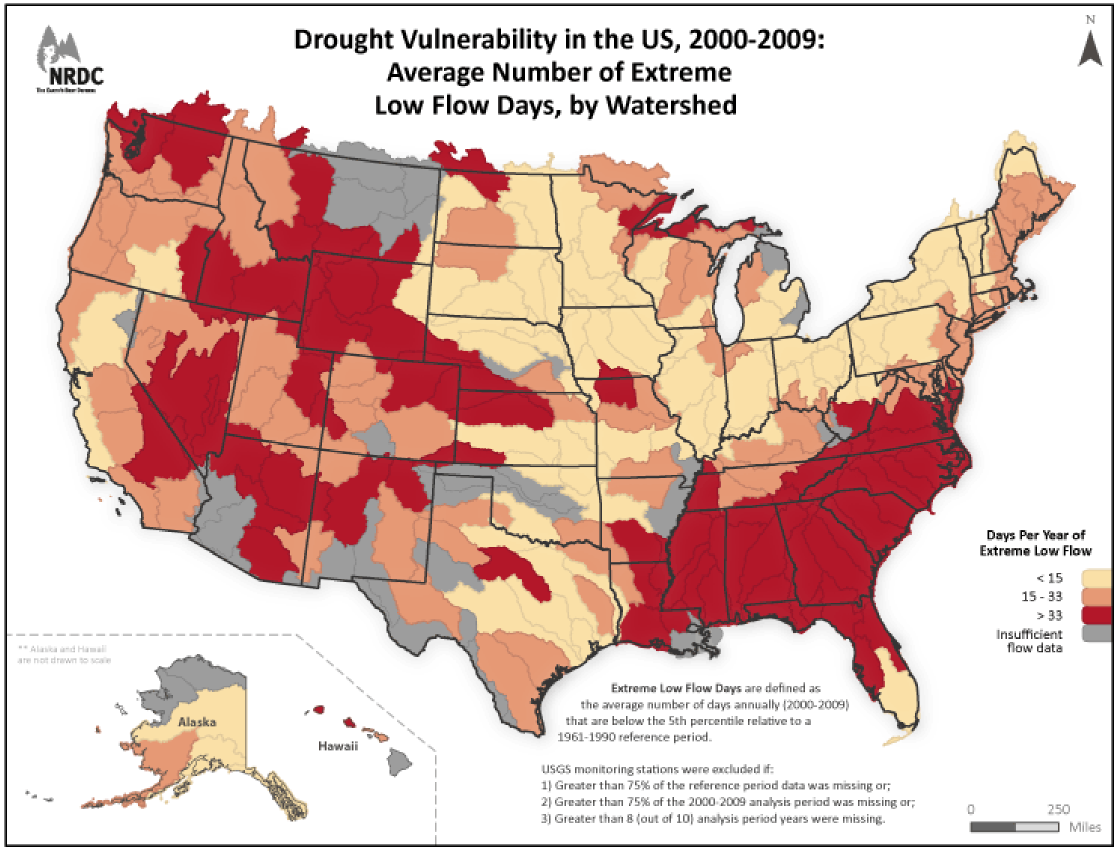
RISK AND UNCERTAINTY

Scarce resources create opportunities costs, which renders the idea of a zero-risk society a noble but unattainable goal.

