, focus groups, and expert panels to estimate how much money individuals are willing to spend to obtain a desired impact or avoid an undesired impact. An analyst might ask a forest manager how much he would be willing to pay for data to decrease the average detection time of wildfires by 10 percent. This category is also referred to as **contingent valuation**.
- ***Revealed Preference:*** Analyzing observable actions or behaviors associated with people taking advantage of an impact. If a scientist flies to Chile to perform an experiment at a specialized observatory, his travel costs plus any user fees are a floor on his "revealed" valuation of the services provided by the observatory.

Stated preference methods generally make use of survey approaches, of which there is a large body of literature. **Conjoint analysis** is an example of a stated preference method used extensively in socioeconomic impact analysis. Survey participants choose between pairs or bundles of impacts, and numerical analysis is used to estimate the policy maker's valuation of previously non-monetized impacts. For example, a national policy maker may be asked to compare different combinations of

Gross Domestic Product (GDP) growth, early childhood education levels, and infant mortality. Through numerical analysis, the policy maker's valuation of the nonmarket impacts (education, mortality) may be imputed through comparison with the monetized GDP impact.

Revealed preference methods use behavior rather than discussion to estimate valuation. Examples of such methods include **travel cost analysis**, in which users of a good or service are characterized by the distance traveled to enjoy the good or service. The scientist flying to Chile, mentioned above, is an example of this method. In another commonly used method, **hedonic analysis**, impact characteristics are associated with a market good and regression techniques are used to assign prices to each characteristic. For example, a set of houses might be characterized in different markets based on local air quality, access to high-performing schools, recreation opportunities, and other nonmarket services, as well as more conventional factors such as square footage, number of bedrooms, and latest renovation date. Through regression analysis on home prices in these markets, consumer willingness to pay for each factor can be estimated.

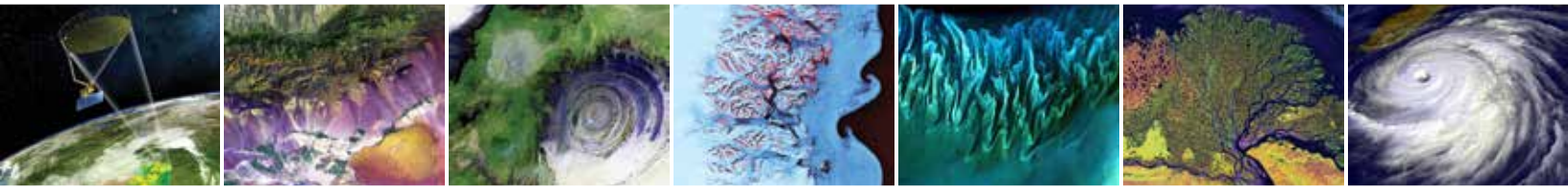
The choice of non-use valuation methodology is complex. Stated preference methods tend to be expensive because of the need for surveys, but they allow analysts to get monetized valuation for very specific impact metrics. There are also some theoretical concerns about the ability of respondents to honestly and accurately estimate their own willingness to pay if there is no actual transaction anticipated. Revealed preference models use objective data to estimate valuations, but they often depend on modeling assumptions about preferences that can be controversial, and they may require data that are difficult to obtain. Analysts for Earth observations project teams should consider discussing these alternatives with experienced social scientists before deciding upon a monetization approach.

If a project's or program's impacts are monetized, they can be compared with project or program costs to derive financial net benefit metrics. This comparison of monetized impacts to monetary costs is referred to as ***Cost-Benefit Analysis***, which is described in more detail in section 5.1 below.

3.8 Report Results

Socioeconomic impact analyses can be reported in a variety of formats. When presented as a stand-alone document, an impact analysis report usually includes the following subjects at a minimum:

- **Problem statement** of why the project was undertaken.
- **Desired impacts** of the project.
- **Literature review**, as appropriate.
- **Methodology description** including approach, metrics, logic model, data sources and cleansing requirements, baseline estimation method, impact estimation method, and monetization approach.
- **Results** including baseline estimates; post-project observations or estimates; estimated impact; statistical properties, uncertainty, and sensitivities in baseline and impact estimates.
- **Discussion of the significance of the findings** with respect to problem statement and explanation of unexpected findings.
- **Recommendations**, as appropriate.



4. Case Studies of Impact Analyses

This section provides two case studies on the use of techniques mentioned above to assess socio-economic benefits of Earth observations. One case study presents the use of Earth observations to support volcanic ash advisories in civil aviation, and one focuses on the use of Earth observations in early warnings of malaria outbreaks. This section offers some lessons learned from each case study.

4.1 Volcanic Ash Advisories and Aviation Safety

This case study describes an impact analysis for a project that applied Earth observations to support aviation volcanic ash advisories. The case study uses a specific event—the eruption of Iceland's Eyjafjallajökull volcano in 2010—to assess the impact of the observations in avoided costs and losses. In a retrospective analysis, this example uses a combination of time-series and VOI approaches. This case also presents a prospective extrapolation for a global estimate of average annual benefits to civil aviation.

Background

Large volcanic eruptions can eject ash to heights at which commercial aircraft normally cruise. At the speeds aircraft fly, the presence of volcanic ash can cause damage to engines, windscreens, and fuselages, making it necessary to reroute, delay, or cancel flights to protect the aircraft and passenger safety.

The international aviation warnings community uses information and warnings from nine Volcanic Ash Advisory Centers (VAACs) around the world on the location of volcanic ash clouds. Each VAAC has a geographic area of responsibility. Air traffic control authorities have the responsibility to decide when and where it is safe for a plane to fly, and information from the VAACs is used to determine areas where flying conditions may be hazardous. The aviation community uses the ash advisories to adjust flight routes and schedules to avoid potentially damaging encounters with the ash clouds.

The Aura satellite's Ozone Monitoring Instrument measures ash aerosols and sulfur dioxide, which serve as reliable markers for volcanic ash clouds. The Applied Sciences Program funded a project beginning in 2006 that worked with the National Oceanic and Atmospheric Administration (NOAA), the Federal Aviation Administration, and U.S. universities to apply and integrate Aura data into the two U.S.-based VAACs and enhance their warnings.

In 2010, Iceland's Eyjafjallajökull volcano erupted, sending volcanic ash into European airspace, which led to the cancellation of more than 100,000 flights. The London VAAC had not previously used Aura data, and the project team developed and delivered requested data products within days of the eruption to support the London VAAC's warnings. European officials used the Aura products to assess their models and predictions in determining which airspace to open. The eruption began on April 12; the airspace began to close April 15; and some flights resumed on April 19, which was the same day the London VAAC first used the Aura products.

Analytic Approach

The team conducting the impact analysis interviewed subject matter experts to understand the decision processes that the observations supported, uncertainties faced, and types of hazards to aircraft. The experts described how the observations could assist authorities in their scheduling and routing, and they described the types of associated benefits from better information.

The team chose a combined time-series and VOI approach to develop an estimate of how much the introduction of the Aura data would reduce the uncertainty about the level of ash threat. The team applied this risk reduction to the estimates of potential impacts in order to estimate the risk-adjusted value of the observations.

The analytic team identified two impact metrics: avoided revenue losses and avoided aircraft damages. The team's logic model held that better VAAC information and more reliable predictions on the location and movement of the volcanic ash clouds could result in better decision making by air traffic control authorities and airlines regarding the closure of airspace, the cancellation of flights, and route adjustments. The impacts of such measures would be (a) smaller revenue losses from more-targeted flight cancellations and (b) avoided or reduced aircraft damages from better route adjustments and ash cloud avoidance.[5]

In its analysis, the team considered the baseline case—what would have happened if the Aura data had not been available to the London VAAC, as before? Presumably, regulators could have either (a) delayed or reopened flight routes slowly because of continued uncertainties about the volcanic ash danger or (b) reopened flight routes more rapidly with greater risk of aircraft damage.

As described in detail below, the team collected data on flight cancellations and revenue losses due to the eruption of Eyjafjallajökull. The team gathered estimates on the costs of repairing or replacing aircraft systems damaged by interactions with volcanic ash. The team also collected data on the historical frequencies of aircraft damage from volcanic ash.

Overall, the team sought to calculate the portion of avoided revenue losses and aircraft damages that could be attributed to the use of the Earth observations in the decision making, based on the likelihood that an aircraft would have encountered the ash cloud.

Data Collection and Baseline Estimate

Probability of an Incident. As part of the analysis, the team collected historical data to estimate the probability of any given passenger aircraft's having a volcanic ash incident. The team used data from before and after the integration of Earth observations into the U.S. VAAC system in 2007 as a proxy.[6] The team gathered data for 1996–2010 on the number of significant passenger aircraft incidents involving volcanic ash, the number of significant volcanic eruptions with effluent reaching commercial flight levels, the number of passenger flight departures, and an eruption index (annual eruptions divided by average eruptions for the time period).

5. For this analysis, the team considered but decided not to include several other potential benefits metrics. For example, the team did not include avoided casualties and deaths from ash-induced plane crashes due to the infrequency of such events and sensitivities associated with monetizing the value of human lives and human health. The team did not address the social cost of time to the stranded passengers, assuming that this was somewhat accounted for in airline ticket revenue. The team did not include increased fuel cost for rerouting, assuming that this cost was marginal relative to other costs.

6. For purposes of clarity in this case study, this approach abstracts some detail and does not address other control measures since 2007.

The team generated an "incidences per flight" figure, representing the weighted probability of any given flight's experiencing a volcanic ash incident. The team analyzed the weighted probabilities of an incident before and after 2007, allowing for a full decade to be analyzed prior to the U.S. VAACs' using the Earth observations. These probability data were used to calculate an average weighted probability of an incident before 2007 (which represents the baseline case) and the average weighted probability of an incident after 2007 (which represents the case that includes the project impacts).

