Chapter 9 – Risk and Uncertainty

The only thing that makes life possible is permanent, intolerable uncertainty, not knowing what comes next.
- Ursula K. LeGuin

This chapter will be rewritten with more about uncertainty, ignorance and surprises – see objects/ignorance.html

9.1 Introduction

Generally, science makes predictions about how a system will behave and then tests these predictions in a rigorous manner. In environmental science we focus on making testable predictions about the real environment we live in. Even if we are studying the outcomes of experiments with test tubes or isolated microcosms, the purpose of this work is to understand the processes, so that we can either react to or control the future of our environment. The real world (as opposed to experimental systems) is full of uncertainties caused by all possible types of interacting factors. Thus, environmental science, working in the real world, must deal with uncertainty as part of everyday work.

This chapter describes the limits on our ability to predict the future and what that means for environmental science. The important message is that we can't always just study a problem or gather more information to make a better decision. There are cases of irreducible uncertainty, cases where it is impossible to predict outcomes with any degree of certainty. There are even situations where our own actions create so many more potential outcomes that we might actually know relatively less after we start solving the problem. For example, if there is an outbreak of a disease carried by mosquitoes, we might have to spray; however, the impact of the insecticide, how it may change the ecosystem, is impossible to predict. As a general rule, the bigger the project or the higher the energy density (kWatts/m^2), the more indeterminate the system becomes. Stated in another way, the harder we try - the more possible outcomes we open up for the future.

It is important to differentiate between three different types of unknowns.

Risk - a probabilistic estimate of how likely an event or exposure will be.

> If we can calculate the risk and the potential damage from exposure, then we can calculate the amount of money or effort we should expend to control that risk.

Uncertainty - a broad range of possible outcomes and complexity makes it impossible to define a set of probabilities.

> We can create and use scenarios to describe the different paths that may happen in the future, but we have no way of knowing which future will actually happen.

Indeterminacy - there is some information that we will not be able to know.

> Sometimes our actions actually increase indeterminacy because as we focus our energy and mobilize resources to address a problem, we create a fundamentally bigger set of outcomes (Adams 1988). This larger set may include "surprises," which are qualitatively different outcomes that are unexpected.

9.2 Method for examining uncertainty and risk

The method outlined here is to start by scanning what is known about the problem with a checklist. The scan will look for what we think we know and can learn easily compared to the information that may be difficult or even impossible to get. The second step is to describe the problem in terms of bounded rationality. The third step is to describe the structure of the information that is available. The fourth step is to bring in values and cultural interpretations of the problem.

Assessing our current level of understanding

We should evaluate our actions by assessing the level of our understanding in the following levels:

- what we know
- what we expect we can learn
- what we can't or might never know
- what we are doing that might create "surprises"

A "surprise" is a change in the system that is qualitatively different than we were expecting. For example, if we overfish a region, it is reasonable to expect there to be fewer fish; however, we would be surprised to discover that overfishing has resulted in a sea filled with jellyfish. The ecosystem has flipped to an entirely different food web dynamics.

The degree of proof or confidence we need to be able to take action is related to our worldviews (see Chapter 11: Values and Worldviews). In particular, the precautionary principle states that if we are uncertain we should decide to take the path that leads to the least potential damage. Some worldviews embrace the precautionary principle as a standard of proof, whereas others believe that progress is generally beneficial and requires tradeoffs to sustain growth. For example, the set of values we called the "committed environmentalists" believe that we need to be more humble about our scientific and technical abilities, whereas "cornucopian" believe in the ability of scientific advancements to solve emerging problems.

Defining the limits to our understanding - Bounded rationality

Though many believe otherwise, there is a limit to what we can know about a problem and how much of that knowledge we can apply. This means that any decision that we make can only rationally consider a limited number of options, i.e. our ability is bounded. If we had instantaneous information-gathering and unlimited money, we might be able to claim unbounded rationality.

