PART 1: INTRODUCTION TO EMPLOYING MULTIPLE PERSPECTIVES

It's a plant! It's a carnivore! But wait there's more!

Chapter 1. Introduction

1.1 Being part of the solution

The reason to study environmental issues is to be part of the solution. We all want to help solve environmental problems either as scientists, policy makers, as citizens or in some combination of roles. Our motivation for solving these problems is straightforward; we want a better life for more people without wasting our resources and spoiling the planet. But in our drive to solve these problems we need to be thoughtful and not cause other problems along the way. The agricultural philosopher Wendell Berry (1981) explains that there are three ways to act on a problem. First we can really not solve it all, second we can solve it in one place by pushing the problem somewhere else, and third (and only real solution) is to solve the problem in the context and pattern of its origin. Although it may seem obvious that the first two don't really work, it is not easy to solve any significant problems in the pattern. For instance, how do we know the total context for a particular problem? How do we know if we are missing a piece of the overall picture? What if we discover later that our solution just moved the problem elsewhere? Consider the case of dairies. The purpose of dairies is to provide milk, but along the way they create much more cow manure than milk. One way to deal with this is to flush the manure away (causing a problem somewhere else). Another method is to put the manure into a high-tech treatment facility (turning the dairy farmer into a sewage treatment operator). A third way, suggested by Berry, is to have a dairy of just the right size such that the amount of manure generated can be composted and spread back on the grazing lands, thus keeping with a pattern of ecological cycling. Thus the problem of running a commercial dairy has multiple contexts including, business, farm practices, ecological processes, and social values.

This book addresses the challenge of identifying environmental problems, viewing them in different contexts and employing a range of cognitive tools to better understand the problem. First, we will examine four basic types of environmental problems and look at how these problems and the central concepts of Environmental Science are connected. Second, we will look at example problems with cognitive tools that can be used for exploration and diagnosis. In the beginning these tools are simple to use and limited in scope. You can practice with each tool on problems that have been designed to illustrate the benefits and limits of each particular approach. Third, we will examine problems from multiple viewpoints; each view provides some overlapping information but also some unique perspectives on the problem. After practice with individual tools and comparing them, we will discuss how this strategy helps us to solve problems in the larger pattern or global context. Finally, we will discuss how to evaluate your personal progress, the progress of a project or group working on a problem and the value of your contribution to the group. Even though this is the last chapter of the book, the evaluation process should be taking place all the time as you learn, as a project is proceeding and for the formative assessment of your contribution.

Table 1.1 Layout of the sections of the book (**would be better in landscape mode)

Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
Problem Types, content and preview of the framework	Exploratory and Diagnostic Tools	Creating and judging narratives on three dimensions:	Choosing appropriate modes of engaging the problem	Evaluation
Problem types: *Simple* *Community values* *Information demand* *Wicked*	Tools: *Patterns* *Scale* *Stock and Flow* *Network* *Accounting* *Risk/Uncertainty* *Values/Worldviews* *Optimization* *Games*	Dimensions: *Control* *Uncertainty* *Values*	Modes: *-Innovation* *-Institutions* *-Project management* *-Scenarios* *-Scientific Adaptive Management* *-Environmental Entrepreneurism*	Evaluate: *Personal* *Project* *Contribution*

Environmental education is supposed to create scientifically literate citizens. The responsibilities of citizens have continued to grow. As problems become more complex, with many moving parts to consider at once, citizens need to be able to see how the problem effects larger areas and longer time scales. They also need to be able to make decisions on limited and imperfect data. It is often necessary to be able to make decisions under conditions of uncertainty or ambiguity. This challenge is exacerbated as new technological problems meet traditional government institutions. It is almost impossible for scientists to stay abreast of progress in their own narrow disciplines let alone elected officials or agency administrators. The highly technical nature of some aspects of environmental science (for example the debate on the toxicity of pesticides) requires an understanding of multiple academic disciplines and several areas outside of normal academic life. Just as being "literate" in English doesn't mean you know all the answers, being environmentally literate is more about knowing how to address the question and the ability to draw on your experience and outside information resources as appropriate.

Sidebar: Are we dumber than we used to be?

Rapid change in technology and the access to energy has created a situation where new discoveries, inventions, innovations, or processes can be implemented on a global basis almost immediately. Do we really know enough to be able to make decisions about these new processes?

For example, consider the invention of chloro-fluoro-carbons, "CFC"s, which took place in an industrial research lab. The rapid adoption of CFCs into refrigeration led to their worldwide use. Better refrigeration lead to many health benefits and reduced loss of food. After a while it was discovered that these chemicals were changing the balance of ozone production and decay in the upper atmosphere and could lead to dramatic and damaging increases in UV radiation. Essentially we were ignorant of the effects of CFCs and it took many scientists many years to accumulate data to show the potential damage. A novel chemical put into the industrial stream, had created a gap in our knowledge, i.e. created ignorance.

It is argued that we may be able to create new products faster than we can test them? Are we producing more uncertainty and ignorance that we can handle?

We will address this further in Chapter 15 on the innovation gap.

Citizens need to have at least these intellectual assets to be literate in environmental science:

1) They need to be able to sense and become aware (from the data, descriptions or personal observations) that there is an environmental problem.

2) They need to be able to key in on particular aspects of the problem that suggest possible approaches for solving the problem.

3) They need to know that they are supposed to act, either to get more information or to participate in solving the problem.

Thus, citizens need to be able to "understand" environmental problems, using Perkin's (1998) definition of understanding. To understand is to be aware, to sense a situation and then to do something about that awareness. This definition of "understanding" is very active; it is not simply a mental image of a problem. Just as with the infinite shampoo loop (wash, rinse, repeat), understanding is a never-ending process to build context around observations and actions.

Humans have unprecedented power to change their environment. In fact, it has been suggested that we call the current era the “Anthropocene” era. We have harnessed energy sources and can direct this energy using very powerful technologies. But the power of science and technology should be balanced with responsibility, and it can be argued that the changes (progress) in scientific and technological tools have outstripped the intellectual, social, institutional, and ethical tools to do the job. For example, the possibility that we could genetically engineer human cells challenged the ability of people to make decisions in a novel arena.

Similarly, advances such as nuclear power, genetically modified seed stock, and artificial hormone pesticides have outstripped human problem-solving approaches for addressing these in the whole pattern. We are now dealing with a new type of modernity (Gross 2010), where the future will not only be qualitatively different than the past such that we can't predict what will happen, but also might be being determined right now by our choices of technology even thought we don't understand it. A very real part of the problem is the "advances" themselves. Technology can only create part of the solution. If our society only creates the machines or the chemicals and doesn't bother to simultaneously disseminate information and create the institutions that are necessary for using these advances responsibly, then we will have failed. For example, we live in a country where anyone can buy a chainsaw, almost anyone can buy a gun and some bullets, or on a whim one can go to the store and buy a gallon of Roundup for home use. All of these items are both useful and potentially very destructive to the environment.

Sidebar: What do we mean by "progress" vs. "providence"?

Progress

moving forward, onward, advance;

the advance or growth of **modern**, industrialized society, its technology, and its trappings

Providence

The **prudent care and management of resources**.

The careful guardianship exercised by a deity.

A manifestation of divine care or direction.

Our society's notion of progress is closely related to the positivist ideas of what is modern. Norgaard (1996) claims that "modern" is also wrapped up in the assumption that science brings progress. So, "progress" and "modern" are reinforcing concepts. We need to re-evaluate our assumptions about what we really want. The underlying assumptions of industrial progress are discussed in Chapter 11: Optimization of Efficiency. Our value systems and how we make decisions will be addressed in Chapter 10: Values and Worldviews.

Our goal should be no less than to learn to live in a way that leads to permanence, health, beauty and peace. These "lofty" goals are value laden and require more sophisticated approaches than just measurement of financial costs and benefits. A serious challenge for environmental science is facing the larger picture of the personal and societal values that go beyond just the economic values and rational decisions. As Schumacher (1973 page 20) wrote:

> "Scientific or technological 'solutions' which poison the environment or degrade the social structure of and man himself are of no benefit, no matter how brilliantly

> conceived or how great their superficial attraction. Ever-bigger machines, entailing ever-bigger violence against the environment, do not represent progress: they are a denial of wisdom. Wisdom demands a new orientation of science and technology towards the organic, the gentle, the non-violent, the elegant and beautiful."

It's not just science that will be able to save us either. David Orr summed this up in a chapter entitled "What good is a rigorous research agenda if you don't have a decent planet to put it on?" (Orr 1992).