Overall, the team calculated that the differences between periods suggest that the use of the Earth observations reduces the probability of an aircraft's experiencing a volcanic ash incident by approximately 12 percent.

Revenue Loss. The analytic team collected information from the International Air Transport Association (IATA) on the reduction of flights and estimated loss in revenue. The team used daily figures for the period of April 15–21, 2010, spanning a time around the introduction of the Earth observations. The IATA data indicated that, on the day of greatest impact (April 18), approximately 80 percent of European flights were canceled, resulting in approximately $450 million in lost revenue. Cancellations and losses began to decline on April 19, and flight operations were gradually restored on April 20–21.

Based on these figures, the team assumed that the maximum potential revenue loss in the absence of the Earth observations was approximately $450 million per day. In other words, $450 million was the maximum possible daily revenue loss that could have been avoided if decision makers had had perfect information about the location of dangerous volcanic ash clouds in April 2010.

Avoided Damages. The analytic team collected information on the incidents of aircraft encountering ash clouds and the types of damage caused to the aircraft, such as damaged engines. The team gathered data on the range of cost to repair or replace engines and systems typically affected by aircraft ash cloud incidents.

Thick ash poured from Iceland's Eyjafjallajökull volcano when NASA's Aqua satellite acquired this natural-color image on April 17, 2010. The ash in this image is at two different altitudes—a concentrated plume rises over a more diffuse cloud of ash. The Icelandic Meteorological Office estimated that the volcano had been emitting ash in puffs that reached between 16,000 and 24,000 feet. Credit: NASA Earth Observatory

The team used data from Boeing, a major aircraft manufacturer, that indicated that repairing an engine with foreign-object damage can cost up to $1.6 million per engine and that replacing an engine can cost up to $10 million. A second source indicated that engine replacement ranged from $3 million to $8 million (in 1998 dollars) and engine repair (from foreign-object damage) ranged from $250,000 to $500,000. (Note: The team did not consider related, indirect costs such as an increase in insurance premiums, litigation judgments, or potential fines imposed by air regulators.)

Quantification of Impacts

Eyjafjallajökull Event. The analytic team evaluated two different baseline cases of regulator behavior: one if regulators had reopened airspace more rapidly and one if regulators had reopened airspace more slowly. Both cases used the 12-percent reduction in an incident to estimate overall avoided losses in revenue and damages and, thus, the socioeconomic impacts of the Earth observations.

If aviation regulators had reopened more rapidly, the team assumed that some aircraft that flew on or after April 19 would have flown into areas that the NASA observations would have identified as high-risk. The team estimated that, if the flights occurred on April 19, two engines would have required repair at $500,000 each. In addition, the team estimated that regulators would have become more risk-averse in the wake of the incidents, leading to a revenue loss on April 20 and 21 from retightened controls. In this case, the NASA observations would represent an avoidance of $1 million in damages and $24 million in lost revenue from unnecessary delays, for a total of $25 million.

If regulators had been uncertain on conditions (without the Earth observations information) and reopened more slowly than was possible, some flights would have been canceled unnecessarily. There would have been greater revenue loss on those days. Thus, the team assumed that 12 percent more flights were likely to be canceled each day on April 19 and later—or, more precisely, that 12 percent additional revenue was lost each day. Based on the IATA data, this loss yields impacts of $48 million on April 19 and $24 million on April 20, for a total of $72 million.[7]

The analytic team also estimated the potential savings if the Earth observations had been used from the beginning of the eruption. The potential savings in this case would include the 12-percent savings to the revenue losses that could have been realized for April 15–18 if the NASA observations had been used. The team estimated that this potential savings was an additional $132 million in avoided revenue losses.

Annual Expected Value. The analytic team extrapolated the risk-adjusted results globally to estimate the typical potential annual impact from the use of Earth observations by the VAACs. The team again used avoided damage repair costs and avoided revenue losses to estimate the annual socioeconomic impacts. The team used or collected data to support the assumptions and construct the scenarios in this analysis of expected value.

For avoided damage repair costs, the team used the weighted probability of a damaging ash encounter with and without the Earth observations. The team used the number of flights in 2010 and a lower bound for engine repairs, and it assumed that two engines would require repairs. In this scenario, the team multiplied the factors, and the difference showed an annual expected savings of $150,000 in avoided aircraft damages.

For avoided revenue losses, the team collected data on the typical length of an eruption (10 days or fewer) and constructed a conservative scenario. Based on one small event (approximately 1/10th

7. IATA documents did not show losses for April 21 but were probably compensated for by additional flights on April 22 to remove backlog.

as disruptive as Eyjafjallajökull) occurring every other year, the team estimated $10 million in avoided revenue losses.

Combined, these figures suggest that the costs avoided through the use of the Earth observations are on the order of $10 million annually. This estimate should be interpreted as an "expected value" of cost avoided, in the statistical sense. The expected value can be interpreted as the long-run average (rather than the actual avoided costs in any given year).

Results

Overall, the team estimated that use of the data following the Eyjafjallajökull eruption saved $24 million to $72 million in avoided revenue losses due to unnecessary delays and avoided aircraft damage costs. If the data had been used from the beginning of the eruption, the total potential impact in avoided losses and costs could have been around $200 million.

Lessons Learned

This case study offers several lessons learned for this type of impact analysis, including the following:

1. ***The number of potential impacts of a project may be large and may require prioritization for analysis.*** There were many different potential impacts for this project, including multiple benefits in terms of time and safety to both the traveling public and the airline operators. A full, comprehensive socioeconomic impact analysis would quantify each separately and add them together. Otherwise, if resources for the analysis are limited, analysts may be required to assess and prioritize the impacts so those that are most likely to be greatest in magnitude are addressed first. Additional analyses can be done in priority order until the resources are exhausted. In this case, the sum of the benefits analyzed would be a floor for the total benefits.

2. ***Historical data alone may not be sufficient to develop a single baseline case; it may be necessary and appropriate to examine multiple baselines.*** The historical record on volcanic ash events and the European regulators' past actions was somewhat limited. As such, the analytic team was constrained in making a strong supposition about how the regulators would have behaved in the absence of the Earth observations data—whether they would have reopened the airspace more quickly or more slowly. Thus, the analysis considered two different baseline cases, and it estimated the benefits in each case.

3. ***Impacts that accrue during infrequent events may be more difficult to estimate statistically than impacts that occur broadly in time.*** Time-series retroactive analyses typically require data series of reasonable lengths to generate baselines and make statistical inferences. Because of the relatively small number of major volcanic eruptions that influence air flight operations, the analytic team had to use several assumptions and proxies in the Eyjafjallajökull case to get sufficient information to complete the analysis.

4. ***Impacts during specific, infrequent events may not necessarily be representative of the steady state; impact analyses should consider the frequency of the event in conveying impacts appropriately to the audience.*** Events with the magnitude of Eyjafjallajökull are not common occurrences, yet they tend to occur at least every decade. Smaller eruptions and disruptions occur more frequently. For event-driven analyses, the impact assessment report should be upfront about the frequency of such events so that the audience is not misled. Where possible, the impact assessment should analyze and articulate the expected value for an annual basis (or appropriate timeframe) to indicate how representative the event's impacts are of the more routine, steady-state condition.

4.2 Malaria Early Warning System Improvements

This case study describes an impact analysis of a project that applied Earth observations to support early warnings of malaria outbreak conditions. This example illustrates the use of a retrospective analysis approach based on time-series and statistical techniques for projection of the baseline. This case study also shows the use of expert opinion as a supplemental approach, and it presents the extrapolation of results from one country to a broader region. Malaria infects hundreds of millions of people every year and claims countless lives. Malaria is most widespread in Africa, where an estimated 90 percent of all human cases occur. In areas where malaria is endemic, health officials may have limited resources to direct preventative measures and protect vulnerable populations. Data from Earth-observing satellites have shown to provide information on environmental conditions associated with outbreaks of some infectious diseases, such as malaria.

The NASA Applied Sciences Program funded a project with USAID and the U.S. Geological Survey (USGS) on a prototype Malaria Early Warning System (MEWS) to provide precipitation estimates and other information to help malaria control planners assess candidate areas for malarial outbreaks and target the allocation of resources for prevention. The project used satellite observations to obtain data over broad geographic areas of sub-Saharan Africa across remote or sparsely populated regions with limited ground-based measurements.

The project applied Tropical Rainfall Measuring Mission (TRMM), Aqua, Landsat, and other observations into models of mosquito activity and developed estimates of malaria transmission efficiency and predictive capabilities. It applied satellite-based rainfall, temperature, vegetation cover, and other environmental data to identify specific regions where outbreaks were likely to occur. MEWS began using the data in 2007.

Analytic Approach

The team conducting the impact analysis investigated the availability of data and interviewed people involved with the project to understand the decision processes and types of impacts. The team identified that relevant historical data and post-project data were available. Consequently, the team chose a retrospective analysis approach based on time-series and a statistical projection of the baseline as its main method to assess the impacts from MEWS use of Earth observations.

The analytic team considered a number of impact metrics and focused on two: Reported cases of malaria infections and reported deaths due to malaria, each per 1,000 residents.[8] The analysts' logic model held that better environmental data could result in better decision making to initiate preventative actions and distribution of prophylactic measures such as spraying treatments and mosquito nets. The impacts of such steps and improved resource allocation decisions would be reduced infections and deaths. The desired geographic extent was all of sub-Saharan Africa.

In the analytic approach, the team considered the baseline case—what would have been the malaria data for 2008 and 2009 (the years after project completion) without the project's introduction of Earth observations data in MEWS? The next section describes the team's projection of the baseline.