The cost (in dollars and human effort) required to collect information is a very pragmatic consideration. Given that environmental science is focused on solving problems, it wouldn't make much sense to spend more money investigating a topic than to simply solve the problem. For example, is it reasonable for a wildlife agency to spend a couple hundred thousand dollars for an emergency study to determine if a wetland has threatened or endangered species, or should they just buy the property or put it into a conservation easement program? Similarly, in many cases it is best to take environmental management actions (such as preservation or remediation efforts) that are designed to be experiments. Combining required management actions with scientific monitoring is one of the tenets of "scientific adaptive management" and is as much a result of bounded rationality as limited funds.

Structure of environmental information

For many environmental problems the problem of bounded rationality is exacerbated by three related characteristics of the structure of the environment. First, the physical environment is made up of individual places, each with unique characteristics and histories. Although we may be able to collect, enter and manipulate data with geographic information systems, there is still a unique set of characteristics and history for every location on the planet that must be considered. Second, because of the spatial nature, environmental data is time-consuming and expensive to collect. There are proxy measurements (related and standing in for the parameter of interest) that might be made from satellites or other remote sensing devices, but these are always suspect and take a lot of information to establish the value of the proxy in the first place. Some crucial information in species conservation, for example, requires that individual elephants, whales, warblers or other animals are tracked and counted. There are many examples in environmental ecology where specific sites have to be studied. Third, processes take place at different scales. A collection of data taken at a small scale does not automatically aggregate to describe the process at a larger scale, and an average measurement at larger scales may miss critical processes that happen at smaller scales. The average slope and soil wetness of a hillside doesn't predict a landslide. A small section of steep and saturated soil can precipitate a landslide that is much larger in extent. Thus the uniqueness of spatial or individuals, difficulty of collecting place-specific information and the problem of scale-discontinuity of processes require that we need to learn to make good decisions with limited information, learn from those decisions and continue on.

Cultural and worldview perspectives on risk

The perception and response to environmental risks has a strong cultural context (Douglas & Wildavsky 1982). Making and decision about the future, such as the impact of population or climate change, is essentially the process of dealing with risk and uncertainty. Different worldview groups deal with risk differently. For example, Douglas and Wildavsky (1982) list four main types of risk (Table 8.1) and claim that the some worldviews worry about some of these more than others. For example, "individualistic" people would worry about the collapse of the market and loss of capitalism as a driving force for change. Hierarchists abhor situations where the rules and regulations are incomplete or ineffective. Egalitarians are worried about general effects such as waste and pollution that may not be controlled effectively by general agreement and may take strict laws or other governmental action. These actions erode the spirit of cooperation for the common good.

Table 9.1 Worldviews and risk emphasis. See chapter 11 for more description on worldviews.

four main risks	world view that worries about this most
economic collapse	"individualistic"
foreign affairs	"hierarchists"
pollution	"egalitarians"
crime	"hierarchists"

We will discuss worldviews in more detail in Chapter 11. The important point in this chapter is that differential sensitivity to risk also means that there is no generally agreed upon definition of acceptable risk. For example, egalitarians would rate the risk of pollution much higher than the other worldviews. Continual dialog is needed to negotiate the level of risk that a community is willing to accept. This reinforces the dilemma in wicked problems where members of the same community who may have different worldviews will not agree on a single or unifying scientific definition of environmental risk. Proposed alternative solutions should be judged against all four value systems. In these situations, one of the best approaches is to explore the problem from many perspectives and workout how the different groups would view the risks of the problem and proposed solutions differently.

9.3 Using simulations to understand risks

Global change with a small chance of flipping to the other mode and then what would it cost

Show simulation of threshold --

9.4 A large portion of the uncertainty can't be turned into risk

There are portions of the overall uncertainty that could be expressed as a probabilistic risk if more research were carried out. This is essential currently un-quantified risk. But there are types of uncertainty that cannot be turned into risk. This requires us to deal with uncertainty differently than just recommending more research to reduce it to risk.