Some of the environmental problems that will be presented and studied in this text seem overwhelming in their scale and power. Large scale, high-energy intensity, complicated social systems and the inertia of existing technology are the defining characteristics of the current environmental crisis. Our society definitely has an "energy crisis" because we have been "solving" all of our problems by using too much power. Applying more energy and at a larger scale can actually increase the uncertainty or indeterminacy in the system, applying more effort pushes these systems further away from stability (Adams 1988). For example, using more powerful tools and machinery in the forest can lead to qualitatively different outcome than simply getting the same job done more quickly with more loggers and small equipment.

When we think about the juggernaut of globalization (Giddens 2003) or the seemingly intractable political issues surrounding global warming, it may seem as if individuals could have no real effect on controlling or reversing the destructive activities and trends. One theme of this book promotes Gidden’s vision that every individual has agency and can play a powerful role. This is not based on unrealistic optimism, but follows from looking at problems from many different disciplinary and stakeholder perspectives. Applying multiple views to the question, "how can we contribute to the health of our environment?" results in an understanding of how individual actions can support feedback controls, lead to changes in a network, aggregate with other individual actions and lead to emergent changes at larger scales. In our society there are people who incorporate sound environmental principles into their every-day activities. If these people lead their innovative lives in a visible manner, other people will adopt and adapt their ideas. These relationships of creativity and imitation are not just important in fashion, music and the arts, but in mundane, everyday activities. Processes that mix ideas throughout our culture are key to creating a viable society (Toynbee 1946). Every day each of us are involved in this process of creating, innovating, and adopting new ideas that relate to sustainability. Our progress toward a sustainable future will include technology of course, but that technology will be guided and controlled by the social structures that we develop as we use it. Each of us can contribute to a sustainable future by gaining a better understanding of environmental problems from multiple perspectives.

1.2 Lists of major problems that are addressed by Environmental Science

Environmental Science as a discipline has historically identified problems in which there is a science or technology component and policy alternatives. Related disciplines, such as Environmental Economics, Environmental Sociology, and Environmental Policy would address many of the same problems with a different emphasis. These connections will be explored later in this book.

Two lists of problems are presented here for comparison. The first list is from Industrial Ecology (Graedel and Allenby, 2003) and the second list is one that I constructed. These are just two possible ways to sort out problems from a large selection of valid lists of problems and environmental crises. Every item in both of these lists demonstrates that problems occur over a wide range of scales, they involve human impact and technology, and each has scientific, technological and social dimension.

List 1: Graedel and Allenby (2003) prioritized by severity

global climate change
human organism damage
water availability and quality
resource depletion: fossil fuels
radio nuclides
resource depletion: non-fossil fuels
landfill exhaustion
loss of biodiversity
stratospheric ozone depletion
acid deposition
thermal pollution
land use patterns

smog
esthetic degradation
oil spills
odor

List 2: List of environmental problems that interact with each other. The list is not ranked by importance.

population growth and human consumption
habitat destruction, loss of natural capital, pollution
climate change
energy use, resource consumption and side effects
agriculture/forestry/mariculture processes
depletion of water resources
urbanization that leads to unlivable conditions
air pollution
loss of biodiversity

Other lists or taxonomies can be created with a focus on the scale of the problem (local to global), potential costs to address, or types of technologies that will need to be employed to address them. Chapter 2 will explore how the problems and the concepts we use to describe them are related.

1.3 Values as part of environmental issues

Scientific environmental management deals with problems. A problem is a situation that we have judged could be better or needs to be fixed. Thus even the idea of an environmental problem includes a judgment or decision relative to what is and what could be. Some scientists argue that science should be objective and not include values into their work because it might bias the results or sway the research in some manner. Bias is definitely a cause for concern and there are times when science should be done as objectively as possible (such as in lab trials for a drug or pesticide or when developing a new method). But in environmental science and management the larger questions (i.e. larger than just one set of lab experiments or development of a new method) are problem driven, not the products of "pure" or curiosity-driven research. Thus we need to address how individuals and society value different outcomes or approaches. Pielke (2007) makes a strong argument that the role of an environmental scientist should be to propose a choice of solutions that could work and help the public to make better decisions. Others, including Norton (2005), argue that environmental professionals need to play a more active role in the decision making process because they are closest to the information and have the most direct experience. Whether or not the technical experts should be kept at an arm's length from value discussions is an on-going debate, but the rest of the participants in the problem will be infusing their values and beliefs into the discussion, and we need to know how to do that in an open and fair manner.

1.4 Types of problems

There seems to be a common misperception that environmental decisions would be easy if we just had more information. If we could just set the right prices or incentives or just pass a law, then everything would be fine. There are certainly some cases where more information could be valuable. However there are many other environmental problems that either can't be helped by more information or where the money needed to acquire new information would be better spent solving the problem. People also have different ways of valuing an environmental condition: where one person may see a dangerous mosquito-ridden pond, another may see a bio-swale that cleans up road runoff. Many times it would cost more to study the multiple possible consequences rather than to just avoid them. For example, should we dump a new type of chemical that we know is toxic into streams? Experience has taught us that we should avoid adding a novel toxin. It might be better to spend research money on finding an alternative compound for the user, rather than to characterize the amount of damage that would be done.

Environmental problems fit into four categories (Cunningham and Sato 2001) (Table 1-2). Some problems might fit into one category easily but others problems might overlap these categories. These four categories are:

> **Easy Problems:** We can apply effort or allocate some resources to a problem. The proposed solution will return benefits to everyone. For example, eliminating lead additives in gasoline or house paint is a simple problem with a solution that is good for everybody.
>
> **Information Demand Problems:** Though extensive information may be needed to decide what action should be taken, it seems as if a solution could be reached that

would benefit everybody. For example, if we do more study on habitat restoration practices, we should be able to use the same amount of money to restore more damaged habitats more effectively.

Community Value Problems: There are simple solutions but they are not equally beneficial to all participants, some people or groups will get a better deal than others. These problems require that we appeal to peoples' ethical principles to reach a solution. For example, water resources may need to be shared by people, whom would each do better individually to use as much as they can, but better off as a community if they cooperate.

Wicked Problems: Even with additional information, the possible solutions seem to have uneven benefits. Wicked problems also change because as more information becomes available, individuals' values change. This type of problem requires community building that can reach a compromise solution and social capital that can endure the stress of the process. A good example of a wicked problem is the question of nuclear power; there are good aspects, bad aspects and these are always changing as the technology improves and as we learn more about the risks and impact of all the other options (i.e. fossil fuels, nuclear, biomass, and others).

Table 1-2. Types of environmental problems and decisions (adapted from Cunningham & Saigo 2001). The most likely approach to a solution is listed for each category.

information demand	alignment between costs and values	
	good	poor
simple	EASY regulations	Community Value community rules
extensive	INFORMATION more research	WICKED scientific adaptive management and political processes

Later in the book (Part 4) we will return to looking at actions that can be taken depending on the characteristics of problem. We will also revisit the idea of how multiple perspectives can suggest different solutions rather than a single approach, i.e. simple prescriptions. For example I will show that the idea of the "tragedy of the commons" is an overly simplistic analysis of the community value problem for sharing a common pool resource, and that once the complex paradigm is applied to include stakeholder preference diversity and spatial linkages (i.e. neighbors), the most promising solution looks more like promoting cooperation rather than imposing strict and broad regulatory control (as suggested by Hardin (1968)). This conclusion bolsters the importance of the second theme of this book, that it is a big mistake to apply simple solutions to complex problems.

Beside mismatches in values there are two other major factors that limit our ability to solve environmental problems: uncertainty and limited control. In many situations we don't know enough; in fact we may not be able to ever know enough about a problem to "solve" it. A commonly held belief (particularly in the USA) is that if we study a problem more we will be able to develop scientific and technical solutions to our environmental threats. Although this may be true in many instances, the weakness with this assumption is that many of the systems that we are dealing with are complex (composed of interacting sub-systems) and they may be changing faster than we can study and understand them. It is very possible that the effort required to study a system is greater than the effort required for plausible solutions. It is also possible that even our correct actions won't have a detectable impact for a while until the problem is so entrenched that it would require an extreme amount of effort to fix it. These are essential issues (rate, irreversibility) when facing threshold effects for environmental impacts. For example, it took a long time after DDT was introduced for us to observe the effects of bio-concentration in the food web and for corrective actions to start. Even many of the thoughtful, well-meaning, and well-studied positive actions that humans have taken have backfired or lead to unintended consequences. As this example illustrates, there are no easy answers. One reason is because of underlying beliefs that people hold. Some people who are skeptical of technology think we should rely more on our ability to avoid impacts and problems than depend on our scientific and technological expertise to fix the damage.

