Error, Uncertainty, and Information Quality: Definitions from the Environmental Literature – Draft 2/15/06-5-12-06

Intro

The environmental movement which arose in the 1960's and generated the framework of our current laws, regulations, and continuing debates about growth, stewardship, and sustainability, is founded on the modernist philosophical approach of logical positivism. Our world's complex systems are "knowable" through investigation and research, and this knowledge will provide the decision guidance needed for protecting and enhancing our natural and cultural resources. (REF)

The National Environmental Policy Act (42 U.S.C. 4321-4347) directs that:

> all agencies of the Federal government shall-
> (A) utilize a systematic interdisciplinary approach that will ensure the integrated use of the natural and social sciences and environmental design arts in planning and decision making which may have an impact on man's environment;
> (B) identify methods and procedures…which ensure that presently unquantified environmental amenities and values be given appropriate consideration in decision making along with economic and technical considerations;
> (C) include in every recommendation or report on proposals for legislation or other major Federal actions significantly affecting the environment a detailed statement by the responsible official on-
> (i)the environmental impact of the proposed action…(42U.S.C.4332 (2)).

NEPA has been determined by the courts to be a "procedural" not a "substantive" law. Where impact analyses are required, agencies and stakeholders must be notified, information on potential impacts of the proposed action and alternatives generated and disseminated, comments received and responded to, and a formal Record of Decision made public. The emphasis is on cooperation and transparency. The law does not create any new rights to environmental quality, and does not preclude decisions that have negative environmental effects.

These substantive issues are the responsibility of topical environmental laws, many of which (Clean Air, Clean Water, Superfund, Endangered Species…) were originally enacted in the "environmental decade" of the 1970's. Typically, the regulations implementing a substantive law, such as such as waste discharges, establish "safe" or economically "feasible" performance standards- numeric environmental concentration levels in the environment. For ecological, and cultural/aesthetic topics the regulations are often non-quantitative. Permits are required for facility owners to generate a new discharge. The permit applications must include technical analyses and/or professional opinions demonstrating that the proposal will meet the standards. They also typically call for some form of monitoring and enforcement provisions. (1)

Both Impact Statements and Permit Applications are, in essence, environmental predictions to inform decision makers. Since their creation, there has been continuing challenges from all sides: industry, environmental groups, natural scientists, engineers, and social scientists about our ability to and the quality of predicting the future. Enfolded in the information quality debates are two additional issue themes:

What values are used in the analyses (what futures are desirable, how equitable are the distributions of effects); and

How decisions are made and by whom.

There is no uniform approach to describing and evaluating information quality in environmental predictions. Rather, a spectrum of approaches and meanings have evolved independently within different environmental disciplines. Because environmental analysis is, by law, interdisciplinary and open to the public, the information quality “Tower of Babel” effect is a frequent dimension of environmental controversies ranging from Not-in-My-Backyard (NIMBY) local facility siting issues, to debates on global warming. The intent of this paper is to review the rich counting debate regarding information quality in the environmental arena .

Compare two types of decisions ca. 1930:
roads/bridges designed managed by licensed engineers
zoning- blue ribbon commission of bankers, developers, farmers…

(How Well) Can we predict the future?

Stewart

" **Every prediction contains an element of irreducible uncertainty**. This fundamental fact is not disputed by scientists or by those who use their predictions to inform decisions. However, **important *implications* of irreducible uncertainty are rely discussed and generally not appreciated.**" (41)

"Uncertainty in prediction simple means that, given current knowledge, **there are multiple future states of nature**. Within this definition, a number of different types of uncertainty can be identified. Probability is the standard measure of uncertainty,an important distinction of ***frequentist*** and ***subjectivist*** views of **probabilities**...The **frequentist view is taught in introductory statistics** courses...probabilities are by l**ong run observations** of occurrences...events have to be **well specified** and their must be an (appropriate) **empirical record**..."
"**Subjectivist probability is simply someone's belief that an event will or will not occur.**...(these) are routinely assessed by decision theorists, who have developed **elaborate methods to elicit them**....Some argue that all probabilities are subjectivist, because relative frequencies are only sample data of past events that influence subjective of future events. Others object to the use of subjective probabilities they are not "objective". Because human judgment invariable plays a role in prediction, i**t is difficult to discuss uncertainty in any systematic way without considering subjective probabilities**."(42)