There are two major components to uncertainty, variability and limited knowledge. Table 9-2 presents a summary of these. Due to variability, some sources can translate uncertaintly into risk if more knowledge is gained, such as a better understanding of the range of values held by the population. Others are not amenable to any transformations that would allow a probabilistic statement to replace our uncertainty. In the category of "limited knowledge", we can reduce uncertainty by generating more exact measurements, collecting more data, and building new ways to measure processes that are cheaper. But the other sources of limited knowledge are pushing the boundaries of what we can ever learn.

Table 9-2. Uncertainty due to sources of variability and limited knowledge. Adapted from van Asselt and Rotmans (2002).

sources of variability	
inherent randomness	non-linear or chaotic nature of the process
value diversity	differences in people's mental maps, worldviews and norm
human behavior	non-rational behavior, deviations from normal, or discrepancies between what they say and what they actually do
social	non-linear or chaotic nature of social systems linked to the process
technological surprises	breakthroughs or qualitatively different technologies
limited knowledge	
inexactness	lack of ability to measure or measurement error
lack of data	lacking data that could have been collected but wasn't
practical immeasurability	technically possible to measure but too expensive or other similar reason
conflicting evidence	directly contradictory datasets or interpretation
reducible ignorance	we don't know what we don't know
indeterminancy	we understand enough of the laws governing the processes to know that they lead to unpredictable outcomes
irreducible ignorance	we cannot know

One approach to reducing uncertainty in highly complex situations is to allow or rely on technical experts to make decisions. This approach removes the uncertainty that comes from injecting a range of values into the decisions and the often non-rational behavior of humans. For example, technical experts should be able to sort out the quality of data and evaluate the merit of technical solutions much more objectively than the general populace. Establishing a technocracy in this manner changes the nature of the uncertainty from technical to social and governance. By eliminating values from the discussion and usurping the public's power and responsibility to make decisions, the uncertainty of democracy is replaced with the indeterminacy of imposing a technocracy, "an all-powerful enlightened Leviathin" (pg 2, Press 1994). Technocracy, especially the command-and-control centralized variety, presents a challenge to democracy. The tenets of democracy cannot be made if we empower someone else to make decisions that involve the allocation of resources in our society. Press (1994) explains that even within strong democracies such as the United States there are decisions that are shielded from simple democratic votes, such as how the Supreme Court is designed to be isolated from legislative and executive actions. Pielke (2007) proposes another template for incorporating strong technological expertise into decisions without it being a technocracy. He suggests that the scientific community must present a range of options to decision-makers and provide un-biased and objective information that is relevant to the decision process but should let the democratic processes reach decisions. The point is that trying to remove uncertainty by employing experts (who have access to large amounts of information and analytical skills) merely shifts the uncertainty from a mix of values and objective facts to, arguably, an equivalent level of uncertainty centered in the domain of governance.

Uncertainty has value, and we might want to learn to embrace those qualities rather than trying to reduce uncertainty at all costs. Berry (2008) suggests that we examine the assumption that more knowledge and less ignorance will help us avoid bad consequences. Vitek and Jackson (2008) suggest that a worldview based on control through rationality should be replaced with a more humble view that is "predicated on the assumption that human ignorance will always exceed and out-pace human knowledge" and we should essentially learn to lead with our strengths (ignorance). Surprises that come from uncertainty are key components of individual and institutional learning. Eliminating or managing uncertainty to the point of avoiding any surprises would dramatically decrease our learning (Gross 2012). Thus learning to deal with uncertainty has advantages that would be masked if the goal were to eliminate it or project the many dimensions of uncertainty onto a simple dimension of risk.

9.5 Summary

Much of this chapter has dealt with the challenges of dealing with uncertainty and risk. My emphasis on these warnings about the difficulties is a reminder that we need to be humble and cautious as we propose solutions. Environmental science is generally an optimistic undertaking. We believe that it will be worth our attention and effort to improve and protect our environment.

The simple scan method provided here (assessing what we know and don't know) is a starting point for analyzing the information needed to support good decisions. If decisions and actions need to be taken with imperfect information and uncertainty, then we need to use an adaptive management strategy so that our management actions decrease the uncertainty for subsequent efforts.