The second major impediment to solving environmental problems is that we may not be able to control the environment sufficiently to implement a particular solution. For example, we may be able to remove invasive weeds from a limited area of a park, but it may be too expensive and damaging to the environment to remove invasive weeds across a wide area of the landscape. The control techniques might damage the soil, the numbers of people and amount of energy required may just be too expensive, and there may be continual re-introduction of those species through human activity. There are problem-solving approaches that acknowledge that certain aspects can't be managed or controlled. For example, in cases where we understand the system well but aren't able to control the possible outcomes, we can employ hedging strategies that reduce the risk of using any one approach. In the event we can't control the outcome and there is a high degree of uncertainty about the mechanisms, we can create scenarios for possible outcomes and then develop indicators that help track and manage our progress. These two approaches (hedging and using scenarios) are discussed more fully in Part 4.

1.5 Science and Reality

Science, technology and reason haven't always been combined flawlessly in the past. Certainly no argument that relies exclusively in the domain of scientific knowledge can ever justify why scientific thinking and approaches should dominate our decision-making processes in the future. Environmental Science is no different. Our discipline needs to move forward along with other scholarly areas into post-modern, integrated ways of thinking and acting (Harvey 1990, Norgaard 1994). Fortunately, as a relatively new area of study, we have the opportunity to incorporate many approaches and meta-disciplinary tools.

One of the main activities in science is to build models and relate the models to the real world. The progress of science in the Western tradition has moved from focusing on observations to allowing for more interpretations (Linstone 1981). As you can see from Table 1-2, it used to be that observations were held to be true and that these didn't depend on theoretical considerations (Locke). Over time we progressed (or changed) to looking for "truth" in elegant and simple laws that described the universe and considered that the raw data from the real world might be flawed by measurement error (Leibniz). More recently we considered that the empirical and analytical models were complimentary and that the best outcome was an elegant model that "explained" the data most parsimoniously (Kant). Currently, there are some who still hold this view while others are working toward a post-modern view (Harvey 1990) in which there may be multiple forms of the data and multiple models and that these

Table 1-3. Historical view of the match between empirical evidence, theory, social constructs and truth. Adapted from Linstone 1981.

Life span	Proponent	Description
1632 to 1704	Locke	Empirical; agreement on observation and data
1646 to 1716	Leibniz	Theoretical; truth is really in the analytical description, the truth doesn't depend on any particular data set
1724 to 1804	Kant	Theoretical and empirical data complement each other, truth is in the synthesis, the synergism of multiple models
1770 to 1831	Hegel	Dialectic confrontation between models or plans leading to resolution
1908 to 1961	Merleau-Ponty	Reality is defined by the currently shared assumptions about a specific situation

forms don't necessarily have to converge to provide one single meaning. “Post-modern” is often misinterpreted as meaning that there are no absolute truths, but a better way to understand it is that there are no universal ways to evaluate a claim as being true. Modern environmental science is focused on solving problems and, as a discipline, is very optimistic. It may be this optimism that separates the underlying philosophy of environmental science from post-modernism, which can seem fatalistic in its rejection of efforts to look for enduring truths.

This may seem like a philosophical detour, but it is important to consider that as social, political and economic thought becomes more advanced, contemporary environmental science needs to keep up and scientists should be able to make arguments that are valid in and relevant to these other intellectual areas. *Scientific Adaptive Management is a philosophically coherent method to address these problems that is more suited to environmental, problem-based issues than the scientific philosophies listed in Table 1-3 above. This approach focuses on identifying problems and using manipulations from management that are designed as experiments. Scientific Adaptive Management will be explored in more detail in Chapter 19.*

The material in this book is most consistent with a form of science called "post-normal" science by Funtowitz and Ravetz (1992, 1993, 2003) or "Mode 2" science by Gibbons et al. (1994) and Gross (2012). Mode 2 science has five basic differences from traditional science. Whereas traditional science is often solved in academic settings, Mode 2 is carried out in the context and setting of the problem,. Mode 2 is transdisciplinary, drawing on science establishment, social institutions and other sectors of the economy and society. Mode 2 grows heterogeneously by piecing together components from many of these different sectors where as the growth of traditional science has been in expansion of capacity of the existing laboratories and research facilities. Traditional science is very hierarchical and tends to preserve the form of science down to the individual components. Mode 2 is distributed and transient: the research team may be from all over, from different types of enterprises and may disperse after the project is over. Finally, quality control is very well codified in traditional science and has been one of the features that have led to the benefits from investments in science. Quality control in Mode 2 is more reflexive and needs to include “wider, more temporary and heterogeneous set of practitioners, collaborating on a problem defined in a specific and localised context” (Gibbons et al, 1994). Having a reliable way to describe and verify the quality of complex environmental projects is key to justification and continued improvement. Quality assessment using the approach of Mode 2 science will be described in more detail in Chapter 21: Evaluating our progress with a transdisciplinary science framework.

1.6 Summary

This book presents multiple ways to view problems and makes it very clear that these different views should provide some information that will converge and some that won't. There will be other insights and understanding of a problem that you can only achieve by using very diverse, even conflicting or ambiguous, approaches. The natural world, human activities, and our environmental problems are not tidy. Our problems our often ill-defined, and require cognitive flexibility to understand them and simultaneously place them in different contexts (Spiro et al 1999). Science provides some very powerful intellectual tools and often these scientific tools are accompanied with technologies that are also very powerful. Unfortunately the environmental problems that we face are going to require science and technology in a social and ecological context. The challenge for each of us, as scientists, citizens, and policy makers, is to learn how to "solve in the pattern" (Berry 1981), i.e. to solve the problem in its larger context without creating other problems along the way.

Chapter 2: Major Concepts in Environmental Science

2.1 The importance of central concepts

The “first law” of ecology is that everything is connected and thus you can’t just do one thing. The first part of this statement applies to the ecological/social/economic processes as well as the information that we need to understand them. We can take advantage of this connectedness by intentionally learning the new concepts as they relate to the ones we already know, and build out from a set of central concepts. There are terms and sets of concepts that are very important because they connect across the sub-disciplines of environmental sciences. These may be concepts that connect population growth to human impact or concepts that describe the tradeoffs between using different resources (such as land, water, energy). For instance, I have had students who knew much more than I did about particular areas of environmental science, such as plant diversity, but who drew value from the course by being able to connect their knowledge to other areas of the discipline, such as water, energy, and land resources.

In environmental science it is also necessary to use specialized scientific vocabulary that is precise and constrained to a particular sub-domain as well as use public and legal vocabulary. This can often be confusing but it is required that all decisions for public resources be explained in the commonly used language of the citizens (Norton 2005).

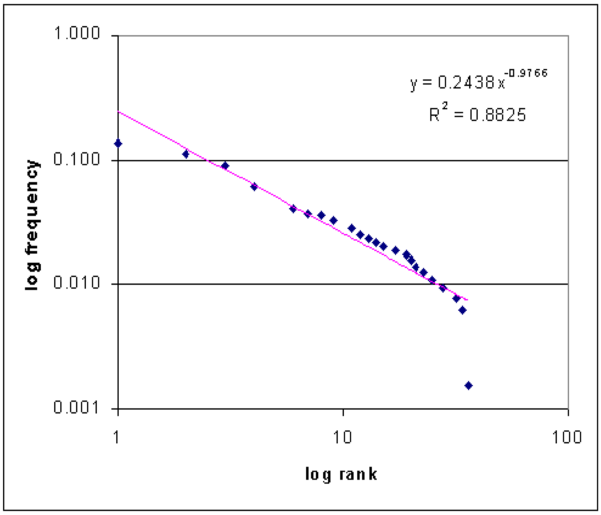
For the purposes of this book we are going to use "vocabulary" to mean words and their definitions. Words may have more than one definition in standard use. A "concept" will be a simple idea in a particular context that can be described and discussed using the vocabulary. Even though I have made this arbitrary differentiation between vocabulary and concepts, all of the ideas can only be explained in terms of their linkages to other ideas. All vocabulary and concepts represent a relationship to other vocabulary and concepts. Everything is related, even in the way we talk about the ideas.

The ideas represented by “energy” and “work” provide a good example. We can define the word “energy” to be "the ability to do work" which relies on the concept of work. In addition, the concept of doing work (force over a distance, or force against resistance) relates to the ideas of human use, fossil fuels, inefficiency, renewable sources, and other ideas. You might be able to memorize the definitions of vocabulary words but you haven’t built knowledge of concepts until you’ve made these relationships for yourself.

