Toward Sustainability: The Integration of Science and Other Stakeholder Values, One Decision at a Time[1] – submitted to the Journal of Environmental Management, February 2, 2009

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Abstract

We use a case study to illustrate a process that allows stakeholders to discern, discuss, and examine the effect of values on environmental decision making. The case study demonstrates how a decision analytic approach can integrate the values held by multiple stakeholders. Sustainability is about human values, so the process of establishing sustainable environmental policies must include a means of integrating the values of scientists with the values of non-scientists. Using the Multi-criteria Integrated Resource Assessment (MIRA) approach, developed by the U.S. Environmental Protection Agency Region III, a variety of indicators was constructed to evaluate the environmental condition of the U.S. Mid-Atlantic region. We used that information to explore the effects different stakeholder views have on their perception of the environment. Addressing sustainability – what is being sustained, for whom is it to be sustained, for how long, and at what cost – requires an assessment of where we are now and what is

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missing in order to achieve a future condition deemed more desirable, that is, more sustainable. Assessment of current and future environmental conditions requires the acknowledgment of all stakeholder values and inclusive discussions about the effect of those values on the perception of and potential decisions affecting those conditions. The case study illustrates how the perception of current environmental condition varies dramatically when the same indicators are filtered through different stakeholder value sets.

1. Introduction

Traditionally, there are two major discontinuities in the environmental policy making process that make it difficult to take steps toward addressing sustainability issues (Brunner and Starkl, 2004, Di Giulio and Benson, 2002, Ravetz, 2005). First, there is the discontinuity between and among scientific disciplines (Fischhoff, 1981, Getzner, 2002, Hoppe et al., 2001, The Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997). Disciplinary scientists collect data on those ecological indicators accepted (valued) within their disciplinary paradigm (Kuhn, 1970) to assess the condition of the environment, which are then presented as foregone conclusions, incontrovertible, and not subject to questions from scientists outside their paradigm. Second, there is the discontinuity between scientists and non-scientists in the assessment of the environmental condition (Funtowicz and Ravetz, 1993, Hisschemoller et al., 2001). Most often, scientists first complete their work and, when proceeding toward final decision making, only then seek to engage non-scientists in the implementation of environmental policies; in other words, considering the values of these non-scientists secondary to or outside of the decision making process. Typically, there is little or no explicit discussion of values as part of the policy evaluation or policy making process. Furthermore, challenging arguments based on values in environmental decision making is generally considered a weaker strategy than challenging the data even when scientists have no significant disagreements about the data (Jasanoff, 1990, Yankelovich, 1991). Particularly when issues are controversial, stakeholders with different perceptions of the policy argument often seek scientists willing to support their position against the other alternatives, even if the arguments are not primarily scientific, including those that fall within the uncertainty range of the data. Disagreements among scientists indicate that there are value judgments in data interpretation that are being made as well. In advocacy situations, science alone appears to be especially inadequate (or appears to have failed) for making policy decisions because, for the stakeholders, science does not clearly point to a particular solution or option (Hisschemoller and Hoppe, 2001, Korfmacher, 2002, Schotland and Bero, 2002). As a result, science is no longer relied on to inform policy making and contributes to the further divide between and among scientists of different expertise and between scientists and non-scientists. In contrast, this paper illustrates an alternative process guided by the use of the Multi-criteria Integrated Resource Assessment (MIRA) approach, developed at the U.S. Environmental Protection Agency Region III (EPA Region III), where scientist stakeholders and non-scientist stakeholders interact within a transparent framework and start making more informed and sustainable policy decisions.

2. Background

Complex environmental systems challenge environmental policy decision makers because of the variety of indicators and perspectives that must be considered (Davis and Kottemann, 1995, Krimsky and Plough, 1988, Nyhart and Carrow, 1983, U.S. Environmental Protection Agency, Science Advisory Board, 2000). Although more recent analytical approaches seek to integrate scientific data from multiple disciplines, the influence of values and the views of non-scientist stakeholders tends to be ignored or substantially downplayed (Brunk et al., 1991, Charnley, 2000, Chopyak and Levesque, 2002, Clark et al., 2000, Endter-Wada et al., 1998, Intergovernmental Panel on Climate Change, 2001, Portney, 1991). There is a need to integrate data with values but in a manner that preserves the role of scientists within the process even as non-scientist stakeholders are included (Fischbeck et al., 2001, Hilden, 1997, Mehta, 1998, Renn, 1999, Robertson and Hull, 2003). An alternative approach developed for environmental policy analysis offers decision makers and other stakeholders an opportunity to examine and analyze environmental data and develop new understanding/knowledge based on those data. Through an iterative, learning-based process, the MIRA approach challenges these stakeholders to (Stahl et al., 2002, Multi-criteria Integrated Resource Assessment (MIRA), 2008):

- articulate the decision or analytical question,
- determine what the relevant decision criteria are,
- determine the relative decision significance of relevant data used to construct indicators, and

- assess the relative importance of the decision criteria.

These four major features of MIRA present a new opportunity for all stakeholders (scientists and non-scientists) to learn about the relative environmental impacts of the potential decision alternatives.

Addressing issues of sustainability requires not only a more holistic approach and process for discussing and deliberating environmental issues because the issues are complex but also because people with conflicting interests and needs are involved (Faucheux and Hue, 2001, Gutmann and Thompson, 1996, Holling, 1995, Keeney, 1992, Moore, 2000, Parson and Clark, 1995, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1996). Sustainability is difficult to define because it is about human values (Allen et al., 2003, Naess, 1973, Pepper, 1993). These values vary depending on perspective and culture, change over time, and determine what is to be sustained and how.

Consider, for a moment, a simplistic world with only humans and rabbits. In this world, each rabbit seeks to preserve its life; in other words, rabbits run from danger and seek food and shelter to survive. In this world, a person can decide whether a rabbit is negatively affecting their life. The human animal has a greater capability than the rabbit to reshape their environment to their benefit. Human values drive the actions that reshape their environment and determine the effective sustainability of the balance between humans and rabbits.

In our world of humans and rabbits, one could argue that from the rabbit's perspective, the more rabbits the better. Even when the rabbit population explodes such that too many rabbits compete for the same, limited resources, rabbits will not change their behavior (though their environment will effectively correct that lack of an ability to change). However, through their science, humans could determine that such a population explosion will ultimately cause the extinction of rabbits. The science that allowed this determination to be reached does not, however, suggest the need for any action. The decision to act in a way that limits the population of rabbits, and thus sustains that species, is a human value not a scientific conclusion. To take such action requires humans to decide that the preservation of the rabbit as a species is more important than the life of a single rabbit, given that individual rabbits will not make selfless decisions to benefit the whole population.

Once humans agree on current and desired future environmental conditions, the next steps toward sustainability require collectively determining the answer to four questions (Allen et al., 2003):

1. what is being sustained,
2. for whom it is to be sustained,
3. for how long should it be sustained, and
4. what cost are we willing to pay to sustain it.

These next steps will also require the integration of scientific data and stakeholder values in a transparent and inclusive discussion process. We believe that an approach such as MIRA could help facilitate such a process. In this paper, we examine the importance of including equal places for input of values from scientist and non-scientist stakeholders in an integrated analysis that is supportive of examining different world views, which is the first step toward examining the four sustainability questions.

3. The Mid-Atlantic Case Study

The MIRA approach was developed to facilitate integrating physical/natural science and social science perspectives through an iterative, learning-based process. The study area is the jurisdiction of the U.S. Environmental Protection Agency's Mid-Atlantic Regional Office (EPA Region III); one of ten regional offices that comprise the U.S. Environmental Protection Agency (USEPA). The Mid-Atlantic region comprises the states of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia and the District of Columbia along the eastern U.S. coast. In order to take steps toward integrating science in decision making within EPA Region III, agency decision makers (generally non-scientists) directed staff scientists to become involved in examining appropriate decision criteria to assess environmental condition, which involves gathering data for those indicators, developing appropriate indicators (reflective of the decision criteria) from those data, and presenting the information to senior managers in the EPA Region III office for policy decision making regarding the condition of the Mid-Atlantic environment.

Nearly 200 indicators were used; ranging from traditional indicators such as air toxics cancer risk and the Index of Biological Integrity, to more non-traditional (and in some cases, more administrative) indicators such as acid deposition as an indicator for the deterioration of buildings and hazardous waste corrective action plans implemented. Indicators are constructed from data and many data were used more than once for different purposes within the analysis (i.e., same data, different indicators).