The team recognized the statistical limitations in isolating the specific effects of the project from only 2 years of post-project implementation data. The team also identified limitations in discerning the significance of potentially small impacts given the high variance of historical malaria rate data. Given these limitations, the team chose to supplement its comparative, time-series statistical

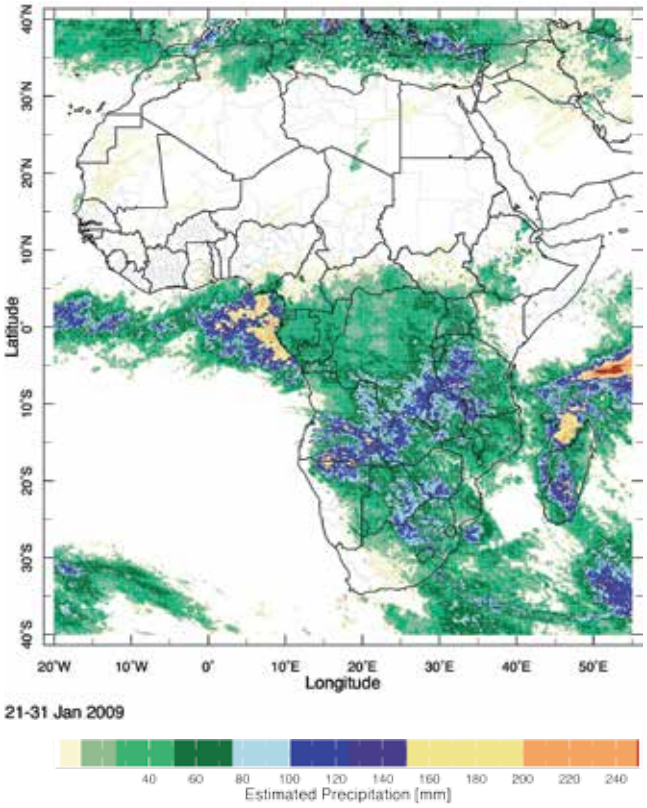
8. The team considered the use of per capita spending on malaria reduction programs as a cost-effectiveness metric; however, the available data were insufficient and inconsistent.

approach with expert opinion analysis. They elicited estimates from subject matter experts on the fraction of the observed reductions after 2007 that might reasonably be attributable to the NASA project.

Overall, the two analytic approaches sought to estimate the reduction in malaria cases and deaths from malaria control measures attributable to the project and the use of Earth observations in MEWS.

Data Collection and Baseline

Malaria Data. The analysts reviewed data on malaria in sub-Saharan Africa and identified those countries for which data were available. The analysts determined that Botswana was the only country where both (a) reliable data were available and (b) the outputs of the project were known to have been used. Botswana had relatively good data collection, and there were fewer confounding factors present (e.g., sudden land use changes, large migration of people, breakdown in law and order) than in other areas under consideration. Botswana had also been successful in reducing malarial infections. While the team recognized that Botswana's success could impede the ability to detect additional control benefits, the team selected Botswana as the area to analyze given the other factors and availability of data.



Rainfall is largely responsible for creating the conditions that allow sufficient surface water for mosquito breeding sites, and it is recognized as one of the major factors influencing malaria transmission in sub-Saharan Africa. This map, as part of a Malaria Early Warning System, provides 10-day estimated precipitation amounts to enable the identification of areas with unusually high rainfall as candidates for malaria outbreaks. The information helps malaria control planners and health officials to allocate staff and resources to areas at high risk for an outbreak. This map shows the period of January 21–31, 2009. Credit: International Research Institute

The team obtained data from the 2010 World Malaria Report of the World Health Organization (WHO). The analysts used data on malaria rates (cases and deaths) per 1,000 people for Botswana from 1997 to 2009; the team selected 1997 as the initial year since it was the earliest date for which comprehensive data were available.

Baseline Estimation. The analysts developed a baseline from the WHO data using time-series analysis. The WHO data for the pre-project phase period showed that the two metrics decreased by an approximately constant percentage each year. Based on this trend, the team used an exponential curve as a model for the baseline, and it extended the curve to project baseline estimates for the years after project completion. In other words, the team developed exponential best-fit curves using the data from 1997 to 2007 and projected the exponential trend line out to 2009.

Expert Opinion. For the expert opinion analysis, the analytic team contacted experts familiar with the project and its outcomes. The experts received data on the observed changes between 2007 and 2009, and the analytic team conducted interviews with them on both a one-to-one and group basis. The experts provided estimates of the percentage of the reductions in malaria-related morbidity and mortality in Botswana that might reasonably be attributable to the project. Using a Delphi-like approach, the experts reached a consensus estimate that as much as 10 percent of the total impact could be attributed to the NASA project.

Quantification of Impacts

Analysts compared the baseline projections with actual data to identify the net change. The team found that there were insufficient post-project data to disaggregate the project's effect from confounding factors. The results of the analysis were ambiguous. An initial analysis led to an impact estimate of an approximately 2.5-percent annual decrease in malaria case rates as a result of the project and an approximately 5-percent annual decrease in deaths from malaria. However, these estimates did not meet statistical significance standards and were therefore considered evocative but unproven.

The team also used the expert opinion methodology to estimate the maximum value of the impact of the NASA Earth observations. The team multiplied the actual decrease in the number of cases and deaths between 2007 and 2009 by the 10 percent maximum fraction assessed by the experts. There were 2,105 fewer confirmed or probable cases of malaria in 2009 than in 2007, leading to an estimate of the maximum impact of the project of about 211 fewer cases in Botswana over the interval, or about 105 per year. There was no net change in malaria-related deaths between 2007 and 2009, so the project's impact estimate on malaria-related deaths was zero. The analytic team chose not to monetize deaths avoided and cases of malaria, due to sensitivities associated with placing a value on a human life or human health.

In this analysis, the team sought to estimate to the first order the potential impact of the use of Earth observations in MEWS for the broader sub-Saharan region. The analytic team applied the two approaches to assess the impact for 28 sub-Saharan African countries for which population and malaria case data were available for 2005–08 in the WHO World Malaria Report. The team did not find consistent data on malaria deaths for these countries, so the analysis focused only on malaria cases of infections.

Using the comparative time-series approach, the team created a model for the baseline case, though the limited years of data posed challenges. In the absence of more-complete data, the team pursued this approach to obtain an order-of-magnitude result for comparison to the expert opinion approach. The forecast number of cases for 2008 was approximately 59 million, and the observed number was 52 million, suggesting a reduction of 7 million cases.

Using the 10-percent attribution factor on annual decreases from the Botswana analysis, the expert opinion approach provided an estimated impact of approximately 660,000 fewer cases. This result was an order of magnitude smaller than the estimate from the time-series approach. While these project impact estimates are not consistent for the greater sub-Saharan region, they do suggest that the magnitude of the potential impact over the region would be about a half million or more avoided cases of malaria per year.

Results

Two analytic methods were used to estimate the impact of integrating Earth observations into MEWS for malaria control in sub-Saharan Africa. One approach, using a retrospective time-series comparison, was unable to identify statistically significant evidence of impacts on malaria cases or deaths in Botswana attributable to the NASA project in the 2 years following its implementation. Botswana's efforts to control malaria reduced the country's infection and death rates to low levels, and the incremental impact of the Earth observations was not distinguishable from variation in the predicted morbidity and mortality rates based on the available data. There were too many confounding factors to distinguish the impact from all of the other factors involved in the malaria control activities, especially from a purely retrospective analysis.

The second approach, employing expert opinion analysis, suggested an estimated average of approximately 105 cases per year avoided in Botswana as a result of the NASA project. Applying the two methodologies to data for 28 sub-Saharan countries provided broadly differing estimates of about 7 million to 660,000 potential case reductions due to the project. Combined, these approaches suggested that the impact would be on the order of a half million or more avoided cases per year.

Lessons Learned

While the results of this analysis were ambiguous and the data did not support strong findings, this case study provides valuable lessons in understanding the processes and types of data involved in impact analyses. Notably, it demonstrates some difficulties in performing impact analyses, especially post-project retrospective ones. This case study highlights the need to prepare a data collection plan and gather appropriate data from the outset of a project, if possible, to support a project impact analysis.

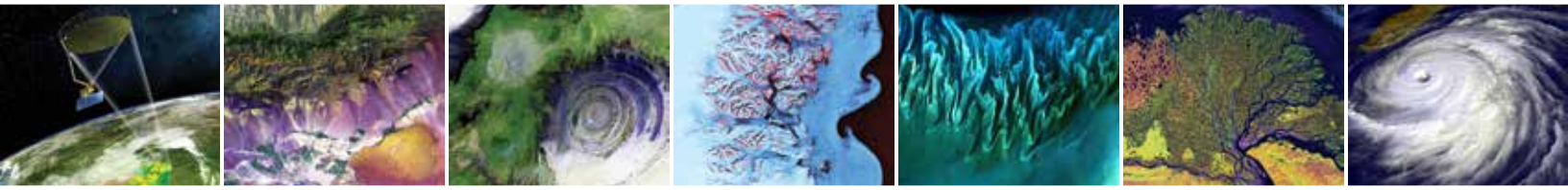
1. ***Expert opinion and VOI approaches may be more appropriate than a baseline-comparison approach for analyzing recently completed projects.*** Impacts of some projects introducing Earth observations into decision making may be sustained and long-term, so baseline-comparison approaches may not be feasible in the first few years after project completion. In this MEWS project, only 2 years of post-project data were available, and they were insufficient to verify statistical significance of changes in metrics.

2. ***Distinguishing the impacts of project-related enhancements from other inputs on a decision or from actions taken may require significant data.*** Earth observations data products may well be just one part of a broader set of inputs to a decision-making activity or process. A project applying Earth observations should understand the decision-making activity in detail and design a thorough data collection plan to gather information specific to the decision-making activity and impact metrics.