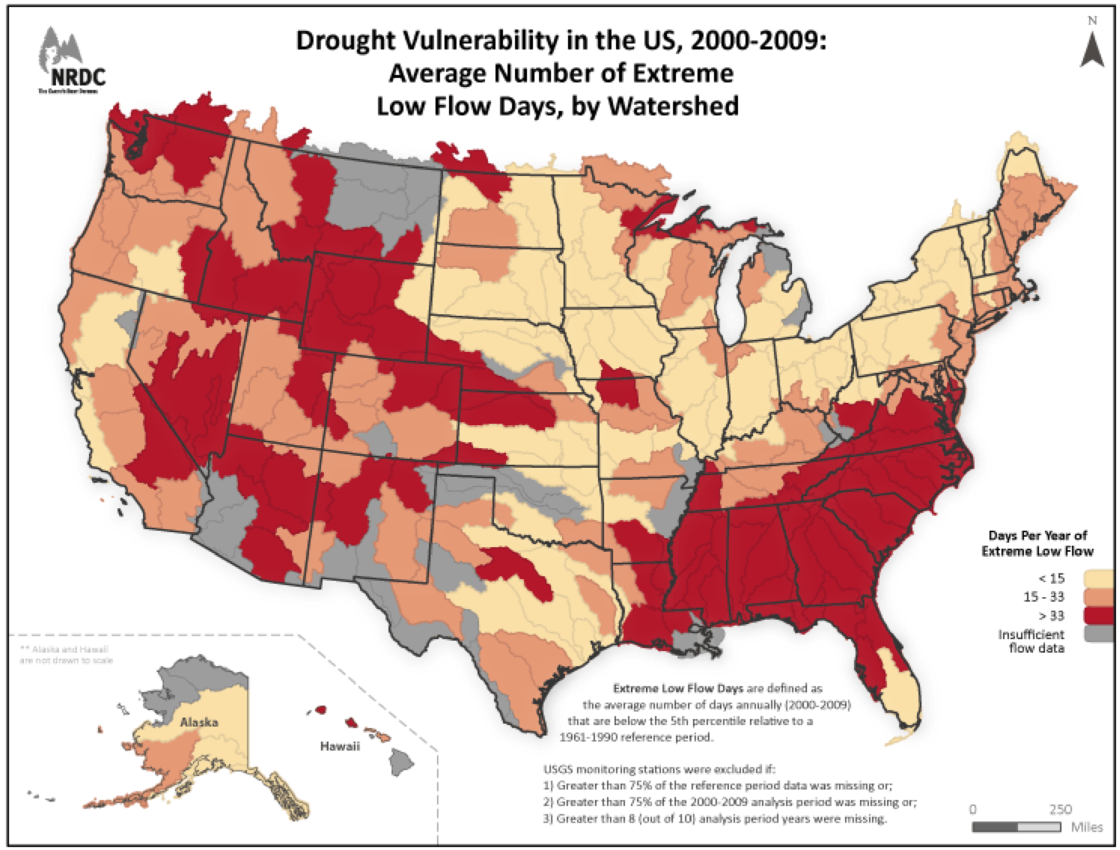
Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