I have used three different methodologies to develop lists of central concepts. First I examined the terms used in several different introductory environmental science textbooks (Section 2.2). I did this by looking at the index but also looking for the terms on a page-by-page analysis of several sections. The second list was created by starting with six seed terms or questions that come from different areas of environmental science (Section 2.3). A concept map was generated for terms that are linked to a full description of this problem. The third list was created by sorting through key terms in the case studies that are presented later in this book (Section 2.4). The full lists are presented in Appendix 1.

2.2 Textbooks and the structure of knowledge in the discipline

Information and its organization in textbooks represent each author's version of the structure of the discipline. There are many different textbooks on environmental science/studies that provide good introductions to the range of concepts explored by environmental scientists. Introductory textbooks must, by design, contain a wide range of concepts and only devote a limited space to these. I analyzed the structure of the concepts in one popular text and found that rank and frequency of concepts (as evidenced by of key words) are related in a log-log manner. This pattern is evident in many other works such as Joyce's *Ulysses*, and indicates that common words are used very frequently and uncommon words are used much less frequently. The ratio between rank and frequency remains remarkably constant over a broad range of rank. For example the change in frequency going from the 10th to the 11th most used words would be similar to the change in frequency going from the 100th to the 101st ranked words. This is a "fractal" pattern (see Chapter 3). This pattern results from the effect of describing new concepts by using common terms, terms that help establish the context for a more rare, more specific term. Thus each time a specific and rare term is introduced, it is surrounded by more common terms to provide context.



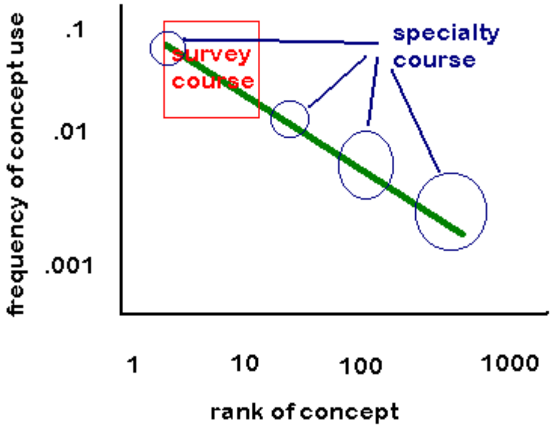


Figure 2.1 Frequency of use *vs.* rank diagrams for vocabulary terms in an environmental science text (a) or (theoretically) a curriculum of different courses (b).

The underlying message from this analysis of structure is that you really need to know the most common words and that as you learn more specific terms, you can link them back to more common terms to fully integrate that term into your functional, working knowledge.

2.3 Generating a list from seed concepts

A useful way to explore how concepts are related is to create a map of vocabulary, facts and simple concepts that you would need in order to understand a particular problem or phenomenon. Pick a starting concept and then determine which other concepts or ideas would be prerequisite knowledge for that concept or what other concepts this might lead to. For example you might pick the "precautionary principle" and then start by linking it to other ideas (Figure 2-2).

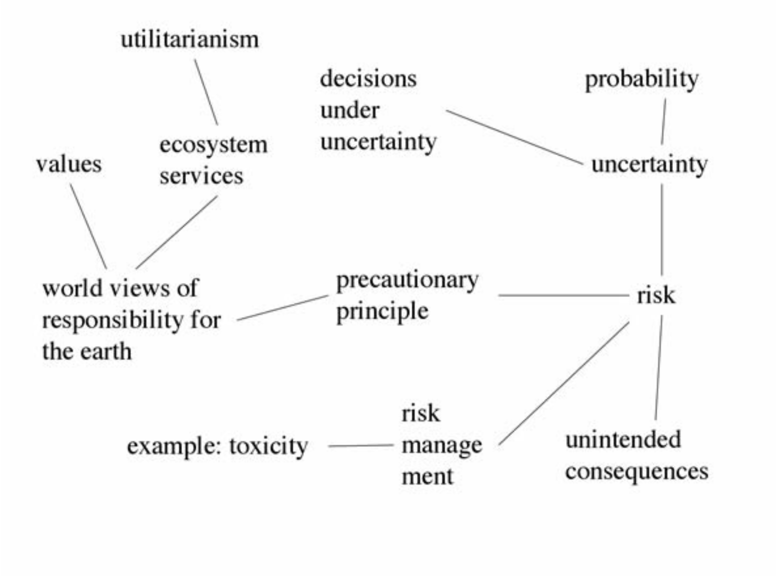


Figure 2-2. A concept map used to generate a list of related concepts to "precautionary principle". Only the first three or four levels are shown. A more elaborated map is shown in the appendix that has almost 50 linkages and expands out from the precautionary principle.

In addition to the precautionary principle, five other starting seed concepts are used to generate maps. There are almost 300 links shown in these diagrams, which show the relationship of the major terms and concepts. See Appendix 1: Table Y: Concept lists generated from starting seed concepts.

- precautionary principle
- tragedy of the commons
- Hubbert bubble
- technology side effects
- 1st law of thermodynamics

- Why do humans pollute their environment?

Again, each of these maps is only one way to elaborate the linkages to other terms. There are endless ways that these concepts can be linked. The important point here is that we can generate more diagrams or look at the diagrams that exist and see that all of these concepts are connected in someway. Learning these concepts requires more than memorizing the definition; it requires you understand how each concept, vocabulary word or example is connected to the other terms. It's like a game of Kevin Bacon's Seven Degrees of Freedom. You can see that crucial, central concepts will be linked even when you start from very different seeds. Common and central concepts will show up very often, whereas specific examples may only show up once.

2.4 Concepts central to the case studies presented in this text

Based on the exercises presented above, a list of central concepts, vocabulary words and examples has been generated. This list is given in Table 2-1 and Appendix 1.

Table 2-1 List of major concepts addressed in the examples from this book.

* insert table
*
*
*
*
*

*
*
*

2.5 A note on using Wikipedia or Encyclopedia of Earth to lookup concepts

Wikipedia (http://wikipedia.org) has several advantages and disadvantages as a source of environmental information. The main advantage (which is not trivial) is that anyone can access Wikipedia. Given how ubiquitous web access is these days (through web-enabled phones, tablets, portable computers, etc.) there are more and more places where you have access to this resource right now and for free. If you are connected to the web, you can think of Wikipedia as a resource not unlike "spell-checker". If in-doubt, you really should use your spell-checker, but you can't just accept every word change that the spell-checker suggests, nor can you trust that your spell-checker caught misspellings that lead to legitimate words.

Many of my colleagues don't like Wikipedia because there is no ultimate authority or process for the final verification of an entry. This is a legitimate complaint that is handled in academia by the use of a range of peer review processes (from blind review to committee reviews). While my colleagues are correct to discourage reliance on this quick-search source for research papers and student work that are supposed to rely on primary resources (i.e. peer-reviewed journal or other publications), I feel that Wikipedia has a legitimate role in learning about environmental science. No source is as broad as Wikipedia or as up-to-date. Terms that may take years to reach the glossary of a standard environmental science text (because of the writing, editing and production cycle) can show up almost immediately on Wikipedia. For example, the concept of Reducing Emissions from Deforestation and Destruction (REDD) were being discussed in the national press several years before these were addressed in any introductory environmental science text. Additionally many of the concepts that I have examined in Wikipedia or EoE show links to other concepts, creating a valuable context for that term.

Another valuable concept in Wikipedia is to identify ambiguous concepts and to direct the reader to different meanings in an attempt to disambiguate these terms. A good example of this might be if you searched for "mustang". You might get information about the car or about the iconic feral horse of the West. Wikipedia attempts to sort this out, whereas Google mixes the search hits together (after the paid links) and most environmental textbooks would only address the wild horse. Given that our goal is to learn and convey ideas in a common language, these internet resources are a crucial asset in being able to learn how our ideas are being received.

To address this limitation of Wikipedia, Encyclopedia of Earth (http://www.eoearth.org/) has a large number of short, peer-reviewed articles on environmental concepts. The articles are solicited based on a list of topics that is also under editorial control. This has the promise to be a very valuable resource but is still growing and has significantly fewer entries than Wikipedia.