In the sections below, an example that uses fine particulate matter data for three different indicators is discussed (an example of the same data used for different purposes). The geographic unit analyzed was at the Hydrologic Unit Code (HUC) 12-digit scale[2]. The problem or question being investigated in this case study pertains to the condition of the Mid-Atlantic environment as assessed by available indicators. For the analysis, every HUC12 was populated with relevant indicator data. For the purposes of this paper, we define the following terms in these ways. Data refers to quantitative or qualitative values for the collective 3700 HUC12s in this analysis. In this MIRA analysis, we do not use a single value or datum alone (i.e., datum for a single HUC12). A decision criterion is contextual and starts as a narrative description by stakeholders based on the decision question they want to answer (see Section 4.1 below). Therefore, the context of the analysis is determined by the participants and a criterion's context is reflected by its placement in the MIRA analytical hierarchy. A decision criterion is manifested quantitatively by an indicator, which may be a construct of one or more pieces of data, which has been indexed (as described in Section 4.3 below). For example, the impact of acid deposition on Mid-Atlantic streams is a decision criterion and could

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[2] The U.S. Geologic Survey (USGS) (www.usgs.org) organizes the drainage basins of the U.S. into a hydrologic system of watershed boundaries that provides a uniquely identified and uniform method of subdividing large drainage areas and showing the relation of the hydrologic units to each other. Hydrologic Unit Codes are used to represent each of these hydrologic units. The Hydrologic Unit Code at the 12-digit level used in this study is the most refined level of watershed boundaries currently available. To provide the reader with a relative sense of size for these HUC12s, there are approximately 325 counties in the Mid-Atlantic region, which consists of nearly 3700 HUC12s. At the time of the case study, there was no standard consensus for the definition of the 12-digit HUC boundaries so estimates were used.

use data consisting of the nitrogen deposition spatial field across the Mid-Atlantic geographic area. The acid deposition decision criterion manifests as the indicator, which could be constructed as follows: the indexed nitrogen deposition spatial field data (at the HUC12 resolution) as weighted by the stream density (also at the HUC12 resolution) in the Mid-Atlantic area. In general, when referring to the indicators organized in the MIRA hierarchy, the term indicator is used interchangeably with decision criterion because the indicators in the hierarchy become the best (as determined by the stakeholders) representation of the decision criteria.

4. Method

The Multi-criteria Integrated Resource Assessment (MIRA) approach was designed specifically to address the science-policy interface and to facilitate a process in which learning about the relationship between the data and the policy options is possible. In the MIRA approach, hierarchical organization of decision criteria reflects the decision question or problem (Stahl et al., 2002, Multi-criteria Integrated Resource Assessment (MIRA), 2008). In general, the MIRA approach consists of 6 steps: 1) determining the decision question, 2) identifying and organizing decision criteria into a hierarchy that reflects the decision question or context, 3) gathering data, 3) indexing the data and constructing the indicators, 4) assessing the relative importance of the decision criteria (i.e., creation of a value set), 5) producing the initial ranked set of options, and 6) iteration.

4.1. Determining the Decision Question

The decision question was determined by a series of meetings with EPA Region III senior managers (generally non-scientists) and, separately, with staff scientists. Potential decision criteria were identified. These decision criteria were initially narratives such as finding something to represent the exposure of children to asbestos or finding something to represent the vulnerability of forests to urban encroachment. To include the decision criteria in the analysis requires finding the right data and constructing indicators to credibly represent those decision criteria. The decision question initially articulated by senior managers was subsequently shaped by the staff scientists who knew and understood the availability of applicable data and indicators. Use of a facilitator ensured that participants did not rush toward the indicator identification and data collection phase without a clear common understanding of the decision question. During the process, the group periodically returned to the decision question in the indicator identification and data collection phases in order to allow for all participants to validate the purpose of the case study and to determine how to accommodate for indicators in the analysis did not fully represent the initially desired decision criteria. The final decision question was: What is the condition of the EPA Region III environment using the best currently available indicators? The MIRA analytical hierarchy reflecting this question is shown, in part, in Figure 1.

In Figure 1, the overall condition of the study area is defined by three composite indicators: Human Health, Welfare, and Future Vulnerability. Each of these composites is further defined by the indicators in the respective branches of the hierarchy (moving to the right in Figure 1). Human Health is composed of those Inhalation and Ingestion indicators that represent Disease and those Aquatic and Terrestrial indicators that relate to the condition of our Food Supply (as pertains to Human Health). The Catastrophic indicator represents the potential for catastrophic events that could affect Human Health. In similar fashion, Welfare is composed of the Lands, Wetlands, and Waters indicators that represent the Ecosystem Integrity in the study area, those Exercise and Fishing indicators that represent Recreation, those indicators that represent Natural and Built Infrastructure (such as flood protection from wetlands and acid deposition damage to urban buildings; not shown in Figure 1), and those indicators that represent Energy (such as coal mining, coal product recycling, and biofuels; not shown in Figure 1). The Future Vulnerability is represented by indicators pertaining to climate change, population growth and landscape vulnerability. The fully constructed MIRA hierarchy for the case study contains 6 levels and 187 indicators. In this manner, the condition of each of the HUC12 areas within the study area is represented by a single numeric value that is a composite of all those indicators, organized by the stakeholders in a particular way to represent the decision question. By comparing the HUC12 composites, stakeholders can examine the relative environmental condition of subareas within the Mid-Atlantic study area from a variety of perspectives. The MIRA hierarchy reflects an acknowledgement of both public health and ecosystem function concerns within the EPA Region III jurisdiction. Because context gives data its meaning, many pieces of data were used several times within the MIRA hierarchy but in different ways. We explain this in more detail below and discuss one of them, fine particulate matter (PM2.5), specifically in this paper.

4.2. Identifying Decision Criteria and Gathering Data to Construct Indicators

Once there was initial agreement on the decision question among the EPA Region III senior managers, staff members from all divisions were asked to identify decision criteria that would help to answer that decision question. It was difficult for many staff to separate the discussion of decision criteria from the discussion of indicators. Typically, the discussion about indicators presumed that context is understood. The staff discussions revealed that there was often not a common understanding of context. Throughout the process, it was necessary to remind staff scientists of the decision context and to ask them whether or not particular indicators were adequately representative of the articulated decision criteria. Many staff discovered that some of the typical indicators used in their program assessments or evaluations were not suited to answering the decision question in this case study (because they did not represent or reflect the decision criteria). Typical of many large organizations, numerous indicators used to track progress in program activities tend to be administrative (counting permits or areas attaining the applicable standard) rather than a reflection of the environmental condition. In some cases, the data from administrative indicators could be reconfigured as more relevant “environmental condition” indicators and, therefore, used more appropriately. In other cases, entirely new types of data were collected and new indicators were constructed.

Nearly 200 public health, ecological, and social indicators were linked together in order to help decision makers view the environment as a composite of all these concerns. A closer examination of five decision criteria or indicators will help us to illustrate this point. These five indicators are: 1) fine particulate matter (PM2.5)[3] used as a public health indicator for lung disease, 2) PM2.5 used as a social indicator for exercise, 3) PM2.5 used as a social indicator for viewing scenic vistas, 4) crops requiring bee pollination (an ecological indicator) (BEECROP)[4], and 5) nitrogen deposition used as ecological indicator for stream quality pertaining to acid deposition (NITRODEP-S). NITRODEP-S is a constructed indicator using nitrogen deposition data (NITRODEP)[5] weighted by stream density and acid neutralizing capacity (or the buffering capacity) of the soils for every HUC12 in the study area. Although there were nearly 200 indicators used in the case study, these five indicators will illustrate how stakeholder learning about the relative contribution of science and values to the assessment of the environment is facilitated when there is an integration of science and values within MIRA.

4.3. Indexing

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[3] PM2.5 is a criteria air pollutant regulated by the U.S. EPA under the Clean Air Act. There are short and long term health effects associated with PM2.5 exposure, including premature mortality, increased hospitalizations and emergency room visits, and development of chronic respiratory disease.

[4] The indicator represented by crops pollinated by bees was included in this analysis because of the concern related to the global (but, as yet, not understood) observation for bee colony collapse. This indicator is intended to reflect an increased environmental vulnerability in those areas where there are more crops grown that require bee pollination than in other areas where fewer or no crops require bee pollination.