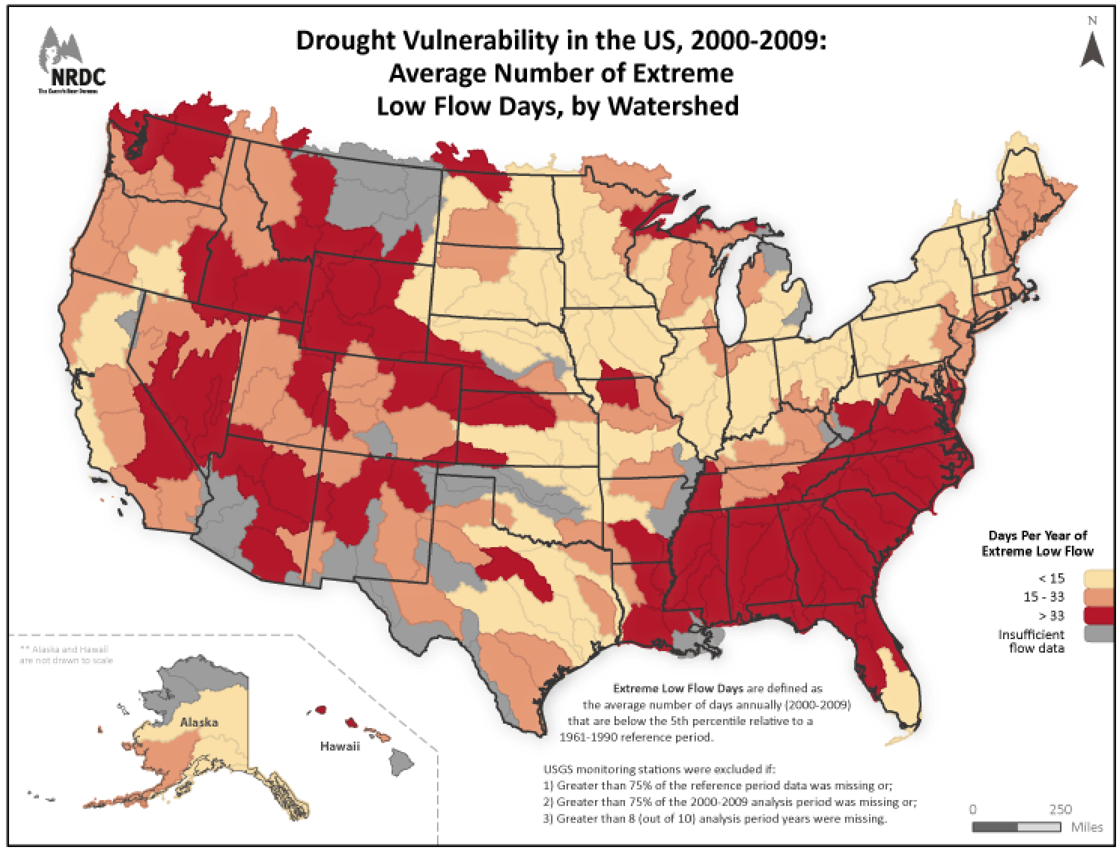
Introduction to Risk and Uncertainty

- Risk is defined by combination of two elements:
  - Probabilities (chances)
  - Outcomes (consequences)

- Types of risk
  - Exogenous
  - Endogenous

Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



Exogenous Risk

- Dominates theoretical/empirical risk management
- Risk management
  - Natural sciences assess the states of nature
  - Economics used to help manage risk by designing and valuing the net benefits of alternative control strategies
    - Focus on properties of risk preferences rather than on technologies of risk control
- Describing risk

Probability and Expected Value

- Probability, p, is the likelihood that a given outcome will occur
  - $0 \leq p \leq 1$
  - Calculated using relative frequencies
    - Fire example
- Expected value of an uncertain outcome or choice is just what is expected to occur (on average)
  - Weighted average of the payoffs associated with all possible outcomes.

Variability

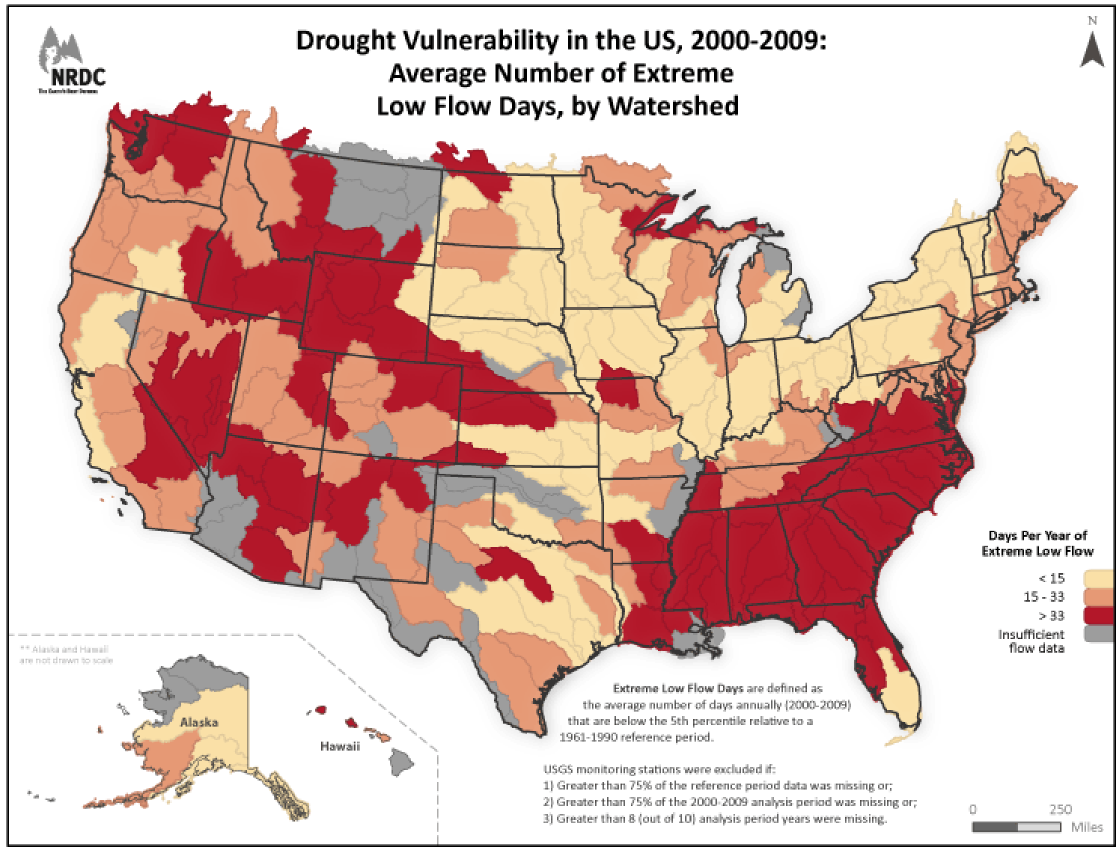
- Variability of an uncertain outcome or choice is how much the possible outcomes differ
  - Income example
- Variability is measured by the difference between actual and expected payoffs
  - $deviation = x_i - E(x_i)$
  - Larger deviations imply more risk
- Given deviation always sum to zero, we square the deviation
  - $square\ deviation = (x_i - E(x_i))^2$