   In this analysis, Botswana was chosen, in part because the country was known to use MEWS. However, it is also a country where malaria is relatively well-mitigated through various control measures. Thus, there were many confounding factors that made differentiating the impacts of the Earth observations data in MEWS from other elements in Botswana decision making and malaria controls difficult. In this case, there were insufficient data available in retrospect. Large sample sizes or a specially designed data collection plan from the project's outset might have provided enough data to distinguish impacts.

3. ***Analysis can estimate the potential impact from the use of Earth observations in a decision, yet the realized impacts rely on the ability and willingness of decision makers to use the observations data.*** This is the "agent" problem discussed in section 3.6 above. Nations other than Botswana were considered for analysis, but experts suggested that many did not have the organizational or political means to apply the improved environmental data made available by the NASA project.

   As mentioned above, a project applying Earth observations should understand the decision-making activity in detail, in part to understand the potential sustained use of the observations and the likely realized impact.



5. Cost-Benefit Analysis and Cost-Effectiveness Analysis

Socioeconomic impact analysis, as described in the previous sections, focuses on quantifying the impacts attributable to the physical outcomes of a project. These impacts include both positive and negative benefits. While there is some inconsistency in terminology, the costs required to execute the project and maintain the outcomes are not usually considered part of a standard impact analysis. When they are considered, a method by which they are combined or compared with the output-driven impacts must be chosen. If the impacts are monetized, they can be combined with costs into one of several net metrics through Cost-Benefit Analysis. If impacts are not monetized, they can still be compared with costs required to achieve them through Cost-Effectiveness Analysis.

5.1 Cost-Benefit Analysis

In **Cost-Benefit Analysis (CBA)**, the monetized impacts and costs of a decision are systematically identified, accounted for, and compared. Here, "benefits" is synonymous with "impacts." While there is some flexibility in terminology, for this discussion the negative outcome-driven impacts will be included in "benefits" and costs will only include resources required to complete the project and maintain outcome-related products. Costs and benefits are described in more detail in section 6.1.

The basic idea underlying CBA is that if total monetized benefits of a project exceed total costs, the project provides positive net benefits:

$$Benefits - Costs = Net\ Benefits$$

Since the costs and benefits of a project may accrue at different rates, the cost-benefit equation must be modified to account for "discounting": the preference most decision makers have for receiving money now rather than later. Discounting is typically modeled using a discount factor r; in this model, a decision maker is equally happy receiving (a) an amount of money M immediately or (b) $M \times (1 + r)$ one time period from now. A decision maker's discount rate is usually assumed to be constant over time.

The discounting concept can be extended to derive a value, the NPV for any time series p of positive or negative payments, which a decision maker would accept immediately in exchange for rights to the time series of payments. Some important discounted quantities used in CBA (and BCA) are shown in table 2 on the following page.

Table 2: Discounted Quantities Used in Cost-Benefit Analysis

CBA/BCA Measure	Definition
Net Present Value (NPV)	The sum of a series of payments over time, expressed in terms of a single equivalent payment received today. Mathematically, it is expressed as $NPV(p) = \sum_{t=0}^{\infty} \frac{Pt}{(1+r)^t}$, where p is a series of payments over time, t is a time period index, p_t is the payment for time period t, and r is a discount rate describing a preference for money today compared with money at a later date.
Present Value of Benefits (PVB)	The discounted sum, or Present Value (PV), of a stream of benefits associated with a project or program.
Present Value of Costs (PVC)	The discounted sum, or PV, of a stream of costs associated with a project or program.
Net Benefits (or Project NPV)	The difference between PVB and PVC. If the difference is greater than zero, then the benefits are greater than the costs.
Internal Rate of Return (IRR)	Discount rate that yields net benefits of zero.
Benefit-Cost Ratio (BCR)	The ratio of PVB to PVC (i.e., PVB/PVC). If the ratio is greater than 1, then benefits are greater than costs.
Net Benefit Investment Ratio (NBIR)	Similar to BCR, but only project costs are included in PVC; operating costs are excluded.
Discounted Payback (DPB)	Time period at which the discounted benefits to date equal the discounted costs.

There are multiple ways of expressing the results of a CBA, including net benefits (or project NPV), Internal Rate of Return, Benefit-Cost Ratio, Net Benefit Investment Ratio, and Discounted Payback. Each may be used to determine if a project's benefits exceed its costs; some are also used to compare and rank different projects, depending upon whether there is a budget constraint or not and whether projects are mutually exclusive.

Net benefits are calculated from the NPV of benefits (Present Value of Benefits, or PVB) and the NPV of costs (Present Value of Costs, or PVC). A project's net benefits equal the difference between PVB and PVC. If the net benefits of a project are positive, then the project is a reasonable investment, in the sense that the discounted benefits it provides exceed its discounted costs. If the net benefits are negative, then the project's monetized benefits do not justify its costs. The sign (positive or negative) of the net benefits serves as a first screen for deciding whether or not to fund a project. If there is no budget constraint, net benefits can serve as a ranking rule among multiple projects, identifying the projects that will generate the greatest discounted benefits. If the ranked projects are each within the budget but are mutually exclusive, then the project with the highest net benefits should be chosen.

Internal Rate of Return (IRR) is the discount rate r at which net benefits equal zero. If a project's IRR is greater than the interest rate charged for loans, then a project can be considered worth performing since the benefits generated exceed funding costs if financing is required. When considering an individual project, IRR gives identical results to the net benefits ranking. However, when mutually exclusive projects are compared, the net benefits ranking provides better results than rankings by IRR, as the IRR does not consider scale.

Net benefits are expressed as an amount of money. When comparing two projects under budget constraints, one might wish to understand the return on the initial investment in costs. For example, if one project has a net present benefit of 1,000 euros and the second a net present benefit of 750 euros, one might think the first project is preferable over the second. However, if the discounted costs for the first project are 10,000 euros and the discounted costs for the second are 5,000 euros, then one might reconsider. The first project gives a return of 10 percent on investment (1,000/10,000), whereas the second project returns 15 percent on investment (750/5,000). The second project returns more benefit per euro invested: its **Benefit-Cost Ratio (BCR)**, defined as PVB/PVC, is higher than that of the first project.

BCRs are not generally used to compare projects of widely differing size. For example, a BCR of 15 percent might be impressive for a major capital project, but it might not justify the trouble of buying a new personal computer. BCRs can also give suboptimal rankings in certain conditions. The use of **Net Benefit Investment Ratio (NBIR)** corrects this problem. NBIR is similar to BCR, but operating costs after completion of the project are not included in the PVC calculation. If multiple nonexclusive projects are being considered under budget constraints and projects can be partially funded, then NBIR can be used to rank the projects effectively.

Discounted Payback (DPB) is another way to compare the costs and benefits of a project. DPB is the amount of time (days, months, years) after the beginning of a project at which the discounted benefits equal project costs. Because DPB does not take into account benefits realized after the break-even date, it is generally not as effective a ranking criterion as others, such as net benefits or NBIR.

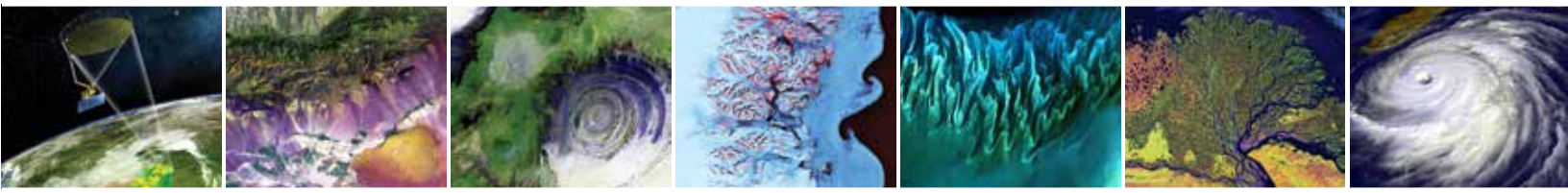
This section provided an introduction to some of the cost-benefit metrics in common use, but it is not exhaustive. For example, there is a range of approaches to deal with projects of differing lengths of benefits streams and other, similar refinements. Interested readers can consult the references cited in appendix A for more information.

5.2 Cost-Effectiveness Analysis

Not all impacts can be monetized, so not all impact analyses can be used to create CBAs. However, the costs of achieving measurable, non-monetized impacts can be calculated in a procedure called Cost-Effectiveness Analysis (CEA). CEA is typically used to compare costs and impacts of two or more alternative projects. In CEA, analysts estimate the quantity of an impact given a particular input cost. For example, in the area of health effects, analysts may choose not to assign a monetary value to a positive health outcome (e.g., reduction in malaria cases). Thus CBA may be inappropriate. Instead, analysts may use CEA, comparing the reductions in malaria cases from alternative projects and calculating the cost per case reduction for each alternative. This was demonstrated in the example given in section 4, in which the costs per malaria case avoided due to the MEWS improvement were calculated. If budgets were limited, this metric could be used to compare the MEWS project against other malaria mitigation approaches to choose the most cost-effective approach.

In summary:

- CBA is an extension of socioeconomic impact analysis in which the costs and benefits of a decision are systematically identified and accounted for and compared to each other.
- CBA is based on a simple formula, but challenges lie in identifying, quantifying, and monetizing benefits.
- There are numerous ways to express the outcome of CBA; they are all roughly equivalent for evaluating individual projects but have different strengths and weaknesses when used to compare projects.
- CEA is a method for comparing the outputs of a decision given a particular resource input. It is particularly useful to compare projects with similar objectives when benefits are difficult to monetize.