[5] Nitrogen deposition is a result of agricultural and urban practices as well as atmospheric deposition due to emissions from combustion sources such as power plants. High levels of nitrogen in the waters of the Mid-Atlantic cause ecosystem stresses including eutrophication. The NITRODEP-S represents the specific concern pertaining to acid streams.

In the MIRA approach, staff scientists convert all the data from their original units to the units of the decision scale through indexing. By convention, this relative scale runs from 1 to 8; where 8 represents the poorest condition of the environment, while 1 represents the best condition (Saaty, 1980). Indexing is the first step in converting data into an indicator, which represents a decision criterion in the analysis.

The conversion of all data from their original units to the decision scale units is done using the following logic. When we make a decision, we use several different criteria to help us rationalize our choice. For example, when we consider what kind of car to buy, these decision criteria may include economic cost, reliability, and conveniences. The data for these decision criteria may include price (economic cost), make/model (economic cost, reliability), repair record (reliability), space (convenience), standard accessories (convenience, economic cost), and warranties (reliability). In order to decide which car to buy, we must consider how the criteria and our valuing of those criteria point us to the final decision. In other words, decision making is about relatively ranking decisions options, given our constraints. Before we can do this, we must first determine how to convert the data into indicators. Price and repair record are two pieces of data that represent economic cost and reliability (two decision criteria that we want to include in our analysis). Conversion of the price and repair record data into indicators requires putting both of these on a common decision scale. Once indexed, the datum is an indicator. In this case, the decision scale might be something like the attractiveness of a particular make and model of a car. But in order to determine “attractiveness,” context is important. What is the purpose of buying the car? Is it just for short distance commuting or long distance travel? Is reliability important? Is it important to have enough room to transport a soccer team? In this manner, we evaluate each datum against that context and then determine how to index those data relative to that context. For example, does the price of a particular make/model tend to point us more toward buying (attractive) or not buying (unattractive) that car? If it's a very high price (in our opinion), that price would point to not buying. If an extremely inexpensive model is not spacious enough to carry a soccer team and the car must be able to carry a soccer team, then even an inexpensive car is not a good choice because it does not hold up well in our decision context. In other words, for the decision maker, price is not the only decision criterion. Likewise, if each make and model of the car has a different repair record, this can also be considered before deciding which car to purchase.

In the decision making process, we evaluate each criterion in a similar fashion but in the end, we must come to an overall conclusion about which car to buy. Decision making requires us to compare disparate criteria or "apples and oranges." In indexing, each datum is considered individually and contextually on the decision scale. In the following example, the buyer has the financial means to consider all cars, including those that may cost $200 000. However, if the $200 000 model car has no other features (i.e., decision criteria) that would compel its purchase, then this car would not be included in the analysis. If, however, the $200 000 model car has other features that would compel its purchase, then this car should be included in the analysis. This represents the decision context.

In order for a stakeholder knowledgeable about cars to index the relevant car-purchase data, the following process is used. For example, a price of $200 000 for a car may be considered very high (i.e., unattractive) and indexed at an 8.0, while a price of $5 000 may be considered very cheap (i.e., attractive) and indexed at a 1.0. If another criterion is the reliability of the car as represented by the repair record, a repair record of 10 repairs per year may be considered a lot and indexed at an 8.0 while 5 repairs per year may be considered average and indexed at a 4.0.[6] One repair per year may be considered excellent and indexed at a 1.0. In other words, the car proficient stakeholder (in this example, you) has set $200 000 and 10 repairs per year both to 8 on the index scale because they elicit the same "unattractive" response when considering these criteria as part of the decision of whether or not to purchase that particular car. Similarly, $5 000 and 1 repair per year are both set at an index value of 1 because they elicit the same "attractive" response when considering these criteria in the decision context. Perhaps you are considering several different car models and another model costs $80 000. You might still consider this price to be quite exorbitant and could index $80 000 also at an index value of 8. Alternatively, as a person knowledgeable about cars, you may know that while there are very few cars in the $200 000 range, there are several models in the $80 000 range that you want to consider. While $80 000 is a high price, it is not exorbitant given your decision context, as there may be circumstances that could lead you to choose such a car (if, for example, it had many other features that make that car attractive to you from a decision making perspective). Consequently, you might index $80 000 at a 7 or lower.

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[6] Note that the repair record of 10 repairs per year or 1 repair per year is data but once indexed, these data are indicators.

Through indexing, separate pieces of data (e.g., the price and repair record) for all the car models being considered have been put on the same decision scale and become indicators, which represent decision criteria organized in the MIRA hierarchy. It is important to note that, thus far, we have not considered the relative importance of the two criteria; rather we have only considered their significance relative to the decision context. Deciding on the relative importance of these criteria (i.e., “preferencing” in the MIRA vernacular) is the next, and independent, step in the MIRA process. Where indexing requires the judgment of people knowledgeable in the field, preferencing relates to a judgment of relative importance, independent of specialized knowledge in a particular field. In the valuing of the indexed data about the car purchase, you must now consider which criterion is more important and by how much. This is performed via a pair-wise comparison of all the decision criteria and described in more detail in Section 4.4. MIRA formalizes and makes transparent the separate indexing and preferencing processes for all decision criteria.

The process of indexing the data for the decision analysis also provides additional opportunities for learning pertaining to the use of data and indicators. When these are placed within a contextual analysis supported by the MIRA hierarchy and the MIRA approach, these additional data concepts are: 1) the same data can be used as different indicators, 2) disparate indicators can be used together in the same analysis to help answer the decision question, and 3) how the data are viewed depends on the decision context (i.e., the decision question).

Table 1 shows the range of values for the three pieces of data used in the five indicators described in Section 4.2: PM2.5 (in micrograms per cubic meter, µg/m^3), BEECROP (in hectares, ha), and NITRODEP (in average kilograms per hectare per year for the three year period from 2003-2005, kg/ha/yr). Table 2 shows the range of PM2.5 data in the Mid-Atlantic region indexed as a health impact indicator (PM2.5H), indexed as an exercise indicator (PM2.5E), and then indexed as scenic vista or view-shed indicator (PM2.5V).[7] The index values range from a minimum to 1.0 to a maximum of 8.0. Therefore, the actual PM2.5 data values are assigned to an index value between 1.0 and 8.0. For example, in first row of Table 2, the PM2.5H value of 3.0 receives an index value of 2.0 with values between zero and 3.0 receiving index values between 1.0 and 2.0. Any PM2.5H value of 18.0 or higher receives the maximum index value of 8.0. Therefore, since the PM2.5 data are used in three different ways (i.e., three different indicators must be created), stakeholders are provided with three different options to index the data. The MIRA approach gives the stakeholders an opportunity to consider the significance of the data relative to the context that it is being used (i.e., to determine what that data indicates). Since scientists know that lower concentrations of PM2.5 have more damaging impacts to humans with respect to pulmonary disease than to humans interested in engaging in outdoor exercise or to viewing beautiful vistas, the staff scientists choose to index PM2.5 related to human health (PM2.5H) more conservatively than that for the PM2.5 related to exercising (PM2.5E) or viewing vistas (PM2.5V). Similarly, when comparing PM2.5 relative to vistas or exercise, we are willing to tolerate

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[7] The indexing in Table 2 is an illustration of how the same data can be indexed in different ways and how the scientist stakeholders involved in the Mid-Atlantic case study indexed those data. The more important the decision, the more important it is to involve more scientist stakeholders in the MIRA indexing process.

higher levels of PM2.5 for vistas than we do for outdoor exercise because lower levels of PM2.5 are more damaging to exercising than they are to visibility. If, however, the same level of PM2.5 produced the same impact to exercise as to visibility, from a science perspective, we would index these data the same.

Combining these PM2.5 indicators with non-similar indicators, such as crops requiring pollination by bees (BEECROP) and nitrogen deposition (NITRODEP) in the same analysis requires the capability to put all the data on the same decision (or index) scale based on the context in which these data will be used. Table 2 shows how the three PM2.5 indicators are indexed relative to the BEECROP and NITRODEP indicators for this case study. For constructed indicators such as the NITRODEP-S, we index the raw data (NITRODEP in this case) prior to weighting them. NITRODEP-S is an indicator created by weighting NITRODEP with stream density and acid neutralizing capacity, a measure of soil buffering capacity.