Measures of Variability

- 1. Variance
  - The weighted sum of squared deviations
  - $\sigma^2 = \sum_{i=1}^{n} p_i \left(x_i - E(x_i)\right)^2$
- 2. Standard deviation
  - On average how much each outcome varies from its expected value, i.e. the spread of possible outcomes
  - $\sigma = \sqrt{\sigma^2} = \sqrt{\sum_{i=1}^{n} p_i \left(x_i - E(x_i)\right)^2}$
- Return to income example

Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



Risk affects choice

- Suppose you are offered the following proposition:
- You can buy into a gamble based on a fair coin toss (50-50%). If a head comes up on the first flip, you earn $2;

  if it takes two flips before a head comes up, you earn $4;

  three flips before a heads, you earn $8;

  four flips, $16;

  five, $32;

  six, $64;

  seven, $128; and so on.
- The question is: what is the maximum you would be willing to pay to buy into playing this gamble?

Risk affects choice

- Larger variance implies more uncertainty about the outcome, which many people would rather avoid.
- Daniel Bermoulli: “$2,000 is worth more to a person than a gamble with an expected value of $2,000.”
  - Translated into utility function $U(x_i)$, which illustrates risk aversion through the curvature of the function
  - Compare risk neutral, averse, loving
- 1940’s von Neumann and Morgenstern used this basic insight to create expected utility theory

Expected Utility (EU) Theory

- The formal theory of expected utility reflects the idea that people make choices about risk based on:
  - their beliefs about the probability that good and bad events will be realized
  - the consequences of good and bad events
  - the utility or satisfaction a person gets from the consequence that is realized.
- EU theory assumes people think about probabilities and outcomes simultaneously

EU Theory

- Suppose an individual is considering alternative choices that result in different levels of wealth:

$$W_i = [W_1, W_2, W_{3,\dots} W_{n-1}, W_n]$$

and the probabilities each outcome could be realized:

$$p_i = [p_1, p_2, p_{3,\dots} p_{n-1}, p_n]; 0 \leq p \leq 1; \sum_{i=1}^{n} p_i = 1$$

- EU is the weighted average of all possible wealth outcomes

$$EU(W) = p_1 U(W_1) + p_2 U(W_2) + \cdots + p_n U(W_n)$$

$$= \sum_{i=1}^{n} p_i U(W_i)$$

Attitudes towards risk: Risk Neutral

- A person is risk neutral relative to a lottery if the utility of the expected value of the lottery equals the expected utility of the lottery

$$U(E[W]) = EU[W]$$

$$U(pW_1 + (1-p)W_2) = pU(W_1) + (1-p)U(W_2)$$

- Such a person is only interested in the expected value and is oblivious to risk
- Functional form example

Attitudes towards risk: Risk Averse

- A person is risk averse relative to a lottery if the utility of its expected value is greater than its expected utility

$$U(E[W]) > EU[W]$$

$$U(pW_1 + (1-p)W_2) > pU(W_1) + (1-p)U(W_2)$$

- Such a person prefers a certain outcome to an uncertain one with an expected value
  - Utility function is strictly concave over the wealth domain
- Functional example

Attitudes towards risk: Risk Loving

- A person is a risk lover relative to a lottery if the utility of its expected value is less than its expected utility

$$U(EV[W]) < EU[W]$$

$$U(pW_1 + (1-p)W_2) < pU(W_1) + (1-p)U(W_2)$$

- Such a person will always take a fair bet
  - Utility function is strictly convex over the wealth domain