2.6 Characteristics of useful information

Environmental science doesn't have a central organizing principle that helps define the discipline, such as the Periodic Table, Newton's Laws, or Darwin’s theory of evolution. Instead it is incumbent on all of us to be very aware of the ill-defined nature (multiple competing contexts) of all information that we gather and use. The process of placing information in context is essentially creating the network of relationships that give individual facts and value. Because of the way information is used and created it will have several characteristic dimensions of quality:

- the level of reliability
- authority of the source
- availability
- timeliness

Often the best quality information will require tradeoffs between these characteristics, i.e. it won’t be perfect and complete. We may have to rely on current information that is at best moderately reliable and which may come from an authority of moderate reputation. There is often limited time or money to get the highest quality data from the most recognized authority. Federal agencies have been instructed to use the “best available information” which means the best of the information that is currently available (NRC 2004). This has been used to clarify that environmental agencies are not required to do more research before they make a decision. These ideas will be discussed more in later chapters (Chapter 8: Risk and Uncertainty, Chapter 9: Games, and Chapter 19: Scientific Adaptive Management). Understanding the structure of the information, i.e. how concepts are related, in the discipline helps us use the best possible total quality of the information to make difficult choices.

2.7 Summary

Chapter 3: Preview of the Nine Exploratory and Diagnostic Tools and Overview of the Framework

3.1 Introduction

The ability to address any real environmental problem draws on information from several disciplines, specific local knowledge, and the know-how to interpret and use this information. Environmental scientists, managers and policy makers are required to use many tools and approaches to analyze problems because any single approach only looks at limited aspects of the problem. Thus, it takes multiple approaches to really see and address any environmental problem.

Even though these approaches have to be used together, it is effective to learn how to use and practice them individually on example problems. This is will allow you to better understand the characteristic strengths and weaknesses of each approach before you use several in concert.

3.2 The nine tools

I will describe each of the following approaches using exploratory and diagnostic tools (EDTs) with example problems throughout this book. The explanation for each approach will be introduced in a simple, step-by-step manner. These simple starting steps are for the purposes of learning each approach. Don't be lulled into thinking that these tools are this simple or limited. Each of these approaches could be expanded to any level of sophistication and experts in many disciplines use powerful extensions of these initial approaches.

There are nine tools. Two of them (Patterns and Scale) describe the texture and extent of the problem in its context. Three of them are very useful for systematically collecting numerical data (Stock and flow systems, Networks, and Accounting). Two deal with uncertainty either in information (Risk and Uncertainty) or in human deliberation and action (Values and Worldviews). The final two tools are approaches to decision-making and application if the underlying processes are known (Optimization of Efficiency) or unknown (Games – in particular games against nature). Each of these exploratory and diagnostic tools is useful for an initial study of a problem and they may serve as an heuristic device. This means, you can attempt to use the initial steps for each viewer on a problem to see if that viewer could be useful in addressing that problem. All nine are recombined in a framework that demonstrates how the extra work it takes to intentionally look at problems from multiple perspectives and then put them back together pays off.

A chapter will be devoted to each of these EDTs. Each will be described in detail later and an example case study provided for practice. Below is a snapshot of what each viewer entails: a list of the steps to start using the viewer, a potential challenge for each, and several examples of how they are used.

Patterns of Interactions (Chapter 4)

Observed spatial and temporal patterns are compared to a repertoire of patterns that can be generated by complex interactive processes.

Initial steps include:

- Discover patterns in primary observations or collected data.
- Describe these patterns verbally, graphically or with mathematics.
- Use the observed pattern to make hypotheses about what the most likely causes or important components.
- Consider possible solutions based on the pattern and hypothesized causes.

Challenges:

> Just because you find a similar pattern in the catalog to the one you observed doesn't mean that you have identified the cause or mechanism of the observed pattern. The similarity alone does not prove that one particular mechanism caused your pattern. In fact, it may be impossible to find and prove that a single process is causing this pattern.

Examples:

- The geographical patterns of acid rain input, low pH in watersheds, and the death of trees are used to argue that smokestack emissions in Ohio are damaging forests in New York.

- The population size of rodents demonstrates a cycle. The hypothesis is that this general pattern observed is likely to be related to either 1) seasonal driving factors or 2) a predator-prey interaction.

- The decrease in birth rates as nations becomes industrialized and wealthier (the “demographic transition) is a pattern that results from complex interactions between women’s rights, education, employment opportunities, and individual or family decisions.
- Erosion often forms landscape patterns of streams and tributaries that can be described using a fractal equation, but the equation can’t be used to predict where any particular stream will form.

Figure 3.1 Erosion that forms a network of streams shows a fractal pattern that can be analyzed by comparing the length of the streams. The exact pattern can’t be predicted, but the characteristics of the fractal relationship can be.

Scale (Chapter 5)

There are many features of the environment (such as lakes, mountain ranges, cities) and processes (such as river flow, erosion, population growth) that occur over a wide range of time and space scales.

Initial steps include:

- Characterize the time and length dimensions of objects and processes in the environment.
- Assess the texture of an environment by determining the size and distribution of objects (such as small rocks to boulders).
- Identify cross-scale processes of interest.

Challenges:

A common oversimplification is that large processes are just made up of a bunch of smaller scale processes and that if you understand the small scale, you can just aggregate these processes to understand the larger scales. But there are distinct processes that only happen at particular time and space scales. There are also emergent behaviors, small-scale behaviors that combine to create something that is fundamentally different (qualitatively and quantitatively) at the larger scale.

Examples:

- Lakes are often studied and managed at a whole lake scale for periods of several years. However in many of these lakes the crucial biological processes (such as harmful algal blooms) happen in isolated parts of the lake over time periods of months while the forcing processes of eutrophication are often examined on the scale of the entire watershed over decades.

- The description of biodiversity depends on assumptions of the time scale and geographic extent such as: the diversity of birds in a city park, the survival of bird species throughout their range, and the continued evolutionary adaptation of birds that inhabit this range.

A “Stommel” diagram is one of the best ways to visualize the range of time and space scales that are involved. By representing this in on log scales, it allows the representation of a wide range of values over five to six orders of magnitude.

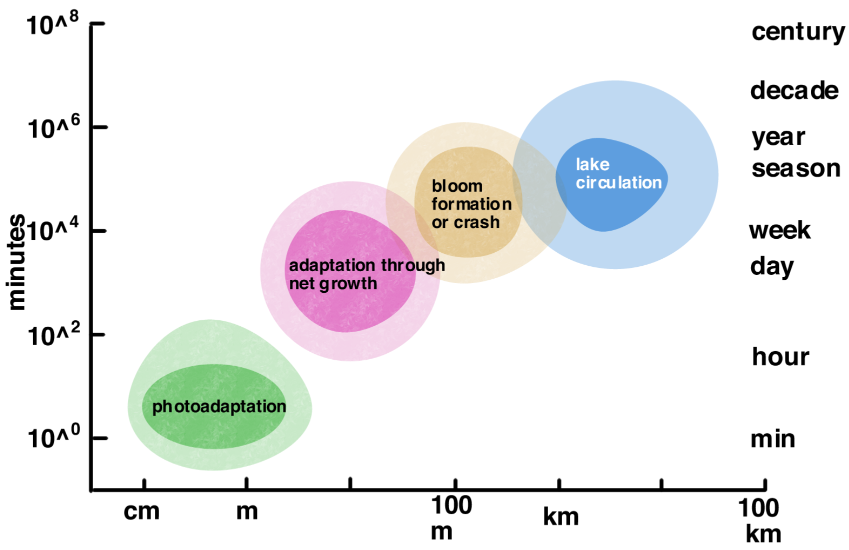


Figure 3.2 Time and space scales of processes in Upper Klamath Lake that are important for understanding growth and blooms of algae.

Stock and Flow Systems (Chapter 6)

A good stock and flow systems description of an environmental problem can help identify the major processes, biogeochemical limits, and potential for control or runaway feedback or traps.

Initial steps include:

- Identify the major reservoirs of energy or material in a system and link these with flows.
- Describe the boundaries to the system being studied.
- Describe how the flows are controlled in, out and within the system.
- Use the system model to describe current conditions and hypothesize about future directions.
- Focus on the potential for positive or negative feedback loops within the model.
- Use the model to explore different conditions or controls and base decisions on these predictions.

Challenges:

The flows have to strictly match the content of the reservoirs to faithfully represent the system. This requires being careful with units of measure and mass or energy balance concepts.

Examples:

- Human birth, death, immigration and emigration rates all contribute to changes in the size and distribution of human populations. A decrease in the death rate in a country can have an explosive effect on the population unless balanced by a decreased birth rate or changes in immigration and emigration rates.

- Global climate change may lead to the melting of high-latitude glaciers, which in turn could increase the absorption of solar energy at those latitudes, leading to faster melting. Such a positive feedback loop could be a crucial process to understand well for a prediction of global climate thresholds.