Table 2 shows the data values assigned to particular index values based on scientific judgment about the significance of that data within this decision context. The units of the bee crop indicator are hectares (ha) and the units of the nitrogen deposition indicator are kilograms per hectare per year, kg/ha/yr. This means that, for this analysis, nitrogen deposition values of 10 kg/ha/yr or larger were set at the same index value (significance) as 350 000 ha of crops requiring bee pollination and 35 $\mu g/m^3$ of PM2.5 when considered as a pollutant threatening viewing scenic vistas. In other words, the scientist stakeholder knowledgeable about nitrogen deposition impacts and the scientist stakeholder knowledgeable about bee pollination agree that the significance of these pieces of data to the decision context (not the importance, which is discussed as preferencing in the next section), are equivalent. Indexing converts the disparate units of the data into a common decision unit for the analysis. It is important to emphasize that the indexing process must not consider the relative importance of the indicators if scientific judgment (i.e., determining the significance of the data) is to remain separated from the application of societal values. In the next section, we discuss the role of non-scientist stakeholder values in the MIRA process.

4.4. Value Sets, Initial Ranked Set of Options, and Iteration

A value set is a set of preferences articulated by decision makers, which is reflected in the relative weights being placed on each decision criterion. In obtaining a value set, the decision maker or group of decision making stakeholders, as in this case study, are asked to compare two decision criteria (as represented by indicators) at a time and to articulate which is more important to them and by how much (Saaty, 1990). In doing this for every combination of decision criteria used in the analysis, the decision maker is establishing the relative importance of those decision criteria. The relative importance is a question that decision makers can determine independent of a detailed understanding of the scientific data. In other words, a non-scientist decision maker can determine that bee pollination is more important than nitrogen deposition to him without knowing or understanding how the scientist stakeholders indexed that data. Another stakeholder could just as easily determine the opposite: that nitrogen deposition is more important than bee pollination. Figure 2 uses the simplified MIRA hierarchy shown in Figure 1 to illustrate one possible set of relative weights or criteria importance for the composite indicators[8] at the first two levels of the analytical hierarchy for the case study. Note that the relative weights for each branch at a single level of the hierarchy are fractions that add up to 1.0. For example, at the second level of the hierarchy, the relative weights for Disease (0.5), Food Supply (0.4) and Catastrophic (0.1) sum to 1.0 and these three composite indicators define the Human Health branch (or the Human Health composite indicator), which is shown at the first level of the hierarchy.

All the Mid-Atlantic HUC12 areas are ranked by the linear weighted sum of the indexed data (i.e., indicators) and the relative values placed by the decision makers on those indicators (representing decision criteria). Each HUC12 area will have a criteria sum calculated in this manner. Higher criteria sum values mean that the area is in poorer condition than those areas with lower criteria sums, as determined by stakeholders with respect to the data's meaning or significance (indexing) and the relative importance of the decision criteria (preferencing).

Through the examination of the resulting run and asking questions about why some areas ranked higher than others, decision makers can experiment with 'what if' scenarios by altering value sets and comparing the new results with the previous runs. Table 3 illustrates how decision makers can learn through iterative runs. The top ten HUC12

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[8] At the first two levels of the hierarchy, the indicators are composites because the raw data occurs at a deeper level in the hierarchy and it is the linear weighted sum of the indicators. For example, a composite indicator at the first level of the hierarchy will be composed of the linear weighted sum of the indicators at the second level of the hierarchy.

areas are selected to show how their relative ranks change when the value set changes but the data and indicators remain the same. Lower rank numbers indicate a worse condition (i.e., higher criteria sums). The four runs used as an example in Table 3 represent 1) “Cons,” a consolidated run derived by facilitated discussion among EPA Region III senior decision makers, 2) “Equal,” a run reflecting all criteria as equally important (a benchmark run), 3) “Health,” a health focused run with human health related indicators deemed more important than human welfare indicators, and 4) “Welfare,” a welfare focused run with human welfare indicators deemed more important than human health indicators. These runs are discussed in more detail in the Results section. These are only four of the many possible value sets that can be examined within MIRA.

5. Results

5.1. Learning about the Condition of the Mid-Atlantic environment

For this case study, the mixed scientist and non-scientist stakeholder group consisting of EPA Region III senior managers and staff define the condition of the Mid-Atlantic environment as that represented by the 187 indicators arranged hierarchically as partially shown in Figure 3. Figure 3 shows the hierarchy reflecting the decision question for the case study while illustrating the locations in the hierarchy for the PM2.5H, PM2.5E, PM2.5V, BEECROP, and NITRODEP-S indicators.

By using information about the HUC12 areas at the top of the list (poor condition) and bottom of the list (good condition), stakeholders can benchmark the analysis and gain a more thorough understanding of those areas in the middle of the ranked range. With the inclusion of both health and welfare criteria in this analysis, it is possible for decision makers and other stakeholders to test “what if” scenarios that encompass a mix of human health and welfare concerns and examine the results.

Table 3 shows the top ten ranked HUC12 areas in each of the four runs (same indicators, different value set). In all four runs in Table 3, Frankford Creek and Big Timber Creek are ranked either as the area of the worst condition (1) or second worst condition (2); while Cameron Creek varies from a rank of 10 to a rank of 16. These areas are only ten of nearly 3700 HUC12 areas in the Mid-Atlantic region. In general, areas at the top of the list and at the bottom of list may move positions as the value sets change but will move within a relatively small range. The areas at the top of the list are the “obviously” poor condition areas. The areas at the bottom of the list are the “obviously” good condition areas. For these areas at the top or bottom of the ranked list, most of the characteristics (as represented by decision criteria), can be categorized more clearly as either poor or good.

However, for the decision makers knowledgeable about the condition of the environment, the areas at the top and bottom of the ranked list do not necessarily require much analysis to determine. It is more useful to these decision makers to examine the HUC12 areas in the middle range of this ranked list. This is the area in which decision makers are likely to be less certain as to the environmental condition and can benefit from the use of an approach that applies the science and articulated value set consistently. These mid-range areas have characteristics that straddle good and poor conditions, depending on how the decision makers want to value those criteria. In other words, it is not as obvious as to whether a particular area in this mid-range is poor or good; it depends on the value set.

For example, Table 4 shows how ten mid-range HUC12 areas change relative ranks using the same four value sets used in Table 3. As can be seen with these mid-range areas, as the value sets change, decision makers can see how these area ranks change even more drastically than the ranks for the areas in Table 3. By studying the HUC12 areas and their relative ranks through a variety of different value sets, decision makers can learn about which decision criteria drive which areas to change ranks (either higher or lower).

Using the four example value sets discussed above, decision makers can begin to characterize particular HUC12 areas as health-oriented areas or welfare-oriented areas. For example, in Table 4, Backlick Creek, ranks 719 when a health-focused value set is used but is ranked 382 when a welfare-focused value set is used. Backlick Creek has more serious problems (as characterized by the decision criteria) pertaining to welfare but is perceived as being in substantially better environmental condition if a health-focused value set is used. Through this unique kind of learning resulting from the integration of science (which in this example, is invariant) and values (that which we vary to produce different perspectives), decision makers can gain a richer understanding of the relative environmental condition of a particular watershed when different perspectives are used.

Figure 4 illustrates the spatial integration of all the decision criteria in a combination of indicators and values across the U.S. Mid-Atlantic. The four maps of this region show four different perspectives of the condition of the environment based on the same indicators. Value set A represents a perspective that all the decision criteria are equally important to the decision maker. By starting with setting all decision criteria as equally important, decision makers can initially benchmark the HUC12 areas and then examine the relative rank changes of those areas as different Health or Welfare indicators are weighted more or less heavily.[9] Value sets C and D represent a human health- and a welfare-focused perspective, respectively. Value set B represents a consensus view, obtained through the examination of and iteration among different stakeholder perspectives. In Figure 4C, the human health focused value set substantially changes the spatial view of the region when compared with Figures 4A (Equal Preference run) and 4B (Consolidated preference run).

In the maps in Figure 4, darker areas represent higher criteria sums or areas of poorer condition and, therefore, of greater environmental concern. For example, the dark areas in map C are primarily high population centers, reflecting the focus on human health decision criteria. Along the coast from north to south, these high population areas are

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[9] Note that there is an inherent importance among criteria clusters within a decision hierarchy by virtue of the location of those clusters in the hierarchy. This variation is not a statement of preferences as revealed by the preferencing step in MIRA but rather a reflection of the importance of the criteria based on the decision context or the decision question, which is used to structure the decision hierarchy.