6. Additional Terms, Concepts, and Approaches

The previous sections provide an overview, detailed methodology, and examples of socioeconomic impact analysis; background to help analysts and physical scientists design their projects to facilitate impact analyses; and a discussion of the CBA and CEA extensions to impact analysis. The current section reviews and defines some key terms from section 2.1 in greater depth, provides descriptions of additional concepts often encountered in discussing impact analysis, and provides some theoretical background on socioeconomic impact analysis. This section can be considered optional, enriching reading.

6.1 Scarcity, Decisions, Opportunity Costs, and Tradeoffs

When describing socioeconomic impact analysis, social scientists may refer to concepts of *scarcity, decisions, tradeoffs,* and *opportunity costs*. These terms have specific meanings in a social science context.

Traditionally, economics start with the presumption that human desires are unlimited but that resources to meet these desires are limited. Under this presumption, it is impossible to have everything we want. There will always be **scarcity** since there cannot be sufficient resources to satisfy every individual preference. Even if we could produce every material individuals want, there would still be scarcity because some goods cannot be reproduced or shared, such as the experience of being alone on a particular stretch of beach at a particular time, or possession of a unique piece of art or ancient artifact. Because of this inherent scarcity of resources, human beings must make **decisions**[9] among alternatives of how to allocate available resources. A decision can be defined as "an allocation of resources that cannot be costlessly reversed."

In making decisions, humans are assumed to attempt to obtain the maximum benefit for a given amount of resources. In selecting one alternative over another, decision makers forgo the benefit they would have received from selecting other alternatives and eliminate the opportunity to benefit from those allocations in the future. Thus, one negative implication of any decision is the forgone opportunity to make other competing choices.

9. In some economic literature, "decisions" as defined here are referred to as "choices."

The negative implication is referred to as an **opportunity cost**. The opportunity cost of a chosen alternative represents the next-best benefit: that is, the benefit that would have been realized if the decision maker had chosen the next most beneficial alternative over the one actually chosen. In an Earth sciences context, opportunity costs are typically seen as the net benefits of the next most preferable use of available funds. For example, if a funding agency provides a grant to a remote sensing project (P_1) expecting a socioeconomic benefit (B_1), the agency is forgoing the opportunity to invest in a project (P_2) with benefit (B_2). Assuming these are the only two choices, the opportunity cost of the investment P_1 is B_2: the forgone benefit from selecting P_1 over P_2.

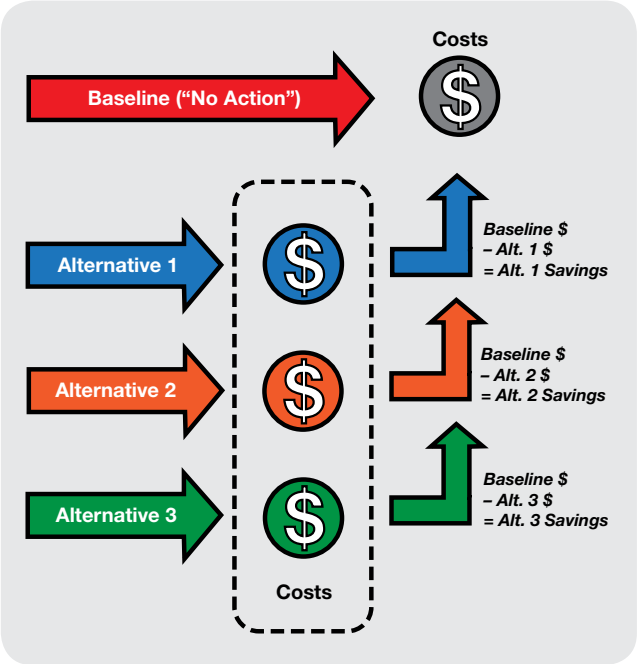


Figure 8. Analysis of Alternatives

The idea of scarcity, decisions, and opportunity costs introduces the concept of **tradeoffs**. A tradeoff involves losing one potential benefit in return for gaining another benefit. It implies a decision to be made with full comprehension of both the upside and downside of a particular choice.

The concepts of tradeoffs and opportunity costs normally enter project comparisons as an **Analysis of Alternatives (AoA)**, as illustrated in figure 8.

In an AoA, a series of mutually exclusive alternatives—in this case, one or more projects or programs to be funded—is developed and compared to a baseline, "no action" alternative. The alternative producing the greatest net benefit is then selected as the preferred alternative. The benefits from the other alternatives are not realized, but they are willingly forgone because the selected alternative produces the greatest net benefit.

For example, if an Earth observations project uses a remote sensing asset to monitor air emissions from roads in a densely populated metropolitan area, the metropolitan area can avoid investing in ground sensors, communication equipment, and processing capacity to collect the same data. Thus, the project might be able to show as a benefit the **avoided cost** (a form of opportunity cost) the metropolitan area no longer incurs as a result of the project.

In summary:

- Human wants are unlimited while resources are limited. As a result, decisions are inevitable.
- All choices imply that there is forgone opportunity to spend resources on another project and obtain the benefits from that choice.
- Opportunity cost refers to the next-best choice an individual would make who has already picked from several choices. In the case of CBA, the opportunity cost is typically seen as the net benefits of the next most preferable use of the project funds.
- The idea of opportunity cost typically enters CBA in the form of AoA, in which alternatives are compared to a baseline and to each other.
- The benefit of one alternative can sometimes be thought of as the avoided cost of another alternative.

6.2 Costs, Benefits, and Discounting

Costs are defined as any expenditure of resources made to obtain an outcome. One type of cost, opportunity cost, was defined previously in section 6.1. Other types of costs often considered in socioeconomic impact analysis of Earth observations projects include project capital and operating costs and post-project operating, maintenance, and recapitalization costs.

The outcome for which costs are expended generally involves **benefits** (that is, things that are of value) to the individual who made the choice. These benefits accrue for the individual who made the choice, to other individuals, to a larger group, or to society at large. Thus, in the case of Earth observations projects, the decision to fund the project (i.e., to assume certain costs) is undertaken with the expectation of a positive benefit to society, either as a whole or to some subset.

A benefit can be anything perceived to be a positive change in an individual or group's life.[10] For example, improvements in human health, reductions in mortality, improvements to the ecosystem and the environment, and a better quality of life can all be regarded as benefits. For analysts, a key issue is how these benefits should be measured and how reliable the measures are. For many benefits (e.g., improvements in human health), measures can be quite simple to develop (e.g., reductions in the rate of malaria cases diagnosed per thousand people). However, there are often analytical challenges involved in assigning causality and controlling for confounding variables. For other benefits (e.g., improvements in the quality of life from having clear horizons due to reductions in uncontrolled forest fires), measures are more difficult to ascertain. As a result, social scientists developed the concept of tangible and intangible benefits.

Market and Non-Market Benefits

Non-market benefits are those that are not subject to market-based means of valuation. That is, there is no market to buy and sell the good and therefore no way a monetary value can be easily placed on the benefit. Conversely, a market benefit is one that can be exchanged according to some kind of market mechanism and can easily be valued in monetary terms.

Tangible benefits are those that produce a quantifiable gain measured on some objective scale using reliable indicators. They may include metrics such as the number of cases of a disease per thousand, number of fish harvested from a river in a given time period, reductions in travel time as a result of a new congestion-reduction measure, or reductions in the number of accidents.

Intangible benefits are those benefits that cannot be easily measured via some objective scale or measurement system. These benefits involve such things as changes in safety as a result of an investment in a defense system, aesthetic benefits from the preservation of some natural monument, or the ability to access information more easily from information technology. Measurements of many of these benefits can, in fact, be addressed through indirect means. However, these intangible benefits differ from tangible ones in that they are more difficult to measure, and it is often difficult to build consensus regarding metrics to measure them.

For tangible benefits, direct measurement is possible, but determining whether and how they can—or even if they should—be translated into monetary values as **monetized benefits** must be considered. Numerous public- and private-sector organizations place an explicit or implicit monetary value on a human life. For example, insurance companies routinely calculate the value of a human life in setting life insurance rates and paying out in insurance settlement cases. Similarly, the United States Government has used various methods to assess the value of a human life in regulatory and compensatory systems.

10. Projects can result in negative as well as positive impacts. While there are some differences in opinion about the convention, in this primer negative impacts are accounted for as negative benefits, rather than positive costs.

There can be considerable controversy in computing the monetary value of certain benefits. For example, the relative monetary value of maintaining bird nesting grounds compared to providing accessible recreational waterways is difficult to assess and hard to agree upon. Other benefits are less controversial and easier to monetize. For example, the property losses avoided through improved hurricane forecasting are relatively easy to monetize. In general, these challenges lead analysts to identify two subgroups of tangible benefits: monetizable tangible benefits (i.e., benefits for which there is a consensus regarding how they can be monetized) and non-monetizable tangible benefits (i.e., benefits that can be measured but for which there is no consensus regarding how they should be monetized). While difficult and sometimes controversial, monetization allows for straightforward subtraction of costs from benefits to get a **net benefit** of decisions involving benefits and costs.

In budgetary analysis, the net value of different projects is expressed in terms of a common unit. The most convenient common unit is money. Budget analysts, both public and private, tend to compare benefits and costs in terms of monetary value. The comparison of benefits and costs is referred to as **Cost-Benefit Analysis**, which was described in detail in section 5.1.

In considering different sets of benefits among projects, the delay between project costs and resulting benefits is usually considered. Many benefits do not accrue immediately after the cost is expended but may extend far into the future. This leads to the concept of **present value**, since a unit of money spent today is generally considered more valuable than the same unit received 10 years from now. Note that this is not just because of inflation; money available now can be invested to earn interest or dividends for 10 years and is worth more than its original face value at the end of the period.