A simple systems view of natural resource harvest might be used to consider the growth rate of trees, the removal of trees for forest product use and the loss of tree growth due to the harvesting process. This loss of growth rate could be due to soil compaction, tree damage, and other factors that would be expected to increase as the intensity of harvest increases. We could represent this with a diagram (shown below) and discuss the relative strengths of these controls and also consider what other features should be added to more adequately describe this system to meet our needs.

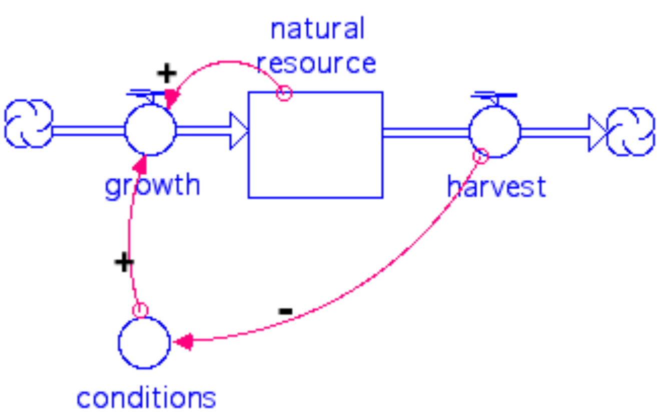


Figure 3.3 A stock and flow diagram that shows how harvest rate can degrade the natural resource by decreasing beneficial conditions for growth.

Network (Chapter 7)

Network analysis focuses on the relationships (of pretty much any kind) between nodes, cells or agents. This approach is much more flexible than the systems approach because many more types of relationships can be included. A network analysis can be used to understand the behavior of complex systems such as resilience (the ability of a system to maintain general operational functions under stress). Both node/arrow and spatially fixed grid of cells can be described and analyzed using the network EDT.

Initial steps:

- What are the nodes in the system and what type of relationships exist between nodes. The relationships aren't confined to being flows or information and can be many different types and strengths of relationships.
- How does a change in any one node affect all the nodes connected to it?
- Describe the structure of the network and calculate several key metrics such as average link density per node, connectivity, and diameter. The nature of this connectivity can determine if the network is resilient or fragile.

Challenges:

It is very easy and tempting to try to create and analyze a system with too many nodes and relationships. A node and link network that has five or six nodes can easily exhibit complex behaviors that will be too complex to analyze with our initial tools. More complicated and busy models might be better described with a narrative until you can create network descriptions that are tight enough to test.

Examples:

- A tropical forest food web can be described as a network of strong predatory-prey interactions combined with other, much weaker interactions. A species of bird may only have a small effect on a tree species in terms of energy and material flow, but may play a crucial role in dispersal of the seeds, thus contributing to the diversity of the forest. A loss of this bird species is inconsequential in the overall biomass but may dramatically reduce the processes that maintain spatial diversity.
- The movement of animals on a landscape can be studied by describing the landscape as a grid of locations that are connected to each other in a 2D network. Connectivity, longest path and biggest patch are network parameters that help understand the issues of fragmentation, reserve size, edge effect, corridors and resiliency.

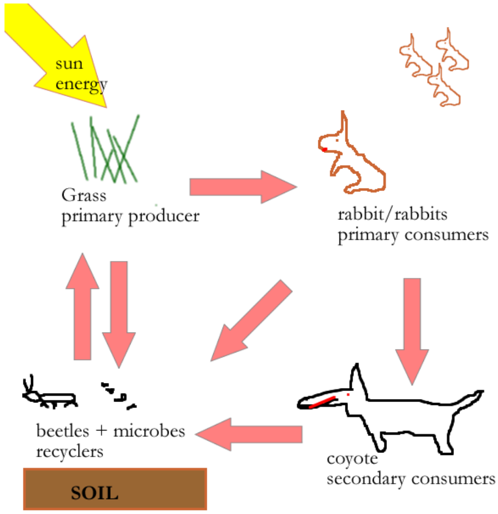


Figure 3.4 A node and arrow diagram of a food web, showing the predator prey linkages.

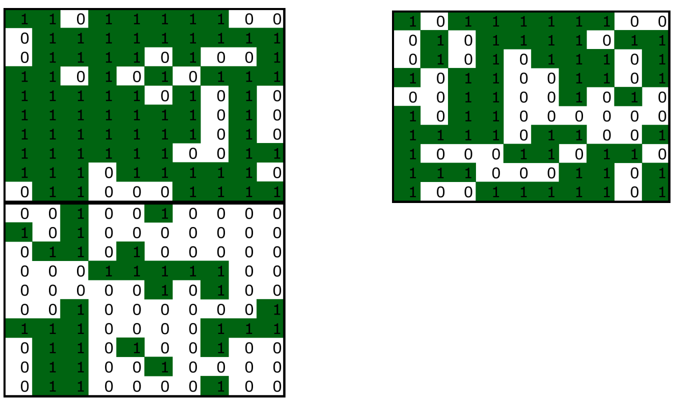


Figure 3.5 A spatial network of connected “cells” that looses connectivity with fragmentation, ranging from a loss of 30%, 41% and 60% of the habitat.

Environmental Accounting and Indexes (Chapter 8)

Accounting is more than just keeping track of money or inventory. Accounting is the whole process that is put in place to gather information that will allow us to make particular decisions. We can take into account expenditures, revenue, inventory and other assets in many ways. Some of these may help us make better environmental decisions or may signal that something is wrong and trigger more data collection and analysis.

Environmental Economics studies data on costs, revenues, and assets in many different forms in order to study how individuals and states make decisions. We will not be addressing economics in this book; however, it is important to note that economics requires an understanding of systems, scale and values.

First steps include:

- Determine what to measure that will help make decisions.
- Set up a method to track those parameters, process the data, and interpret it.
- Look for direct use and embedded use.
- Examine your system of accounting for "completeness" but eliminate any multiple counting of inputs.
- Create combinations of data that are easy to understand and communicate indexes.

Challenges:

Setting up a methodology to collect information in support of decisions introduces strong biases toward making a decision based on what can be measured.

You must examine how these biases affect the outcomes and ultimate goals of potential decisions.

Examples:

- A city could lump all plant related costs (diseased trees, planting new trees, etc.) into one budget category. Alternatively, if the city was worried about increased impact of pollution, they could keep track of the amount of time that city arborists have to remove diseased trees so that this information could be shared with the city managers as possible evidence for change in the plant damage.
- A Life Cycle Analysis can determine the impact of a product, such as diapers. This is essentially an accounting for all of the impacts of using different types of diapers (cloth with home washing, cloth with industrial washing, disposable) and accounting for the impact on trees for paper, cotton growth, water use in growing or washing, and other factors. The purpose of accounting is to gather all the important factors without leaving anything out or double counting, so that consumers can make a decision that fits their particular location. Accounting also helps identify the set of assumptions that are being made in the beginning, such as that in the above example, free-range, un-diapered toddlers are rarely a viable option in our homes (although this is being practiced in some places – see NYT April 18, 2013 "Going Diaperless).

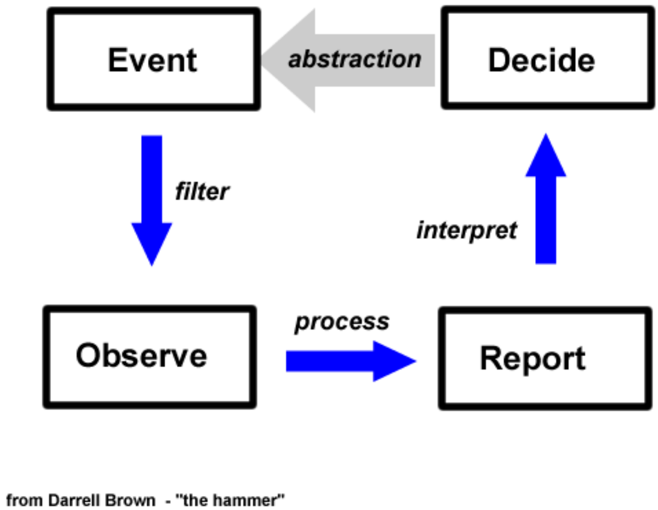


Figure 3.6 Diagram of the accounting process.

Risk and Uncertainty (Chapter 9)

Many environmental decisions entail both risks and uncertainty. Risks can be assessed, calculated and managed. In contrast, uncertainty can't be calculated or estimated well enough to manage directly. Uncertainty can also come from the knowledge gap between what we need to know and what we know.