Philadelphia (PA), Baltimore (MD), Washington D.C., Richmond (VA; slightly inland), and the Norfolk (VA) areas. Comparing maps C (health-focused) and D (welfare focused), there is greater emphasis in the lower population areas (e.g., central PA and WV) in map D when indicators representing the ecosystem integrity and human welfare decision criteria are valued more highly.

Decision makers can also use this kind of information to prioritize implementation actions. For example, in Figure 4B, there are several HUCs on the Delaware eastern shore (adjacent to the Atlantic Ocean) that are highly ranked (poor/more vulnerable condition) but these areas rank lower (better/less vulnerable condition) in Figure 4C when the emphasis is on Human Health. Since Figure 4B represents the values based on the consensus of EPA Region III senior managers, these decision makers are choosing to identify these Delaware HUCs as having more serious human welfare (compared with human health) issues, which could warrant increased attention. By examining these figures and then comparing specific HUC12 areas in the tables, stakeholders can gain an increased understanding of the factors contributing to the assessment of particular areas as in good or poor environmental condition as defined by the case study analytical hierarchy and indicators.

MIRA is designed for decision makers and other stakeholders to use iteratively, applying information gathered from one run to inform how to construct the next run. By performing some additional runs using modified value sets, decision makers and other stakeholders can better visualize the contribution or impact of just human health decision criteria or just welfare decision criteria within the MIRA analysis. For example, by starting with the value sets that produced Figures 4C and 4D, we can modify each of these runs by removing the contribution of human health or welfare decision criteria, respectively. The maps that are the product of these runs are illustrated in Figure 5. Figure 5A is a spatial representation of the ranked 3700 HUC12 areas in the Mid-Atlantic using the value set that produced Figure 4C (human health-focused) but with one modification. This modification was to put no value or weight on any Welfare or Future Vulnerability decision criteria. The result is that only human health criteria are used but in the same proportions that generated Figure 4C. Figure 5B is a map of the ranked areas generated by starting with the value set that produced Figure 4D (welfare-focused) and placing no value or weight on any Human Health or Future Vulnerability decision criteria. The result for Figure 5B is that only welfare criteria are used but in the same proportions as that which generated Figure 4D. Since the scales in Figures 5A and 5B are the same, one can also compare the relative severity of the problem between the two maps. Overall, Figure 5B is a darker map indicating that when viewed with an exclusively human welfare perspective, the condition of the Mid-Atlantic environment appears poorer or more vulnerable than when the area is viewed with an exclusively human health perspective (Figure 5A). As the stakeholders use this information with other analytical runs, it becomes possible to gain a better understanding of the problem and perhaps suggest possible policy options to evaluate. Figures 4 and 5 are illustrations of the learning that is possible through the examination of different value sets. By altering the value sets, decision makers can examine how the perceived condition of the environment (as well as the spatial distribution of the problem) “changes” when the indicators remain the same but the perspective of how those indicators are viewed changes.

In the Mid-Atlantic region, areas where landscape criteria dominate (e.g., forests, streams) became more prominent when a stronger emphasis or value is placed on the welfare aspects of the hierarchy). In this study, stakeholders discovered the extent to which even urban areas have a strong connection with landscapes through their impacts on drinking water quality, food supply, and recreation. The case study demonstrated the interconnectedness between public health and ecosystems without the typical "competition" between these two perspectives of the environment.

5.2. Learning about Data and Indicators

It is also possible to learn about the relative contribution of particular data and indicators to the overall analysis. In Figure 6, the five example indicators (which represent five decision criteria in this analysis) are shown with their relative percentage contributions to the overall assessment of the condition of the Mid-Atlantic environment (using the Consolidated Run value set). Note that these percentage contributions are the relative contribution of the decision criteria, which are combinations of indicators (data as indexed by experts for this analysis) and values (as determined by decision makers for this analysis). The relative percentage contributions are the criteria sum for each criterion divided by the total criteria sum of all decision criteria. Therefore the height of the bars in Figure 6 represents the significance of the scientific data (as judged by the EPA

Region III staff scientists) as adjusted by the relative importance of those criteria (as judged by the EPA Region III senior managers). Since the PM2.5 data and the NITRODEP data were used for multiple indicators in this analysis, it is also possible to calculate the contribution of those data to the entire analysis (using the Consolidated Run value set). This is shown in Figure 7. The heights of the bars in Figure 7 represent the combination of both the science and values for the three pieces of data (PM2.5, BEECROP, and NITRODEP) as used in this case study. The contrast between Figures 6 and 7 highlights the capability of users within a MIRA analysis to consider the contextual import of individual pieces of data, particularly those data that are used for multiple indicators within the analysis. When resources are scarce, this kind of information could help data managers determine what data gaps may be more important to fill for the specific decisions that need to be made.

6. Discussion

As a result of this analytical collaboration, EPA Region III managers and program staff gained insight into the condition of the Region through the examination of data, indicators, and the perspective by which those indicators can be viewed. Typically, program managers and staff were isolated within their own programs and rarely had opportunities to participate in a more holistic environmental analysis. Some found it surprising to discover that their programs were either more far-reaching or less far-reaching than they supposed. Via the indexing step in MIRA, discussions about the relative significance of, for example, the PM2.5 scenic vistas indicator versus the bee crop indicator forced these stakeholders to view the environment as a system instead of a collection of single issues or programs. Furthermore, experimentation with value sets calmed fears among the scientist stakeholders that science data was being changed by others without an understanding of the science. Once the scientists agreed to the indexing, managers were permitted to experiment with any value set in order to construct a variety of regional views. Although each of these pictures were dramatically different spatially and with respect to which indicators ranked as more important, in each of those views, the science data remained constant.   In other words, managers did not alter either the scientists' indexing of the data or the data itself.

The capability to have scientists participate in judgments related to indexing and then to have decision makers examine the condition of the Mid-Atlantic environment based on a consensually derived value set allows for policy discussions about sustainability. This discussion begins with an understanding of the current environmental condition as informed by data and values that address the questions of what to sustain (e.g., human health, scenic vistas, crops requiring bee pollination), for whom to sustain it (those vulnerable to PM2.5 disease or those affected by ecosystems impacted by nitrogen deposition), and at what cost (tradeoffs among disease, scenic vistas, nitrogen deposition, and other interests represented by the stakeholder determined decision criteria). Controlled by the participants but guided by a transparent and inclusive process, stakeholders can begin to understand how values influence the perception of the environment. Particularly when there are controversial issues, stakeholders may find it easier to "hide" behind the science rather than debate the issue of values. Absent a transparent framework and approach for the discussion, it can be very difficult to resolve stakeholder conflicts. In those situations, advocacy science is often practiced and it becomes difficult to separate the non-controversial aspects of the science from the scientific uncertainty and from the values. While there are scientific uncertainties that should be discussed among scientist stakeholders, conflicts in the non-scientist stakeholder discussions are usually about values. However, with a transparent approach like MIRA and armed with an understanding of the impact of values on decision criteria identified by the stakeholder group, it is now possible to use this as a basis for testing "what if" scenarios within a sustainability discussion.

Based on the results of this case study, the EPA Region III senior managers are currently implementing a program of priorities influenced in part by the information learned. Programs of action and of research are currently being conducted in both areas of good and poor environmental condition, and in areas where we need to understand the impacts of pollutants and human activity better.

7. Conclusion

The Mid-Atlantic case study demonstrates the increased capability to have sustainability discussions when a transparent approach such as MIRA allows for the inclusion of science and values in environmental analysis. Additional benefits of this approach with respect to how data are used and gains in learning are also illustrated in this case study. These are: 1) the capability to use the same data in different ways to represent different environmental concerns, 2) the judgment about whether the environment is in good or poor condition is a matter of science and perspective (i.e., values), and 3) improved understanding of environmental condition is facilitated by a discussion of values among the stakeholders as framed by the science.