"uncertainty can also be classified as ***aleatory*** (**random processes- dice**)or ***epistemic*** ***.***..**incomplete knowledge of processes**...(partially a function of) time frame...**Total uncertainty, either frequentist or subjevtivist, is the sum of epistemic and aleatory uncertainty"** (42)

(see also ***Stewart*** below in **Environmental Impact Analysis and Decision Making)**

Karplus

"Recent years have seen intensive attempts to expand the art of mathematical modeling to an ever-expanding range of applications...the tendency of virtually all disciplines in the physical, life, and social sciences to become more quantitative. ...The modeling art has not evolved with difficulty and controversy. ..specialists in the modeling of 'hard systems', such as electro-mechanical controls, have challenged the validity of models in 'soft' areas such as economics and sociology...In fact, doubts have been raised as to whether the term *model* really means the same thing at all in different areas of application." (4)

Fig 1 Excitation- System-Response

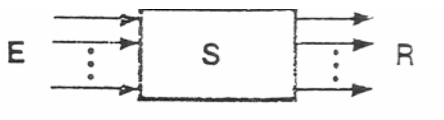


Figure 1. The cause-and-effect relationship between excitation, E, and response, R. as they relate to the system S.

for physical systems, three types of modeling problems:

Analysis (direct)-	Given E,S, Find R
Synthesis (design identification)	Given E,R, Find S
Instrumentation (control)	Given S,R, Find E (5)

Analysis problems are "direct" usually only one solution. Synthesis and instrumentation problems are "inverse"- many solutions.. "there never can be a unique solution" (5)

"An examination of models in any particular discipline reveals that most of the are approximately the same **shade of gray**.

Fig. 2.The spectrum of modeling problems.(6)

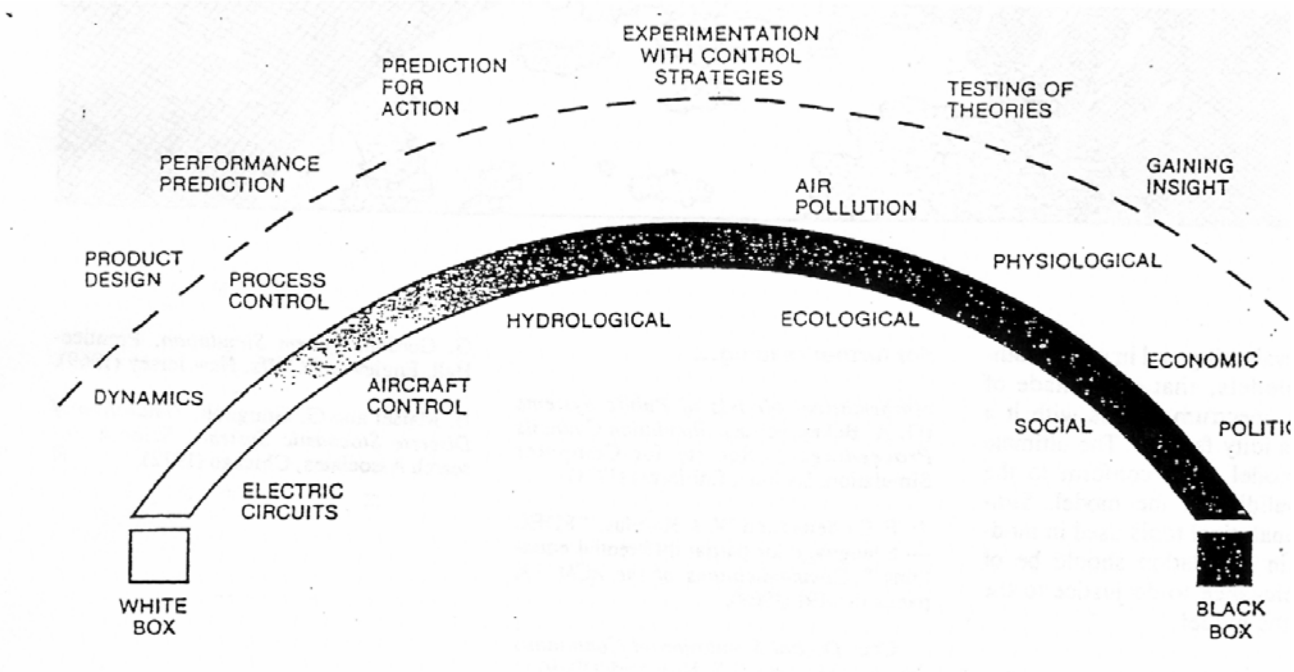


Figure 4. Motivations for modeling, showing the shift from quantitative models (light end of the spectrum) to qualitative models (dark end).