In traditional CBA, costs and benefits are measured as the total costs and benefits spent and received by a society. However, the **distribution** of costs and benefits may be important as well in assessing impacts. For example, if, as a result of a government program, all the costs were borne by one sector of society (e.g., people who lived in an emerging nation) but the benefits were experienced by those in another sector (e.g., people who lived in a developed nation), the program might be viewed as unfair. Therefore, analysts may consider the distribution of costs and benefits in describing a project's impact.

Analysts should also be sensitive to the possibility that a project may not actually create new benefits but may simply transfer or displace existing benefits. **Displaced benefits** refer to the phenomenon of transferring a benefit from one group to another without actually improving the overall benefit to society as a whole. For example, if a project results in better long-term rain forecasting and an upstream community uses the information to better manage its dams and irrigation systems, there may be a resulting negative impact to downstream communities, who no longer have the same water flows available as before the project and for whom irrigation and fishing productivity may suffer. In this case, some of the benefits to the upstream community were not new benefits, but rather benefits displaced from downstream communities.

In summary:

- Virtually all projects have costs and benefits.
- Costs represent any expenditure of resources intended to achieve an outcome that is valued as a benefit.
- Many costs and benefits cannot be easily measured, and there may be a lack of consensus regarding how some should be measured and how and whether others should be monetized.
- Costs and benefits can be divided into tangible (easy to measure) and intangible (difficult to measure) categories. Either category may be monetized if desired.
- Analysts should consider all costs and benefits, including intangible benefits, for inclusion in their analyses.
- Monetized benefits and costs are easy to combine into a net-benefit metric.
- Analysts should use discounting to account for the time discrepancy when costs and benefits occur. In particular, they should account for the difference between current costs and future benefits.
- Analysts should be conscious of distributional issues, benefits transfers, and displaced benefits.

6.3 Use and Non-Use Value

In traditional economics, the value of an object or service is often defined as the price it would bring in an open and competitive market. Price is determined primarily by the demand for the object relative to supply. Thus, the value of a good or service is equal to its price on whatever markets exist for it. From this perspective, everything is seen as a commodity, and if there is no market to set a price, then there is no "economic" value. From this rather extreme view, no commodity has an intrinsic value or a value that is independent of the price assigned to it by a market.

It should be noted that price is different from cost. In the context of this discussion, the cost of a good or service is the monetary value of the labor, land, resources, and capital required to produce that good or service. As noted above, the benefit (or utility) of a good or service is often assumed to be synonymous with its price. The benefit is utility or value an individual obtains from acquiring or using a good or service.

A **use value** is the value that an individual obtains from using a good or service. This value is typically estimated via a market mechanism. That is, if a good or service is used by an individual, it normally can be valued on a market. In contrast, a **non-use value** is the value individuals derive from goods (including public goods or natural resources) independent of any use, present or future, which the individual might personally make of those goods. For example, there is no market for lighthouse services. Lighthouses are a public good. No ship that sees them can be excluded from the benefit they provide, and their services cannot be "sold" to shipping. However, individuals agree to support lighthouses even though they may never directly use them. The individuals support lighthouses because they agree that safe navigation is a benefit all ships and seaborne craft should receive.[11]

11. There is a related use value for lighthouses, in that individuals indirectly benefit from such a public good. Safe shipping means items can be transported more inexpensively to stores for the individual to purchase. This value is distinct from the non-use value described here, which involves perceived value for safe navigation as a characteristic of a good and orderly society.

Public Goods: Non-Rival and Non-Excludable

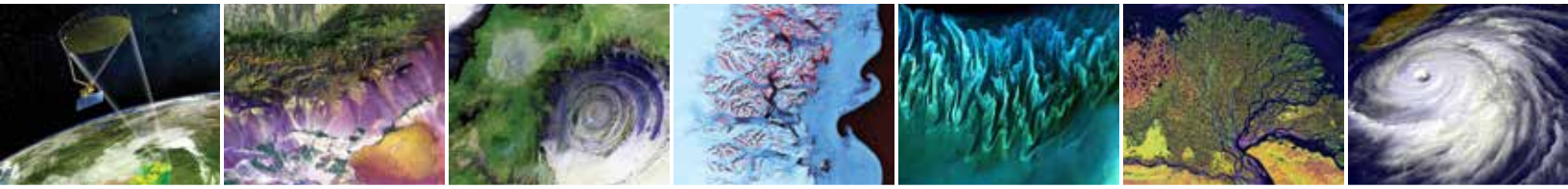
A public good is a good that is non-rival and non-excludable. Non-rivalry means that consumption of the good by one individual does not reduce availability of the good for consumption by others. For example, a TV program is a non-rival good. That is, watching a TV program does not reduce the ability of another individual to watch the program. A non-excludable good is one that no one can be effectively excluded from using. For example, a lighthouse provides benefit to any ship that can see it, and no ship can be excluded from the benefit the lighthouse provides.

Non-use value includes both **existence value** and pure non-use value, as well as bequest value, option value, and value arising from altruism. Existence value is the benefit an individual receives from knowing a good exists. The individual obtains no utility from using the good and instead obtains utility entirely from knowing that the resource exists. For example, an individual might not gain any use value from tigers, yet one can gain value from knowing that tigers exist and are not extinct. A **bequest value** arises from the desire of individuals to preserve a good for the use of future generations. For example, an individual may wish to preserve a historic monument so future generations can enjoy it. An **option value** arises from uncertainty about the future demand or supply for the good. For example, individuals obtain value from allowing a resource to continue to exist and keeping the opportunity for future use. Individuals might value maintaining water in an aquifer rather than using it now because they wish to have the option to use it in the future. Finally, **altruistic value** arises from the utility or benefit an individual experiences from another individual enjoying a benefit. For example, individuals may feel a benefit from supporting a malaria-reduction program in Africa even if they experience no benefit from investment in the program.

There is a great deal of literature on methods to estimate non-use values. For example, **stated preference** or **contingent valuation** methods estimate non-use values by asking people (via expert panels, focus groups, or statistically valid surveys) what they would be willing to spend on non-use goods. Another method is **revealed preference**, which can be used for goods associated with observable actions or behaviors that involve enjoying the good. Using this approach, the value of a good is obtained by estimating the actual amount people spend on actions enabled by that resource. For example, the value of a natural monument might be estimated by the total money people are prepared to spend to visit the monument. As another example, the value of having a tiger in a zoo might be estimated from the cost to acquire and maintain the tiger or the price people are prepared to pay to see a tiger. One problem with this approach is that revealed preference measures are often very difficult (or expensive) to obtain. For example, pure non-use goods have no revealed preference, and it is difficult to combine different measures to produce an overall revealed preference value.

In summary:

- Market value is the price a good or service will obtain on a market.
- Use value is the utility or benefit an individual obtains from use of a good or service—it may or may not be equivalent to market value.
- Non-use value is the benefit or utility an individual obtains from the existence of a good. It can include existence value, bequest value, option value, and/or altruistic value.
- A public good is a good that is non-rival and non-excludable.
- Numerous methods exist to estimate the magnitude of non-use values. Many of these methods are controversial.



Appendix A: References for Further Information

This appendix provides suggestions for books, articles, and Web sites for obtaining additional information on assessments of socioeconomic impacts. It is intended to be useful but not exhaustive.

Books and Articles

- Belli, Pedro, Jock Anderson, Howard Barnum, John Dixon, and Jee-Peng Tan. 2001. *Economic Analysis of Investment Operations: Analytical Tools and Practical Applications*. Washington, DC: World Bank Institute. Available at *http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2006/01/27/000160016_20060127112546/Rendered/PDF/298210REPLACEMENT.pdf*.

- Bellù, Lorenzo G., and Rosaria V. Pansini. 2009. *Quantitative Socio-Economic Policy Impact Analysis: A Methodological Introduction*. Rome, Italy: United Nations Food and Agricultural Organization (FAO). Available at *http://www.fao.org/docs/up/easypol/774/quant_socio-economic_pia_068en.pdf*.

- Boardman, Anthony E., David H. Greenberg, Aidan R. Vining, and David L. Weimer. 2006. *Cost-Benefit Analysis: Concepts and Practice*, 3rd edition. Upper Saddle River, NJ: Prentice Hall.

- Blackman, Allen. 2012. *Ex Post Evaluation of Forest Conservation Policies Using Remote Sensing Data, An Introduction and Practical Guide*, Discussion Paper 12-13. Washington, DC: Resources for the Future. Available at *http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=21820*.

- Durden, Susan D., and Jim Fredericks. *Economics Primer*, IWR Report 09-R-3. Alexandria, VA: U.S. Army Corps of Engineers, Institute for Water Resources. Available at *http://www.corpsnedmanuals.us/zAbstctEconPrimer.asp*.

- Harberger, Arnold C. 1976. *Project Evaluation: Collected Papers*. Chicago: University of Chicago Press.

- Hayami, Yujiro, and Willis Peterson. 1972. "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities," *American Economic Review* 62:1, pp. 119–130.

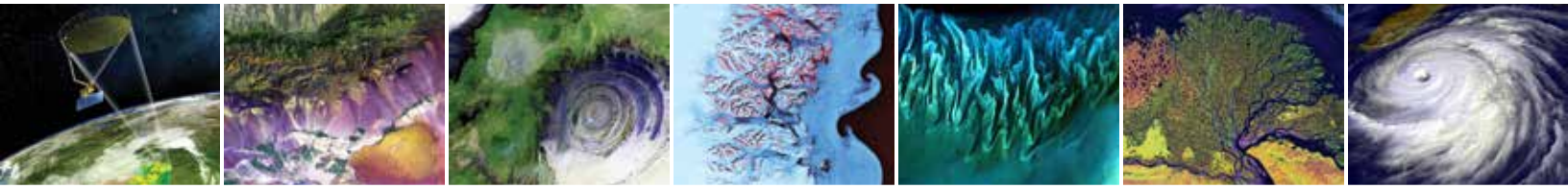
- Keeney, Ralph L. 1982. "Decision Analysis: An Overview," *Operations Research* 30:5, pp. 803–838.