Through the MIRA framework and approach to decision analysis, participants in this Mid-Atlantic case study were able to apply their expertise in areas of air, water, land, and waste toward a more holistic perspective of the environmental condition of the area. Together, these participants learned how data become indicators, to what extent indicators adequately represent decision criteria, and the relationship between science and values for evaluating the decision question pertaining to the condition of the Mid-Atlantic environment. This kind of learning would not otherwise have been possible working in individual fields of discipline, programs or stakeholder groups. Therefore, while it is possible for stakeholders to examine data/indicator details in any part of the case study analysis, providing context in the form of the decision question (as represented by the MIRA hierarchy) is essential for supporting the capability to see how those details relate to the larger environmental view and for supporting discussions about sustainability. With the capability to integrate ecological landscape data with more traditional environmental programmatic indicators, the participants could consider landscapes more integrally to the assessment of the Mid-Atlantic environment.

Assessing the current condition is a prerequisite to the sustainability discussion but, alone, it is insufficient. The MIRA approach helped this group of stakeholders take another step toward sustainability because the distinction between, as well as the integration of, science and values became more transparent to all stakeholders in the process. Imperfect data, indicators, and descriptions mean that the indicators do not necessarily exactly represent what stakeholders want as decision criteria but they are often the only information available to make decisions now. Rather than seeking a perfect description of the entire environment or ecosystem, the MIRA process uses existing information to facilitate an increased understanding of the choices that are being made – in other words, what is being decided for whom, for how long, and at what costs. The move toward sustainability is still difficult but as our understanding of science, values, and the intertwined social-environment system improves, we believe that we can move toward sustainability, one decision at a time.

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Tables and Figures accompanying the paper, “Toward Sustainability: The Integration of Science and Other Stakeholder Values; One Decision at a Time” submitted for publication to the Journal of Environmental Management on February 2, 2009.

Indicator (units)	Minimum	Maximum	Mean	Median
PM2.5 (ug/m3)	5.85	30.74	11.37	10.43
BEECROP (hectares)	0.00	477745.00	9528.99	2177.00
NITRODEP (kg/ha/yr)	0.00	7.01	4.30	4.23

Table 1. Some Data Statistics for Sample Indicators Used in the Case Study.

INDEX VALUES	**Indicator**				
	PM25DV-D	**PM25DV-E**	**PM25DV-V**	**BEECROP***	**NITRODEP**
>1.0 to ≤ 2.0	<3	<10	<12	<1	<1.67
>2.0 to ≤ 3.0	≥3.0 to 8.0	≥10.0 to 14.0	≥12.0 to 15.0	≥1 to 10	>1.7 to 3.06
>3.0 to ≤ 4.0	>8.0 to 12.5	>14.0 to 16.0	>15.0 to 20.0	>10 to 50	>3.06 to 4.44
>4.0 to ≤5.0	>12.5 to 15.75	>16.0 to 17.0	>20.0 to 23.0	>50 to 80	>4.44 to 5.83
>5.0 to ≤ 6.0	>15.75 to 16.5	>17.0 to 18.0	>23.0 to 25.0	>80 to 120	>5.83 to 7.22
>6.0 to ≤ 7.0	>16.5 to 17.25	>18.0 to 19.0	>25.0 to 30.0	>120 to 180	>7.22 to 8.61
>7.0 to ≤ 8.0	>17.25 to 18.0	>19.0 to 20.0	>30.0 to 35.0	>180 to 350	>8.61 to 10.0
8.0	>18.0	>20.0	>35.0	>350	>10.0

*Multiply values by 1000

Table 2. Sample of Indexed Indicators Used in the Case Study

Name of HUC	**Cons**	**Health**	**Welfare**	**Equal**
Frankford Creek	1	1	2	1
Big Timber Creek	2	2	1	5
Schuylkill River	3	3	4	3
Back River	4	6	3	2
Potomac River	5	4	6	4
Gwynns Falls	6	5	5	6
Anacostia River	7	9	9	7
Pennypack Creek	8	7	10	14
Darby Creek	9	11	8	9
Cameron Run	10	16	13	12

Table 3. Top 10 watersheds showing relative ranks across four different runs.

Name of HUC	Cons	Health	Welfare	Equal
Cowanshannock Creek	500	282	441	377
Reed Creek	501	407	83	296
Little Muncy Creek	502	807	452	865
Marsh Creek	503	641	1151	1292
Backlick Creek	504	719	382	295
Kanawha River	505	424	1280	793
Pigg River	506	243	523	466
Redbank Creek	507	246	128	468
Mahoning Run	508	864	906	536
Susquehanna River	509	252	660	476
Delaware River	510	460	865	1758

Table 4. Mid-range watersheds showing relative ranks across four different value sets.

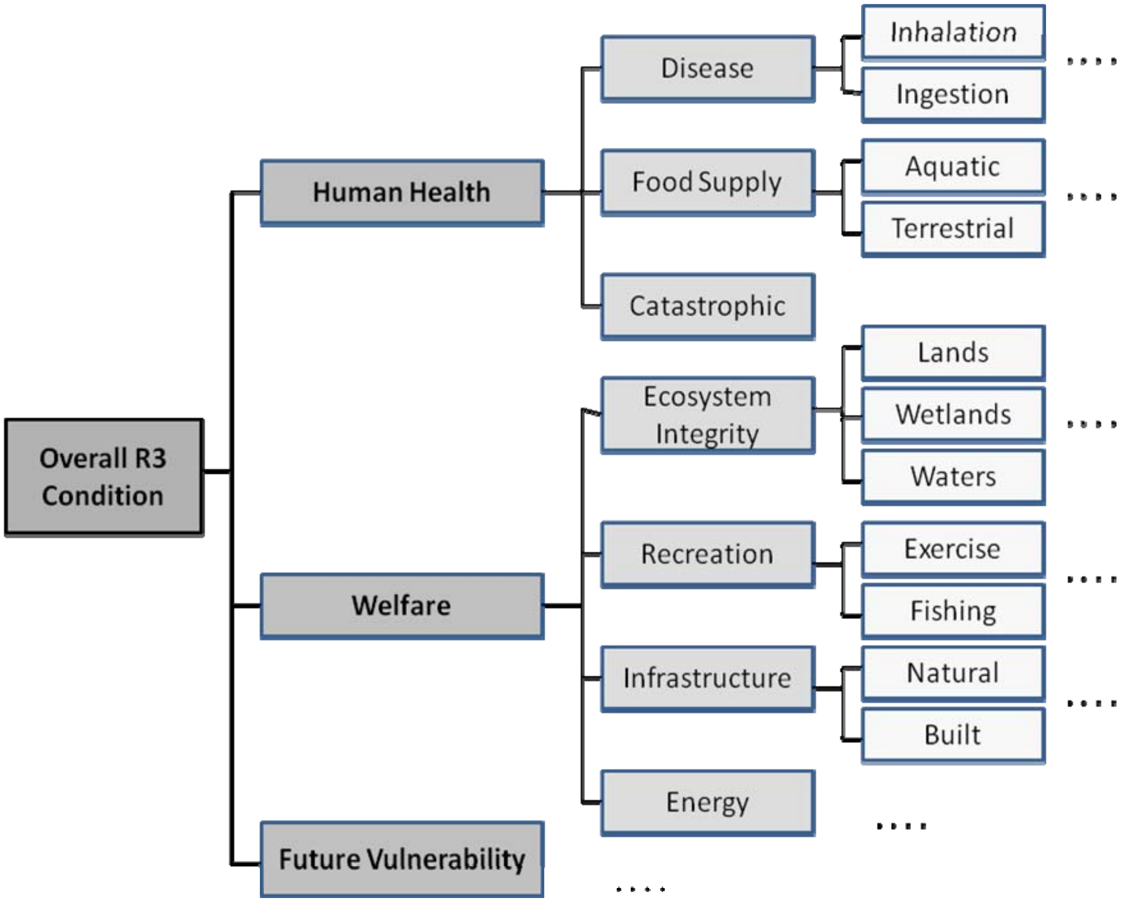

Figure 1. Simplified MIRA Hierarchy; Reflecting the Decision Question for the Case Study