Example in EU Theory

- Income example continued…

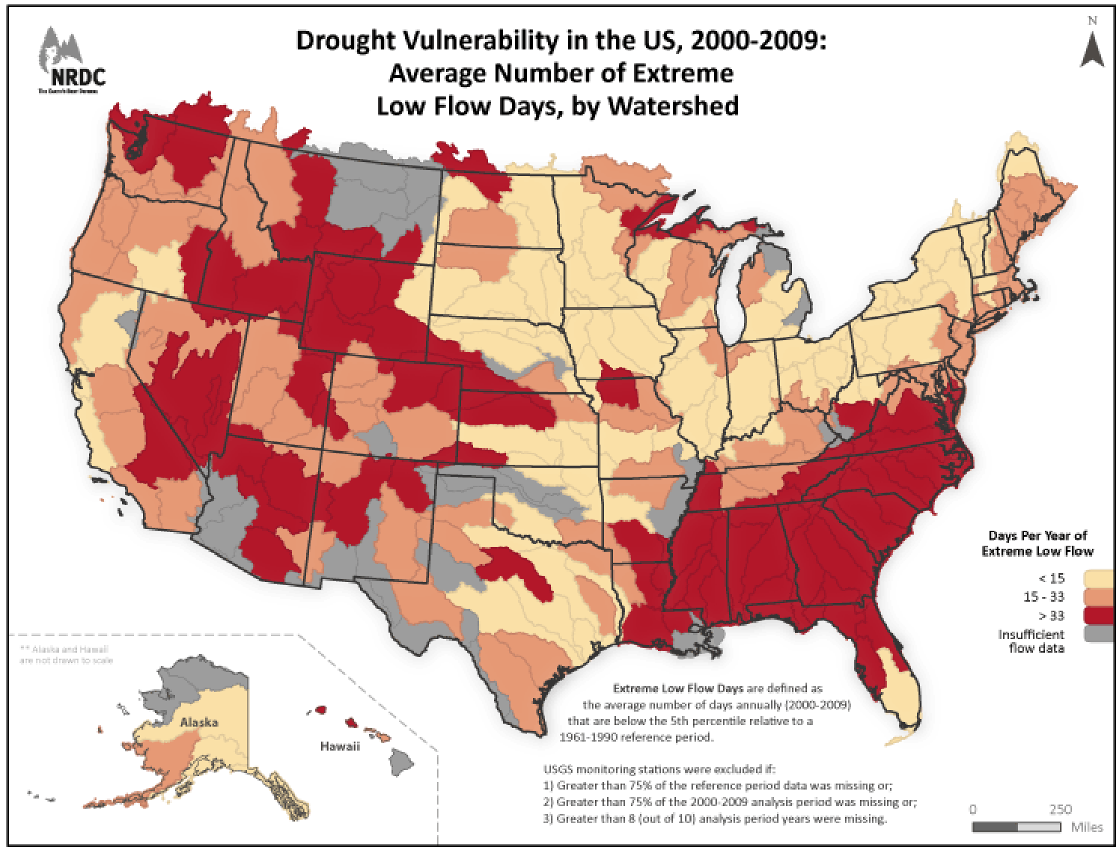
Job 1					
x_i	p_i	$E(x_i)$	$(x_i - E(x_i))$	$(x_i - E(x_i))^2$	$p_i(x_i - E(x_i))^2$
2000	0.5	1500	500	250,000	125,000
2000	0.5	1500	-500	250,000	125,000

Job 2					
x_i	p_i	$E(x_i)$	$(x_i - E(x_i))$	$(x_i - E(x_i))^2$	$p_i(x_i - E(x_i))^2$
1510	0.99	1500	10	100	99
510	0.01	1500	-990	980,100	9801