- Keisler, Jeffrey. 2004. "Value of Information in Portfolio Decision Analysis," *Decision Analysis* 1:3, pp. 177–189.

- Kostoff, Ronald N. 1977. *Handbook of Research Impact Assessment*, 7th edition, DTIC Report ADA296021. Alexandria, VA: Office of Naval Research. Available at *http://www.dtic.mil/dtic/tr/fulltext/u2/a296021.pdf*.
- Laxminarayan, Ramanan, and Molly K. Macauley, editors. 2012. T*he Value of Information: Methodological Frontiers and New Applications*. London: Springer.
- Levin, Henry M., and Patrick J. McEwan. 2001. *Cost Effectiveness Analysis: Methods and Applications*, 2nd edition. Thousand Oaks, CA: Sage Publications.
- Linstone, Harold A., and Murray Turoff, editors. 1975. *The Delphi Method: Techniques and Applications*. Reading, MA: Addison-Wesley Publishing Company. Available at *http://is.njit.edu/pubs/delphibook/*.
- Nas, Tevfik F. 1996. *Cost-Benefit Analysis: Theory and Application*. Thousand Oaks, CA: Sage Publications.
- Scodari, Paul. 2009. *National Economic Development Procedures Manual: Overview Manual*, IWR Report 09-R-2. Alexandria, VA: U.S. Army Corps of Engineers, Institute for Water Resources. Available at *http://www.corpsnedmanuals.us/zAbstctOverviewPDFc.asp*.
- Snell, Michael. 1997. *Cost-Benefit Analysis for Engineers and Planners*. London: Thomas Telford Publications.
- Squire, Lyn, and Herman G. Van der Tak. 1976. *Economic Analysis of Projects*, World Bank Research Paper. Baltimore, MD: Johns Hopkins University Press. Available at *http://books.google.com/books/about/Economic_Analysis_of_Projects.html?id=cYeR2u_DtfQC*.
- Stokey, Edith, and Richard Zeckhauser. 1978. *A Primer for Policy Analysis*. New York: W.W. Norton.
- Tassey, Gregory. 2003. *Methods for Assessing the Economic Impacts of Government R&D*, NIST Planning Report 03-1. Gaithersburg, MD: National Institute for Standards and Technology, Strategic Planning and Economic Analysis Group. Available at *http://www.nist.gov/director/planning/upload/report03-1.pdf*.
- U.S. Environmental Protection Agency, Office of the Administrator. 2010. *Guidelines for Preparing Economic Analyses*, EPA 240-R-10-001. Washington, DC: U.S. EPA. Available at *http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html*.
- United Nations Industrial Development Organization (UNIDO). 1986. *Guide to Practical Project Appraisal: Social Benefit-Cost-Analysis in Developing Countries*. New York: United Nations Publications.
- Varian, Hal R. 1992. *Microeconomic Analysis*, 3rd edition. New York: W.W. Norton.

Web Sites Related to Socioeconomic Impact Assessment and CBA (All accessed February 6, 2013)

- Impact Assessment Page at the European Commission *http://ec.europa.eu/governance/impact/index_en.htm*
- Benefit-Cost Analysis Center, Evans School of Public Affairs *http://evans.washington.edu/research/centers/benefit-cost-analysis*
- Concise Encyclopedia of Economics, Library of Economics and Liberty *http://www.econlib.org/library/Enc/BenefitCostAnalysis.html*
- Journal of Benefit-Cost Analysis *http://www.bepress.com/jbca/*
- Society for Benefit-Cost Analysis *http://benefitcostanalysis.org/*



Appendix B: Example of a Value of Information Approach

A VOI or Expected Value of Information (EVOI) approach generally refers to valuation methodologies where a decision is being made before all relevant information is available. The approach uses a decision maker's prior knowledge about uncertainties and the decision he or she would make if the uncertainty were resolved ahead of time. This appendix provides an example to illustrate the approach.[12]

In VOI approaches, the analyst works with the decision maker to create a decision basis: lists of the impact metrics that the decision maker cares about, the decision alternatives that are available to the decision maker, and the uncertain parameters that might affect the optimal choice among alternatives. Together they develop a decision model that describes how the alternatives will affect impact metrics as a function of values for the uncertain parameters. The decision model also includes a mathematical description of the decision maker's preferences among combinations of impact metrics so that there is a single, combined metric that the decision maker is trying to optimize.

The analyst then helps the decision maker describe his or her beliefs about the parameters in terms of probabilities, such as, "I believe it is 20 percent likely that Parameter 1 will be found to have a value of X, 20 percent likely that it will be found to have a value of Y, and 60 percent likely that it will be found to have a value of Z." Using the model, the analyst performs a deterministic analysis, first identifying the best alternative given the decision maker's current uncertain beliefs about the parameters and then determining the best alternative under each of a combination of possible values for the parameters.

The Expected Value of Perfect Information (EVPI) is the difference between the probability-weighted average of the decision maker's combined impact metric given his current optimal decision and the probability-weighted sum of the combined impact metric under each combination of values. In mathematical terms,

$$EVPI = \sum_{i=1}^{n} p_{v_i}\left(\text{impact}\left[v_i, D_{v_i}\right] - \text{impact}\left[v_i, D_{Current}\right]\right)$$

Where:

- *EVPI* is the Expected Value of Perfect Information about uncertain parameter vector v;
- v is a vector of parameter values that the decision maker believes will be evaluated as having one of n different values;

12. This example is modified, with permission, from Victoria Adams et al., "Impact Analysis of NASA Earth Science Applications Project: Enhancing USAID Malaria Early Warning Systems with NASA Earth Science Results," report prepared for NASA, Earth Science Division, Applied Sciences Program.

- p_{v_i} is the decision maker's assessment of the probability that, when it becomes known, v will be found to have value v_i;
- D_{v_i} is the decision maker's impact-optimizing decision alternative if he or she knows that the value of v equals v_i;
- $D_{Current}$ is the decision maker's impact-optimizing decision alternative based on his or her current uncertain beliefs about v; and
- impact$[v_i,D]$ is the decision maker's belief of the resulting impact if v is revealed to have value v_i and the decision maker has chosen decision alternative D.

Consider a malaria control program manager responsible for the hypothetical region shown in the first map in figure B-1 below. The manager wishes to minimize new malaria infections in the region. The manager does not know precisely where to apply control measures.

In the absence of improved information about soil moisture (which provides information about likely mosquito infestations, corresponding to areas at risk for high infection rates), the manager's plan is to spray insecticide over the large dashed area in the first map, an area in which she knows that isolated areas of high soil moisture are present. Not all of the large area actually requires spraying, but she does not have enough data to identify where all the high-moisture pockets of land are within the overall region. She sprays all of the large area in an effort to ensure she treats all the highest moisture pockets. Based on the area's size, $10,000 of control measures will be necessary to kill or control the mosquitoes within it.

The manager is told that an Earth observations project will increase the accuracy of soil moisture measurements. Based upon discussions with experts familiar with the project, she believes that data from the project will reduce by 40 percent the area of uncertainty around the high-moisture pockets in the region. That is, she believes she will only need to spray a smaller dashed area in the second map in figure B-1. Note that the size and number of the high-moisture pockets in the region is unchanged; what has changed is the total area the manager needs to spray to ensure she has treated all of these pockets. Before receiving the information, she does not know what area she will be spraying, but she believes that whatever area it is, it will be 40 percent smaller than without the information.

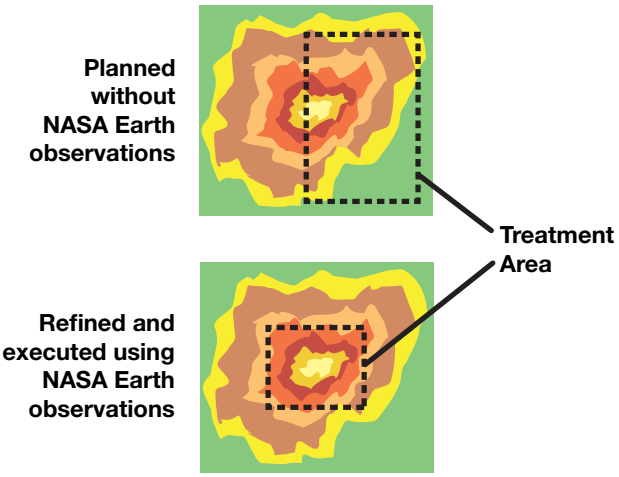
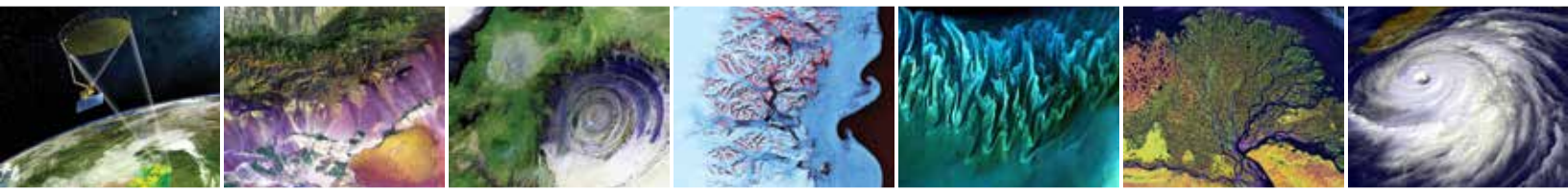


Figure B-1. Example of Comparative Impact Analysis, Malaria Control Measures Spraying

The smaller area in the second map can be treated for only $6,000, which is $4,000 less expensive than the costs she was facing to treat the original area. Therefore, if the manager could obtain the applied sciences data for any cost less than $4,000, she would be ahead financially. The *value of information* of the data to the manager is $4,000.