W. KARPLUS ..
~~W. KAPLUS~~: THE SPECT
MATH. MODELS

"Farther into the dark area of the spectrum are models of environmental systems. In this area there is general understanding of the physical and chemical processes involved (for example movement of water in underground reservoirs, or diffusion of air pollutants), but the system variables are readily accessible fr measurement. In essence the phenomena to be modeled occur in media whose distributed properties are only imprecisely known." (7)

"Continuing further in the direction of darkness, we encounter a variety of life science models. In this are a of the spectrum there is only approximate of the physical and chemical laws that underlie physiological phenomena. furthe the characteristics of the system being modeled are apt to change with time in ways that are unpredictable and uncontrollable."

"Models of economic, social, and political systems are in the very dark region of the spectrum, where the basic laws governing dynamic processes, and even the relevant constituents of the system are open to question and controversy". (7)

Model Uses
Figure 4 Motivations for Modeling
"Near the 'white box' end spectrum, for example electrical circuits, ..the validity of the model is such that the errors inherent in the model are small compared with the component tolerances normally associated with the elements of the electrical circuits...such quantitatively oriented models can be used with great assurance for the prediction of system behavior.

Closer to the 'black box' end of the spectrum, models play an entirely different role. Frequently they are used to provide general insights into system behavior- behavior that is often counterintuitive....Occasionally the primary objective of a model is to arouse public opinion and promote political action by suggesting that the current trends will lead to a disaster in the not-too-distant-future.

Between these two extremes in motivation for mathematical modeling lie the many part qualitative-part quantitative positions. It is important to recognize, in evaluating and in using mathematical models, that each shade of gray in the spectrum carries with it a built-in '**validity factor'.** The ultimate use of the model must conform to the expected validity of the model. Similarly, the analytical tools used in modeling and simulation should o justice to the validity of the model" (11-13)

Lemons:
"...it is questionable whether and to what extent scientific knowledge is adequate to inform env. decision makers with reasonable certainty." (1)

"...when scientists do not provide an explicit and rigorous treat of uncertainty in their analysis of specific problems, env. decision makers often accept sci. analyses of env. problems as being more factual than is warranted." (1)

"...the std. which is used (env. laws, regs.) is often the normal std. of scientific proof, such as 95% confidence level or an equivalent criterion. ..to min. Type I error...for env. decisions, the sci. uncertainty which pervades env. problems means the burden of proof is usually not met, despite the fact that some info. might indicate the existence of env. or human harm" (1)

Adler

" **A. On the Nature of Knowledge**
“1. By itself, **scientific and technical knowledge is neither a “be-all” nor “end-all”** in environmental conflicts. Parties bring to the table different **kinds of knowledge: “traditional” knowledge, “cultural” knowledge, “local” knowledge, and “remembered” knowledge**, all of which have a place at the table in environmental conflict resolution.

“2. **All information (regardless of whether it is scientific, technical, traditional, cultural, local, or remembered in nature) is subject to questions about validity, accuracy, authenticity, and reliability.** Every type of knowledge has standards of quality that can be examined, debated, or shaped. Thus, the issues of what is examined, how it is examined, who examines it, and when it is examined are negotiable.

“3. **Useful knowledge rarely remains static** in the subject matters that come into play in environmental conflict. Knowledge builds off new questions
and new information.

“4. Many **lay people think science is conducted wholly in the realm of testable knowledge**. Scientific methodology stresses experimentation and quantifiable conclusions: observation, hypothesis, experiment, and conclusion. **Subjective knowledge, however, plays a larger role than many people know or that scientists will often admit to**. Past experiences, intuition, hunches, values about what is important to know, and even bidding/betting processes like “Monte Carlo” analysis often enter into the scientific process, particularly in framing questions for research and data collection.

“5. **Scientific and technical research in the life, engineering, and social sciences rarely provides definitive and unequivocal answers**. More often, knowledge is expressed in terms of **probabilities**, beta-weights, and standard deviations. There is usually room for reasonable people to disagree on both the methods by which knowledge is generated and the evidence used to substantiate it.

“6. **Environmental disputes often deal with systems where the whole is different from the sum of the parts. Reductionism**—seeking to understand the system by looking only at the units and their relations with one another—**is prone to inducing error**, where problems cannot logically be traced to faults in any particular element or to the relationships between elements.