Initial Steps:

- Conduct an information scan of what we know and don't know.
- Define the limits of what we can know (bounded rationality) and describe how available information is structured.
- Examine the underlying assumptions of risk.
- Describe the sources of uncertainty.

Challenges:

It is tempting to think that if we could get more information we could simply turn uncertainty into manageable risks. Because our access to knowledge is bounded (by both practical considerations such as cost and other intrinsic reasons) we are unable to gain this information. Therefore it is important to learn to differentiate between risk and uncertainty and deal with them differently.

Examples:

- Global climate change entails some risks that can be estimated and managed and others for which the uncertainty is high. For example, we know that damage in coastal zones of developed nations is probably going to increase and there are measures we can take to reduce the potential damage to property and loss of life. However, there is a large degree of uncertainty about what measures may work to decrease CO_2 in the atmosphere, and we may not actually be able to know what is effective without actually implementing these measures (such as large scale forest restoration).

- We'd like to restore a wetland that has been damaged by some human carelessness and invasive species. We don't really know how the wetland will respond to certain treatments, so we have the option of conducting a long study (to change these unknowns into quantifiable risks), performing some small scale operations (to explore the wetland's response scientifically), or wiping out the whole wetland and reconstructing an engineered treatment (with a large amount of uncertainty). The choice of approach will depend on the context of each wetland.

The decision criteria we use for problems illustrate how risk and uncertainty are related to the overall scale and reversibility of our actions.

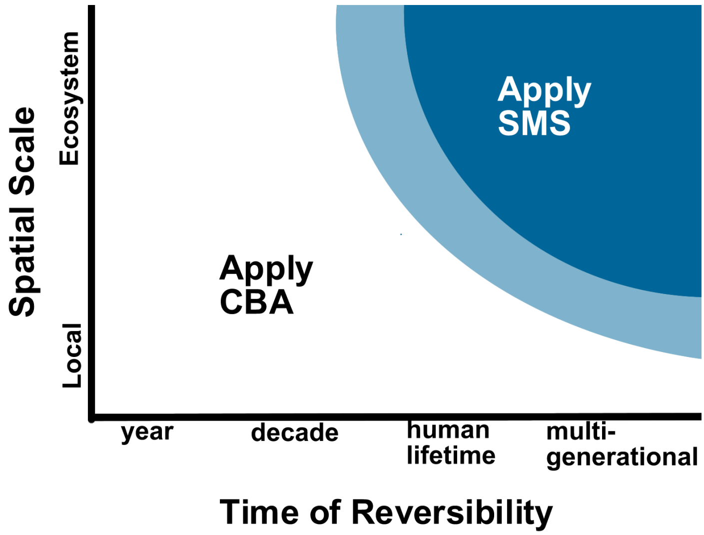


Figure 3.7 Decision space for the types of criteria that should be employed if the impact of a project has impact over different time and space scales. If the project has the potential to impact the environment over long time scales, essentially irreversibly, or if the impact will cover an entire ecosystem then the precautionary principle (or Safe Minimum Standard) should be used. If the impact is at shorter time scales or smaller areas, a cost to benefit index could be used. Adapted from Norton (1985).

Values and Worldviews (Chapter 10)

Humans make decisions based on their values. According to Cultural Theory (van Asselt and Rotmans 1996), some sets of values and cognitive skills are self-reinforcing. This results in a few common sets of values that are called "worldviews". Different authors have constructed similar sets of four categories. We will examine how groups who hold each of these would address environmental issues and make decisions that involve technology and risk. Although it takes sustained effort and time to change the underlying fundamental values that people hold, considering the worldviews of the public can help clarify this challenge and may suggest ways to solve the problem without irresolvable clashes of values.

First steps include:

- Identify the diversity of values that are involved in the problem (felt, considered, fundamental and perspectives/tools).
- Frame the problem and outcomes in the context of the four main worldviews.
- Develop scenarios or simulation models based on assumptions from different worldviews for comparison.

Challenges:

Including values in scientific approaches is problematic and has lead to criticisms of environmental science being an activist discipline. There is an under-appreciation of the ways in which problem-solving depends on social values during definition and implementation. Using worldviews may help put this on a more objective and pluralistic footing.

Example:

- The choice of which approach is considered most likely to succeed for lake restoration depends on the worldviews of the proponent. Hard infrastructure such as sewage treatment plants and diversion solutions are favored by Individualists/Cornucopians, whereas green infrastructure such as expanded wetlands are favored by committed ecologists/egalitarian worldviews.
- Different worldviews see issues around global climate change and population growth very differently. We can formulate scenarios for how the future might play out. We can then choose and work toward general futures by taking action today.

Table 3.2 Four worldview descriptions that focuses on how they view sustainability differently.

- Cornucopian
    - optimistic technologist
    - very weak sustainability that allows technology to substitute for natural capital
    - individual and property rights
- Accommodating - industrial ecology
    - use efficient technologies and market incentives
    - equity for all
    - instrumental value in nature, utilitarianism
    - all capital is interconvertable,
    - weak sustainability
- communalist – committed environmentalist

    - conserve resources
    - green economy
    - collective interests take precedence over individual human interests
    - strong sustainability that requires natural capital and ecosystem services to be maintained
- Deep ecology
    - preservationist
    - severely limit resource take
    - broader definition of rights (animal, plant and earth system)
    - very strong sustainability that argues for rights of ecosystems to exist not just maintaining the services they provide

Optimization of efficiency (Chapter 11)

Efficiency is the ratio of the output to the input. This can be for materials, energy or investment in machinery. Increasing the efficiency is often thought of as the first task for environmental management, i.e. reducing the energy or materials that it takes to make the same goods will reduce the overall use of resources. This approach is favored by particular worldviews, in particular the industrial ecologists and the committed environmentalists see increasing efficiency as a cornerstone of good environmental practice.

Optimizing efficiency, rather then just increasing it, is required if there are multiple processes leading to a final useful product. Whereas a single process may not have an optimum (because more investment leads to more output), a balance of multiple processes is necessary. Too much investment in one of the sub-processes leads to a loss of overall efficiency. For example, if a process has two steps, A and B, the output from A has to equal the output from B to reach the optimal efficiency. Figure 3.8 illustrates that starting from an excess of process A and investing in more and more B, improves the efficiency up to the point where there is a balance. The reason the efficiency drops off is that there is unused capacity for process B.

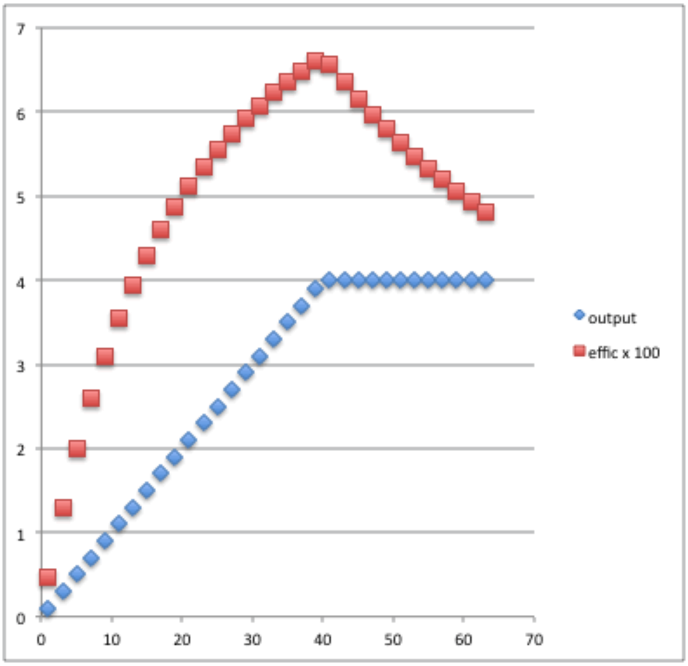


Figure 3.8 Optimization. Increasing investment in process B (X-axis) leads to increasing efficiency up to the point where the total output is limited by process A. Then efficiency falls off as there is excess, unused, capacity for process B.

Optimization is often dynamic. The growth of plants or the replacement of machinery in factories is dynamic because there is always loss taking place. This sort of dynamic optimization relies on turnover and strategic reinvestment. We can learn from biological and ecological systems about dynamic optimization. The tight coupling and regulation in biological systems allows for continual readjustment of the system. A major challenge faced by biological and human systems is how to optimize across multiple parameters such as nutrients and energy (for biological systems) and land, food, water and energy (for humans). Studying the relative time scales and mechanisms that are employed in ecological systems may provide insights for human enterprises.