- Risk neutral, averse, loving

Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



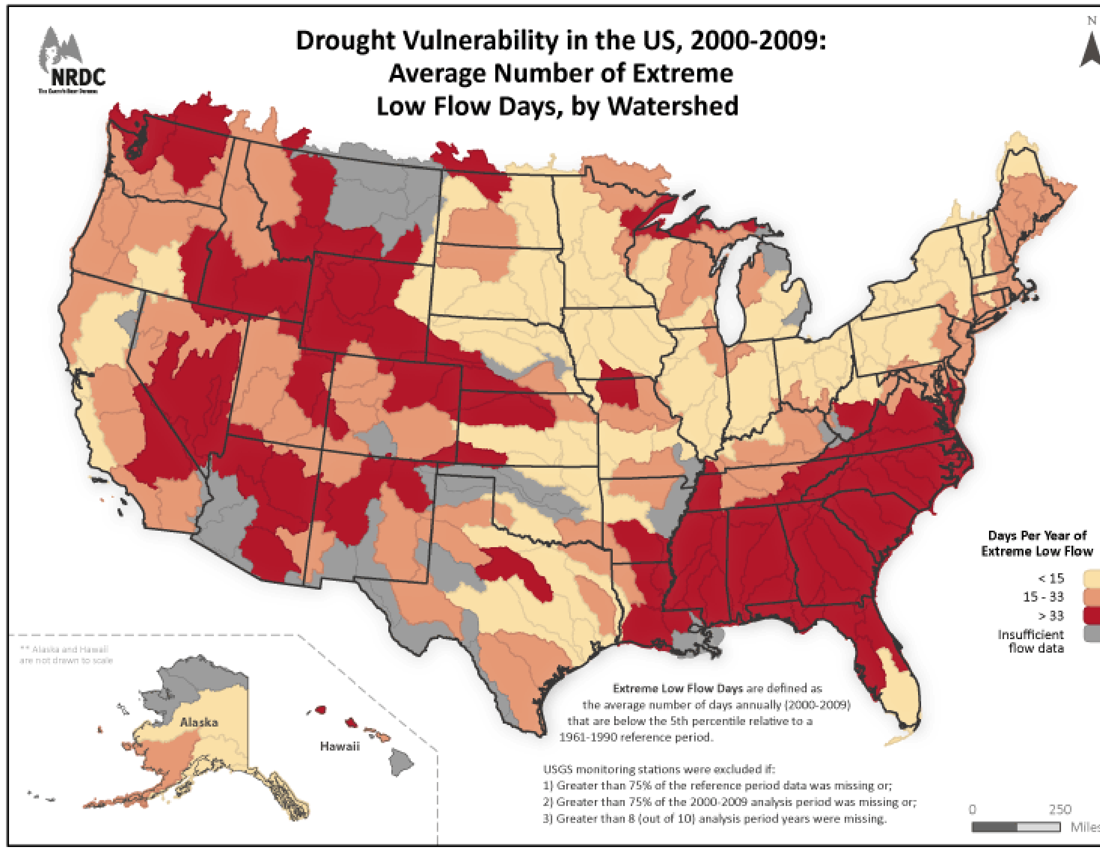
Exceptions to Expected Utility Theory

- Ellsberg paradox
  - Urn example

- Allais paradox
  - **Gamble A:** A 100% chance of receiving $1 million.
    Gamble B: A 10% chance of receiving $5 million, an 89% chance of receiving $1 million, and a 1% chance of receiving nothing.
  - **Gamble C:** An 11% chance of receiving $1 million, and an 89% chance of receiving nothing.
    Gamble D: A 10% chance of receiving $5 million, and a 90% chance of receiving nothing.

Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



Overview

- Ecological risk assessment evaluates the probability of changes to the natural environment linked to such stressors as pollution exposure or climate change
  - e.g., crop damage, soil contamination
  - See the boxed Application on *Climate Change Ecological Risk Assessment*
- EPA has developed guidelines aimed specifically at ecological risk assessment
- Three phases of ecological risk assessment
  - Problem Formulation; Analysis; Risk Characterization

Model of Ecological Risk Assessment

PHASE I
PROBLEM FORMULATION
Information gathering about what is at risk

↓

PHASE II
ANALYSIS
Determination of what is exposed, degree of exposure, and likelihood of harmful ecological effects

↓

PHASE III
RISK CHARACTERIZATION
Determination of what is exposed, degree of exposure, and likelihood of harmful ecological effects

Source*: Drawn from U.S. EPA, Risk Assessment Portal (January 5, 2011).*

Risk Management

Responding to Risk

- **Risk management** is the decision-making process of evaluating and choosing from alternative responses to environmental risk
- Two major tasks:
  - Determining what level of risk is “acceptable” to society
  - Evaluating and selecting the “best” policy instrument to achieve that risk level

Determining "Acceptable" Risk

- The extent of risk reduction determines the level of exposure and stringency of policy
  - Should exposure be set to 0? If not, what positive level is appropriate?
- Officials might use ***de minimis* risk** as baseline
- Might use **comparative risk analysis** to compare risk of environmental hazard to other risks faced by society
  - e.g., risk of exposure to 4 pCi/l of radon compares to the risk of dying in a car crash