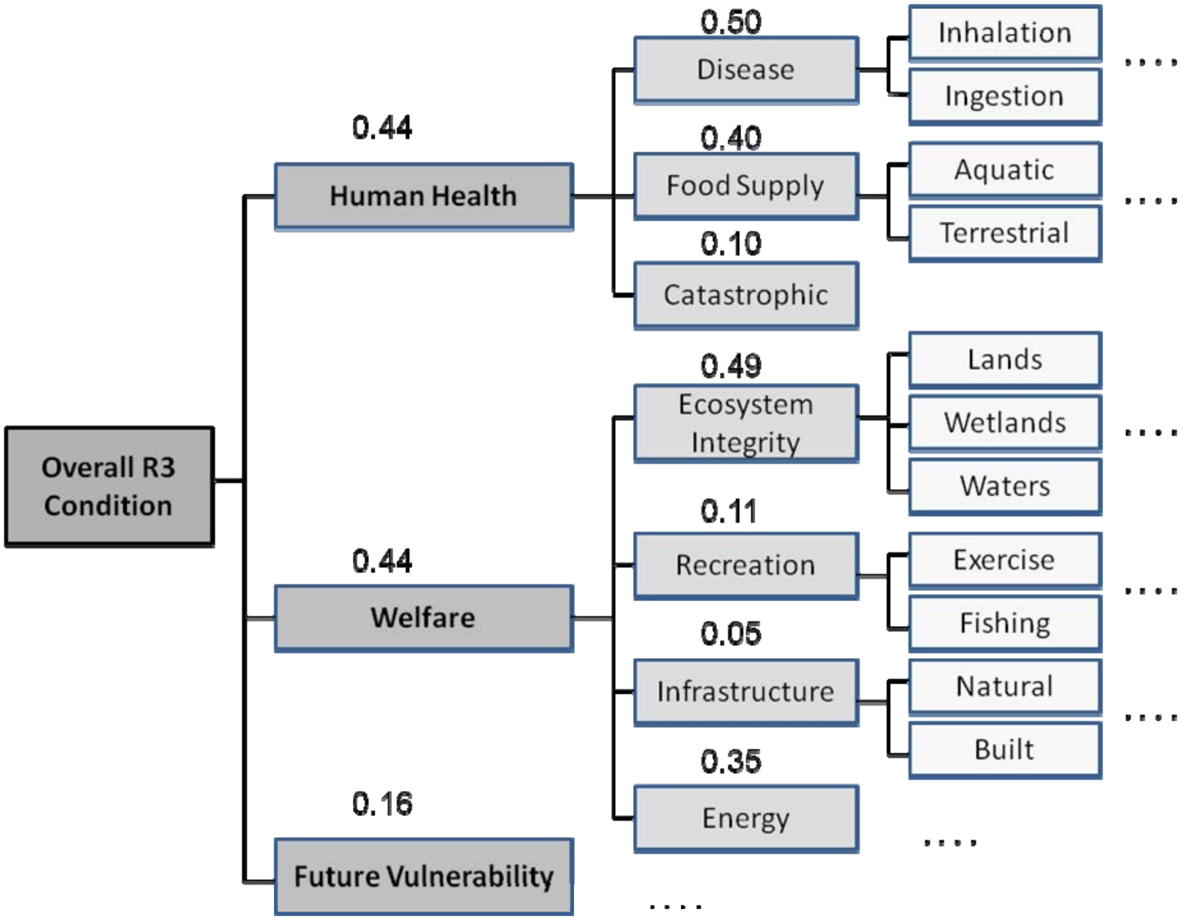

Figure 2. Simplified MIRA Hierarchy for the Mid-Atlantic Case Study: Relative weights for the first two levels of the hierarchy for one possible value set.

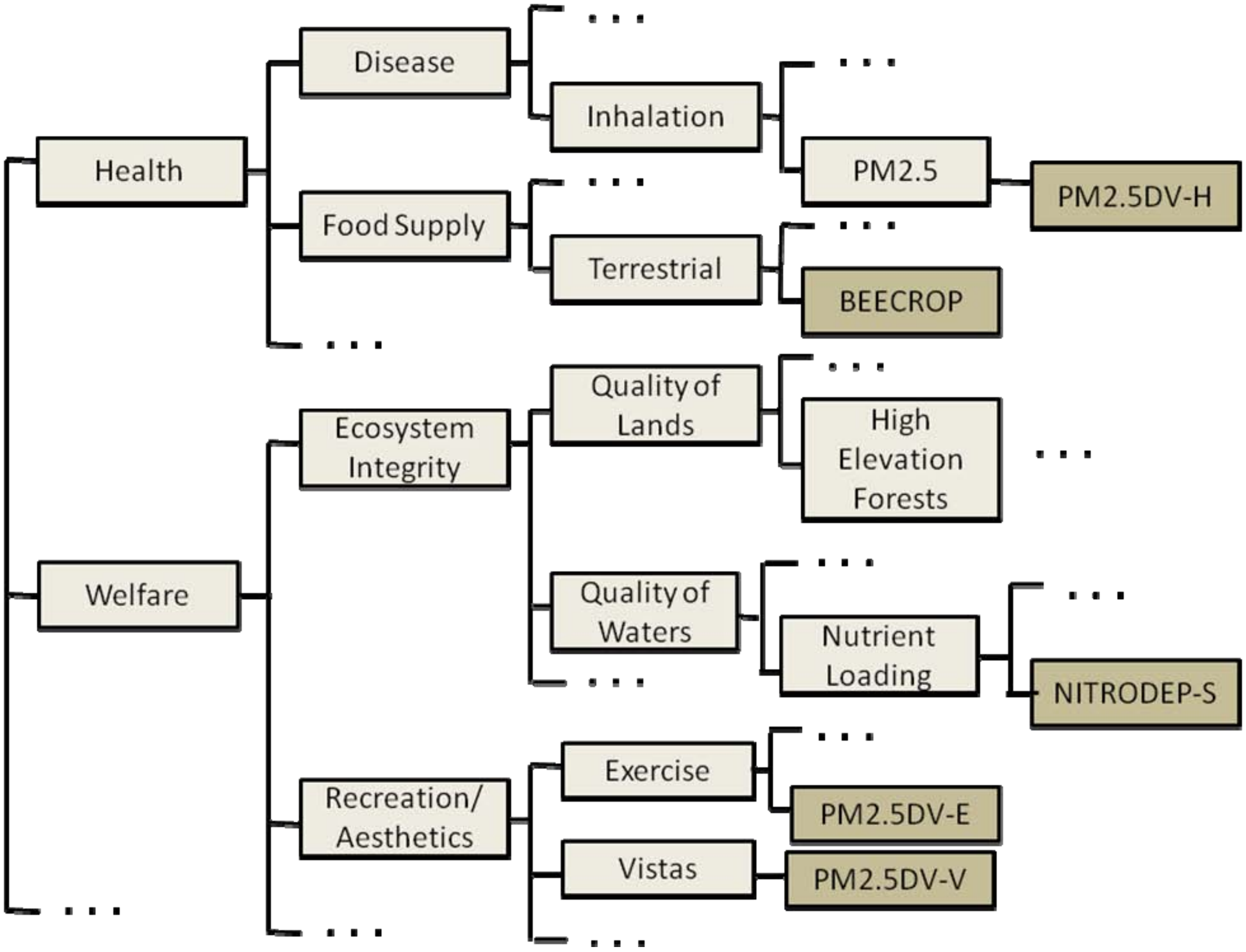

Figure 3. Partial Hierarchy for the case study, showing locations of the PM2.5 indicators, BEECROP and NITRODEP-S indicators.