Note that, for the project information to have value under this framework,

- there must be a linkage between the applied sciences information, a decision, an action, and a socially valuable set of outcomes or benefits;
- the socially valuable benefits must be measurable in some meaningful way and must differ depending on which program action is taken; and
- information must have the potential to cause a different decision alternative to be chosen.



Appendix C: U.S. Federal Guidelines for Cost-Benefit Analysis

This appendix is provided as a reference to members of the Earth observations community performing socioeconomic impact analyses that might be reviewed by U.S. Federal agencies. While some of the sources below refer to analyses of regulations rather than of projects, many of the approaches and much of the guidance in the documents can be used to improve the effectiveness of project-focused impact analyses.

While there is no direct statutory requirement for conducting socioeconomic impact analyses in general, there are Federal guidelines and regulations specifically for CBAs. This guidance was issued by the Office of Management and Budget (OMB), White House, and Congress. The main guidelines include OMB Circulars A-4, A-11, and A-94, as well as the White House's Executive Order (EO) 12866. As previously mentioned, most of these guidelines are intended for regulatory impact analysis. However, they are useful for conducting any CBA and should be followed to the extent to which it is practical. Below are summaries of each of these documents and the relevant components necessary for CBA.[13]

C.1 OMB Circular A-4

The most recent OMB Circular A-4 was released on September 17, 2003, with intent to provide guidance to analysts in regulatory agencies as required under Section 6(a)(3)(c) of Executive Order 12866, as well as the Regulatory Right-to-Know Act of 1999 and the "Regulatory Planning and Review." Circular A-4 replaces the previous OMB "best practices" document of 1996, as well as OMB Memorandum M-00-08. It also provides a standardized way to report costs and benefits for Federal regulatory analysis.

OMB Circular A-4 provides the following guidelines for conducting CBA (or BCA) for Federal regulatory agencies. The analysis must accomplish the following:

- Explain how actions are linked to expected benefits. For example, indicate how additional safety equipment will reduce safety risks. A similar analysis should be done for each alternative.
- Identify a baseline. Benefits and costs should be defined in comparison with a clearly stated alternative. This step normally will be a "no action" baseline: what the world would be like if the proposed action were not adopted. Comparisons to a "next best" alternative are also especially useful.

13. The complete OMB circulars, the Executive Order, and other documents referred to in this document can be found on the Benefit-Cost Center Web site at *http://www.evans.washington.edu/research/centers/benefit-cost-analysis/related-search*.

- Identify the expected undesirable side effects and ancillary benefits of the proposed action and the alternatives. These side effects and ancillary benefits should be added to the direct benefits and costs as appropriate.

Specifically pertaining to non-monetized benefits and costs, OMB Circular A-4 states that

> …the most efficient alternative will not necessarily be the one with the largest quantified and monetized net-benefit estimate. In such cases, you should exercise professional judgment in determining how important the non-quantified benefits or costs may be in the context of the overall analysis. If the non-quantified benefits and costs are likely to be important, you should carry out a "threshold" analysis to evaluate their significance. Threshold or a "break-even" analysis answers the question, "How small could the value of the non-quantified benefits be (or how large would the value of the non-quantified costs need to be) before the rule would yield zero net benefits?" In addition to threshold analysis you should indicate, where possible, which non-quantified effects are most important and why. (OMB Circular 1-4, p. 2)

On discount rates, the OMB Circular refers to OMB Circular A-94, noting that a real discount rate of 7 percent should be used as a "base-case" for regulatory analysis (p. 33). It also notes that the 7-percent discount rate "is an estimate of the average before-tax rate of return for private capital in the U.S. economy" (p. 33). Furthermore, the circular states that when action directly influences private consumption it is pertinent to use a 3-percent discount rate (i.e., the social rate of time preference). When discounting over longer periods (e.g., intergenerationally), the circular states that the discount rate should be between 1 and 3 percent, and, when pertinent, a sensitivity analysis should be conducted using discount rates of 3 to 7 percent.

More information on OMB Circular A-94 can be found in section C.2 below. Further information on guidelines for conducting CBA can be found in Circular pages 14–42.

C.2 OMB Circular A-94

OMB Circular A-94 establishes guidelines and discount rates for benefit-cost analysis within Federal agencies. This document replaces OMB Circular A-94 (from 1972) and A-104 (from 1986) and draws authority from the Budget Accounting Act of 1921. The document's stated purpose is to "promote efficient resource allocation through well informed decision making by the Federal Government."

Broadly, this document outlines the techniques to use in CBA. The sections most pertinent to social programs are sections 5–10 and are summarized below:

- ***Section 5*** identifies the general concept of CBA and discusses the difference between NPV, CEA, and the elements within NPV and CEA. These elements are policy rationale, explicit assumptions, evaluation of alternatives, and verification.
- ***Section 6*** presents Federal policy on how to identify and enumerate benefits and costs.
- ***Section 7*** discusses how to treat inflation and outlines the differences between real and nominal values.
- ***Section 8*** discusses the difference between real and nominal discount rates. This section identifies which type of discount rate should be used with the types of analysis in section 5.
- ***Section 9*** discusses the role of uncertainty in CBA modeling assumptions. Guidelines are given for characterizing uncertainty, expected values, and sensitivity analysis.

- ***Section 10*** discusses incidence and distributional effects. The process of targeting recipients of benefits leads to a discussion of how to measure impacts across diverse groups. Effectiveness should be measured in terms of the target group receiving benefits.

C.3. Executive Order 12866

Executive Order 12866 is the original executive order to mandate that Federal agencies conduct cost-benefit analysis for significant regulatory actions. The preamble identifies the goals of the order: to protect and improve the American people's health, safety, environment and well-being and improve the performance of the economy without imposing unacceptable or unreasonable costs on society.

The body of the order is organized into 11 sections. Of these, sections 1–3 address social issues inherent in cost-benefit analysis and are summarized below. Section 4 outlines the planning mechanism of the order. Sections 5 and 6 outline exemptions and review. Section 7 establishes protocols for resolving conflicts. Sections 8–11 address publication, agency authority, judicial review, and revocations.

Section 1 identifies the goals, the procedures, and the population to be included in cost-benefit analysis. "In deciding whether and how to regulate, agencies should assess all costs and benefits of available regulatory alternatives, including the alternative of not regulating." The definition of costs and benefits includes social values and costs difficult to quantify. "Costs and benefits shall be understood to include both quantifiable measures and qualitative measures of costs and benefits that are difficult to quantify."

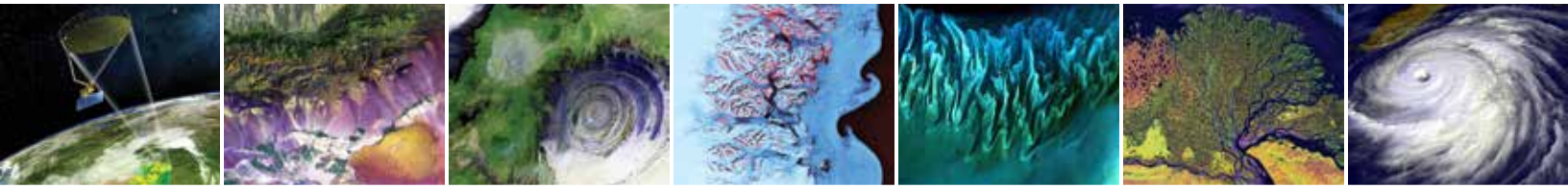
In addition, EO 12866 states that when conducting cost-benefit analysis, the agency must include "risks posed" (Section 1(B)(4)), "distributive impacts, and equity" (Section 1(B)(5)) by regulator options.

Section 2 states that OMB shall conduct EO 12866 compliance reviews. Section 3 limits the type of regulations subject to EO 12866 to only "significant regulatory actions." These actions are defined as "having an annual effect on the economy of $100 million more…or adversely affect[ing] the environment, public health or safety" (Section 3(F)(1)).

Table C-1 gives a summary of these documents with respect to their guidance on impact analysis and CBAs.

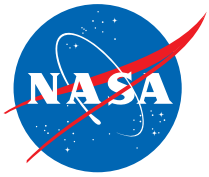
Table C-1: Summary of Relevant U.S. Guidance on Impact Analyses and CBAs

Agency/Document	Summary of Guidance
Office of Management and Budget	
Circular A-4	• Provides guidelines and requirements for conducting CBAs in regulatory agencies • Refers to OMB Circular A-94 for specific discount rates
Circular A-94	• Establishes guidelines and discount rates for CBA within Federal agencies • Reviews CBA methods • Establishes discount rates • Identifies uncertainty • Discusses distributional effects
Executive Office of the President	
Executive Order 12866	• Establishes philosophy motivating use of CBA • Defines the population to be considered for costs and benefits



Appendix D: List of Acronyms

AoA	Analysis of Alternatives
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
DOT	U.S. Department of Transportation
DPB	Discounted Payback
EO	Executive Order
EVOI	Expected Value of Information
EVPI	Expected Value of Perfect Information
GDP	Gross Domestic Product
IAIA	International Association for Impact Assessment
IRR	Internal Rate of Return
MEWS	Malaria Early Warning System
NASA	National Aeronautics and Space Administration
NBIR	Net Benefit Investment Ratio
NGO	Non-Governmental Organization
NPV	Net Present Value
OMB	Office of Management and Budget
PV	Present Value
PVB	Present Value of Benefits
PVC	Present Value of Costs
ROI	Return on Investment
U.S.	United States of America
USAID	United States Agency for International Development
VOI	Value of Information
WHO	World Health Organization



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