Selecting Policy Response

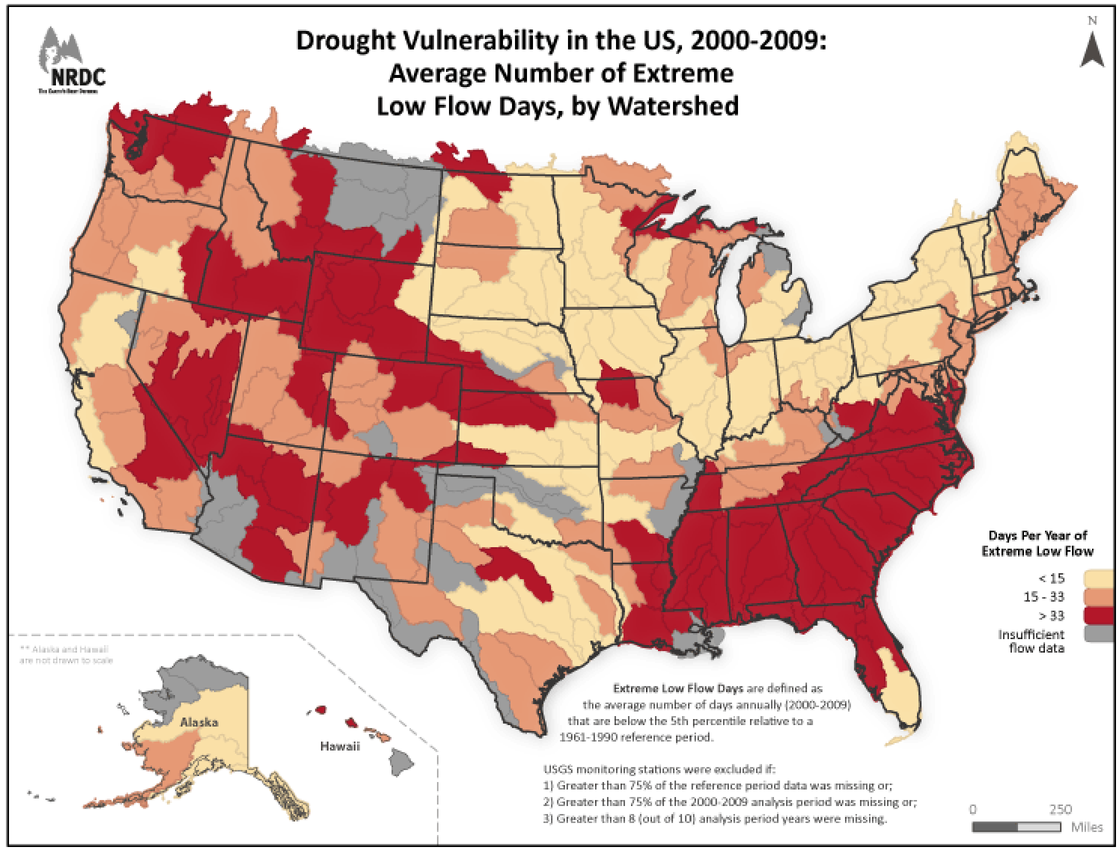
- Evaluates alternative policies capable of achieving "acceptable" risk level
- Selects "best" option
  - How? Uses risk management strategies

Risk Management Strategies

- Used to evaluate options in a systematic way
- Key considerations are
  - The level of risk established
  - The benefits to society from adopting the policy
  - The associated costs of implementing the policy
- Prevalent risk management strategies are
  - **Cost-effectiveness analysis**
  - **Risk-risk analysis**
  - **Benefit-cost analysis**
    - Valuing risk reductions requires that we place a value on death and illness
    - Value of a statistical life

Risk and Uncertainty

- Introduction
- Exogenous Risk
  - Probability
  - Variability
- Expected Utility
  - Risk attitudes
- Behavioral Econ
- Regulating Risk
- Valuing Risk Reduction



Risk Premium

- Risk premium is the maximum amount of cash a risk averse person is willing to pay to avoid a risk

- Calculated as the amount of income a person would give up to remain indifferent between a risk outcome and certain outcome

- Income example continued…
- Vegas example

Option Price

- Option price is the maximum that a person is willing to pay to keep them indifferent between a gamble and the next-best alternative
  - WTP
  - WTA
- Vegas example continued…