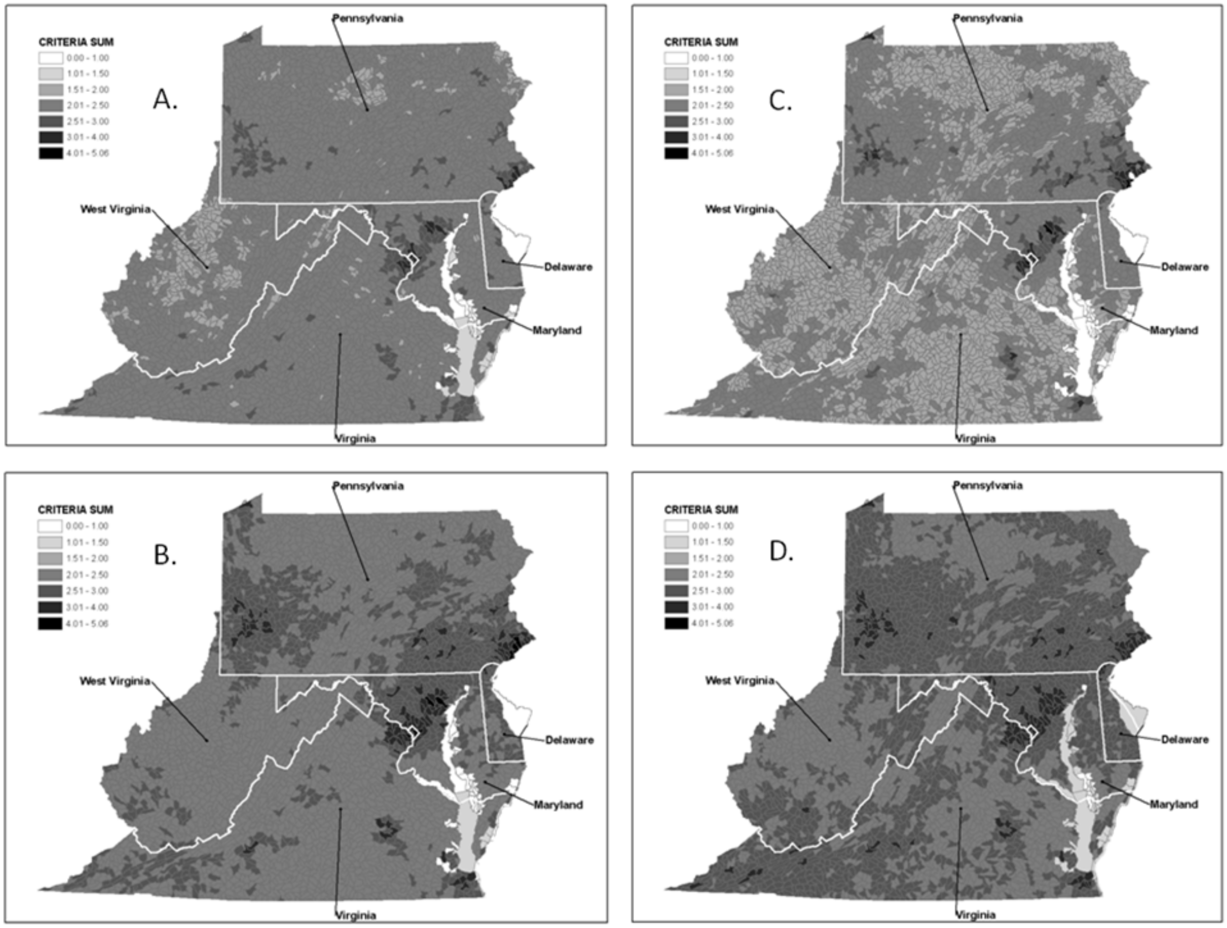

Figure 4. Four Different Perspectives Using the Same Data. A. Equal Preference value set, B. Consolidated Preferences value set, C. Health Focused value set, D. Welfare Focused value set.

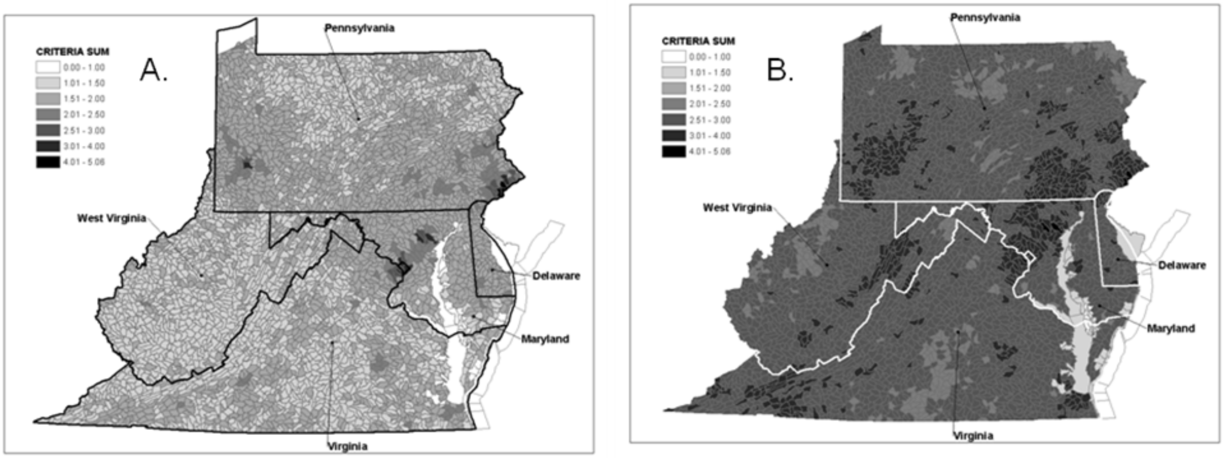

Figure 5. Two additional perspectives. A. Health-focused value set with all welfare components zeroed out. B. Welfare-focused value set with all health components zeroed out.

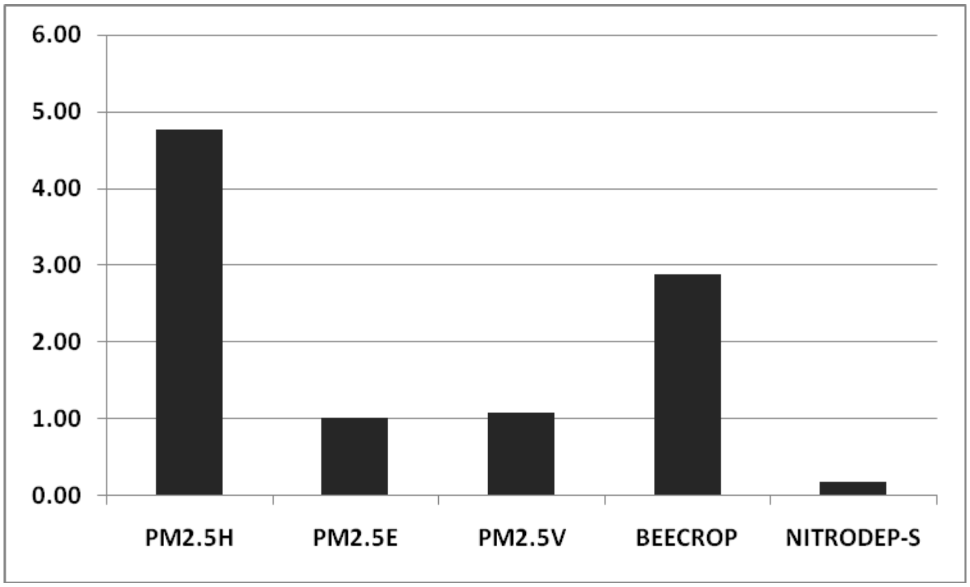

Figure 6. Relative percentage contribution of the five example indicators to the overall analysis.

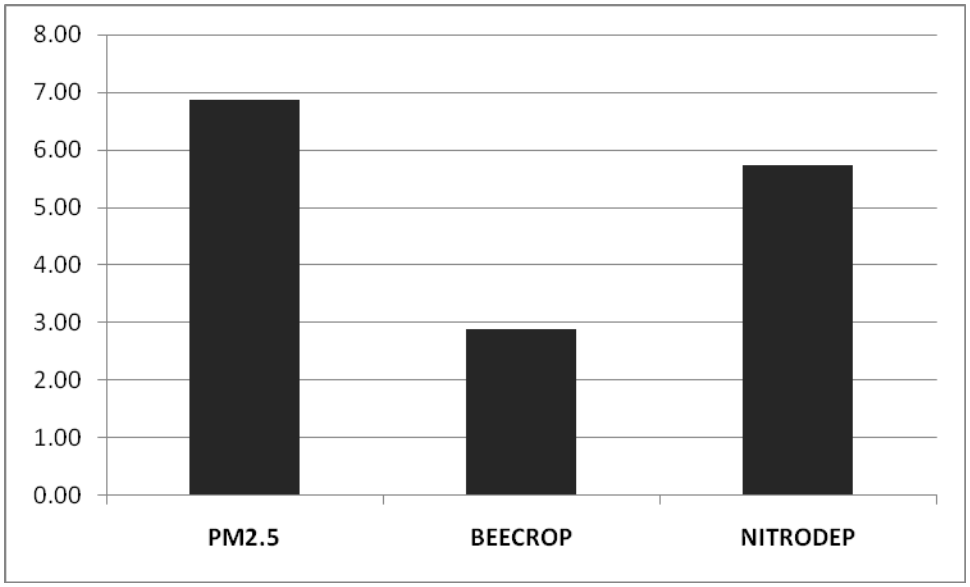

Figure 7. Relative percentage contribution of the raw data used in the example indicators to the overall analysis.