The analysis of efficiency often starts with a comprehensive budget for all the inputs, outputs and processes, much like a stock and flow system. One rigorous approach to this is called a “life-cycle analysis”. This approach can be very useful in identifying factors that could be enhanced or that are particularly inefficient.

Games (Chapter 12)

A simple way to analyze decisions is to list both your choices and your opponent's choices and then determine what will happen for each combination. This approach is called a "decision square" or "choice matrix" and can be extended to understanding your choices when faced with an uncertain environment, or when deciding to cooperate or go off on your own to use a shared resource. A strategy is a general approach that you apply to all situations.

Initial steps:

- Identify your choices and your opponent's choices.
- Combine all possible choices and catalog the expected outcomes for each combination.
- Determine if the game is single-shot or iterated.
- Compare how different strategies might fare.

Challenges:

> This simple games matrix approach is easy to use. The challenge is not to forget that it should be combined with other information-gathering viewers that would improve the choices.

Examples:

- The "tragedy of the commons" is a game matrix against other people who will benefit from the use of a shared pasture. If your neighbor grazes too early he might do well but would ruin the pasture for the rest of the summer. If you both cooperate, you will both be able to use the pasture and the net result will be a good outcome for all involved. The tension between what is good for individuals and what is best for the community as a whole can be explored using this game approach. See Table 3.1.

- The "precautionary principle" is an example of a strategy that you could use in a game against nature in which the exact outcomes are unknown. This principle states that when given a choice of two possible actions, you should choose the action that leads to the least damaging outcome.

Table 3.1 A games decision square for the classic problem of the “tragedy of the commons”. Should you cooperate or graze early on the common pasture?

	Your neighbor - grazes early	Your neighbor - grazes at ap
You - graze early	You both do poorly.	Best for you. Worst for neighbor
- approved time	Worse for you. Best for your neighbor	Good for both of you

The above description for the "tragedy of the commons" game is highly simplified and ignores diversity of individual preferences, spatial context of most natural resources issue (especially the commons), and iterated interactions. When more authentic assumptions are made, this game set approach demonstrates the advantages of cooperation more clearly.

3.3 Four levels of analysis

The section above describes the major attributes and the first directed steps for describing the problem from different views. For example, with the pattern EDT, the first step is to match an observed pattern with a similar looking pattern in the catalog. In the other EDTs, there is also a set of initial steps that either have a constrained vocabulary or a diagrammatic representation (or a combination of both). Thus EDTs are proscribed methods for initial analysis, i.e. the first steps in establishing how to identify characteristics and take apart the whole problem into its various pieces. This set of skills can also be thought of as a toolbox for these approaches. The multiple perspectives framework (described in the section 3.5) shows how these areas of assessment can act as tools and be used together to reassemble a larger picture of the problem.

The pieces of solving a problem using these EDTs at four levels:

1. **probe and describe** - Attempt to analyze the problem for features using each of the viewers, i.e. use the viewer as a heuristic tool. If the approach has any traction, then put the problem into a constrained structure provided by that tool.
2. **Analyze each approach** – Study the problem from the information gathered from each individual EDT.
3. **Compare and synthesize** - Compare the multiple perspectives gained from the first two steps and determine what information is convergent (shared between multiple views) and which is only gathered by using a particular EDT.

4. **Evaluate** - Consider the total set of information holistically to determine whether you judge the information to be useful toward engaging in a solution.

The chapters that describe each EDT in more detail contain a description of how each relates to the others. There are particular features that overlap and other features that don't. For example, the Scale EDT focuses on the extent and texture of a particular problem, whereas the Stock and Flow Systems EDT starts by defining the boundary of the system. The "extent" in the Scale tool is the same as the "boundary" in the Systems tool. However some aspects are very different. For example, a flow in a Systems model can be very different than a link in a Network description. A flow in the Systems view can only be the movement per unit time of what was ever in the stock that it came from and goes to. A connection in the Network EDT can be any relationship that may have a positive or negative effect from one node to another. Later we will explore in detail what it means to examine the same system with simultaneously as a stock and flow system and as a network.

Another feature of each EDT is that it could be extended to include more sophisticated analyses. These follow-up analyses features build on or directly complement the initial steps. If you have trouble representing the problem in with the initial steps, it may be a stretch or even inappropriate to continue forcing the problem into compliance; instead, applying a more sophisticated follow-up analysis may be required. This relates to the common phrase, "When all you have is a hammer, everything looks like a nail." Even if you become an expert in using one of these more sophisticated techniques, you don't want to be locked in to only using thatone approach. However, the heuristic corollary to this is thatOn the other hand, if you hit something with a hammer, and it successfully joins two pieces of wood together, then you probably hit a nail.

3.4 The multiple perspectives framework

The multiple perspectives framework – MPF - described here is the process that starts by scanning multiple perspectives of the problem, choosinges a few (at least three) viewers for further analysis, and bringingthen brings the different types of information generated back into a working description of the problem. Because of the scope of some of the problems involved, identifying a range of different perspectives might require the involvement of a community of stakeholders rather than a single analyst. The purpose of the MPF is to guide this process deliberately from the beginning by addressing a problem with the understanding of how each new piece fits in. A full description of this framework is given in Chapter 13: Multiple Perspective Framework. Experience working through this framework on a range of problems will make subsequent cycles easier. The point of this framework is to help you be able to hold different, non-converging views of the problem until you can study which actions could help solve the problem.

3.5 The value of multiple perspectives

All of the individual disciplines that relate to environmental science are important sources of tools to "drill" down on a problem. The sophisticated methods and theory that these disciplines develop are crucial. However, the authentic environmental issues that we must address are rarely solved by the application of a single disciplinary approach. For example, a veryConsider the straightforward problem is that there wasof lead in house paint, which was determined to be and this was dangerous for human health. The simple solutionanswer to this problem wasis to get the lead out of the paint. After that happenedBut now that lead has been removed from paint, we are still faced with the problem of what to do with homes that already have lead paint. There are a variety of possible solutions to this problem, butand even whilethough we agree it should be donea solution is needed there is a lack of resources to fix this particular problem in everyall the homes. Thus the problem has morphed from one of detection (chemistry) to local environmental health action (urban studies and health fields).

Multiple perspectives and a diversity of views are crucial for solving problems in innovative ways. One estimate is that 90% of innovation comes from outside the discipline. Page (2007) addresses the value of diversity in solving business problems and comes to the conclusion that "Progress depends as much on our collective differences as it does on our individual IQ scores." In developing his "Diversity Trumps Ability Theorem" he describes value diversity and instrumental diversity:

> "People who have different fundamental preferences might be said to have different *values*. People who have different instrumental preferences but the same fundamental preferences have the same values but different *beliefs about how the world works*. In either case, people disagree over what policy or action to choose, but only in the first case does diversity create a problem. In the latter case, it can prove useful.”

Page's point is that it is crucial that we develop teams of people who can work collaboratively on problems in order to innovate and eventually solve these. A diverse group brings together "super-additivity of diverse tools". These diverse groups of approaches don't necessarily have to be hired by a company (Page's focus) but can be assembled *ad hoc* through activist or social groups (Rheingold 2002). Both these authors show thatdemonstrate a big part of the value of collaboration comes from the diversity of inputs and multiple viewsperspectives, not just the agreementagreeing to abide by the majority decision. Better decisions come from more active and sophisticated analysis. For example, what many call a "consensus science" approach to global climate change is actually consists of a diverse group of researchers who formulateing a central model that most agree to and then spending their effort aggressively and rigorously testing the areas of disagreement. Global climate change science has progressed very rapidly because multiple perspectives were brought in and tested.

In order to be part of, or especially to lead, a diverse group that is addressing an environmental problem, it is essential that you see how different viewpoints and methods of analysis bring in different information. The ability to collect information on your own with different methods and then synthesize them into a single narrative is a valuable skill that can be applied to these group situations as well.

3.6 Summary

Nine approaches to addressing problems are described and each of these has a set of initial steps. The information from exploratory and diagnostic use of these tools provides a rich description of the problem that could combine descriptive data, quantitative data, estimates of the uncertainty, relationship to values, and possible decision support approaches. This wide range of information should not be forced into coherence, rather the evaluation and elimination of ambiguities and contradictions must be delayed until these can be methodically documented and considered. The multiple perspectives framework provides a mechanism to collect information and form un-biased sets (or at least it clearly identifies the biased assumptions) of narratives that can be studied systematically. It takes significant effort and cognitive flexibility to maintain contradictory pieces this far into the overall method, but that effort is sustained and justified by increasing the potential for creative and innovative approaches to be fully considered.