“B. On Uncertainty

“1. However great our information and knowledge base is, **our understanding of environmental, social, and economic reality remains incomplete**. We will never know everything we need to know to make perfect decisions, particularly when the decisions concern predictions of the impacts. **Biological and social “uncertainty” is a fact-of-life**, though it may not be at issue in every environmental conflict.

“2. In environmental conflicts, **risks and uncertainties cannot be ignored**. In cases of **future consequences and impacts**, research and inquiry by the parties is usually necessary and advisable, either within the conflict resolution process itself or as part of the outcome.

“3. **Risks and uncertainties must be clarified and understood both in lay terms and in scientific or technical terms**. In general, there are **three kinds** of uncertainties that tend to arise in environmental cases: **(a) uncertainties in which the measurements or observations are insufficient to bound explanation and interpretation; (b) uncertainties that arise because the measurements conflict; and (c) uncertainties over competing or fragmentary theoretical frameworks.**

“4. **The greater the level of scientific or technical uncertainty** about significant outcomes or impacts associated with proposed actions, **the more future research is warranted**, either as part of the conflict resolution process or as part of the agreements that are being made. In turn, the greater the uncertainty, **the more “adaptive and heuristic” the resulting agreement should be**. By adaptive, we mean that an agreement should ideally seek to incorporate mechanisms that build in future information and it should be protean enough to be altered in the face of compelling new evidence.

“5. **Most environmental decisions have unintended consequences**. For every action, law, policy, or program adopted to manage a conflict, no matter how well intended, there is a real risk of unintended consequences. They are not merely calculated risks, side effects, or trade-offs. “Revenge effects” happen because new structures, devices, and organisms react with real people in real situations in ways that cannot be foreseen.” (15,16)

(see also ***Adler*** below in **Decision Making, and ENVIRONMENTAL IMPACT ANALYSIS)**

Earth Sciences

Sarewitz

"Science, with its promise of prediction, seems to be a perfect mate for decision making, with its forward-looking essence. Environmental policy making tests this marriage. .. In fact, the relationship is rocky...each activity is complex and difficult in its own right. The theoretical and technical **difficulties of predicting complex natural systems are immense**, and the **magnitudes of uncertainties associated with such predictions may be not only large, but themselves highly uncertain.** ..the process of making environmental decisions, which often brings together a mix of violently conflicting interests and values, has given rise to some of the most intractable political disputes of the last half century." (4)

"Scientists, decision makers, and analysts have often **suggested** that effective **linkage between science and environmental decisions** depends on the achievement of two goals: First, s**cientific uncertainties must be reduced**, (that is predictions need to become more accurate); and second, t**echnical experts must effectively communicate the nature of these uncertainties to people who must take action.** This intuitively attractive perspective treats uncertainty as something to be overcome, and prediction as a technical product that must be successfully integrated into decision making ***prior*** **to taking effective action**. It also explicitly justifies tens of billions of dollars of publicly funded scientific research...

All the same, it is **often impossible to assign meaningful uncertainties to predictions of complex natural processes**...(such as) hurricanes.." (6)

"Case studies of this book indicate **little obvious correlation between the quality of a prediction as judged by scientific stds. and the success of decisions as judged by the achievement of desired societal outcomes**...earth quakes, acid rain...)

Brown, J.D.

"….reality exists independent of people but cannot be understood independently from the discursive practices that guide our representations...(both) strong forms of realism (e.g. logical positivism), and (post-modern) antirealism in general, discourage openness by manufacturing artificial levels of confidence about the mechanisms through which theories are evaluated."(367)

"Scientific uncertainty is an important consequence of applying general concepts and methods to particular cases, reflecting on particular cases as visible expressions of embedded processes, and theorizing embedded processes beyond their visible expressions". (368)

"...the demand for transparency and accountability in scientific research will continue...the limits of environmental determinism have been illustrated by numerous high profile failures of causal modeling in the earth sciences over recent years where uncertainties in model predictions were not adequately assessed or documented". (368)

"...scientific uncertainties may be reinterpreted by decision makers and will combine with the social and political uncertainties of environmental policymaking. Encouraging transparency in the scientific contribution to this process may not be sufficient for achieving a satisfactory balance between uncertain scientific arguments and uncertain moral, ethical and legal ones, but is arguably *necessary* for achieving this balance" (369)

Origins of uncertainty

"uncertainty emerges because: 1. COMPLEXITY (more complex than our abstractions and simplifications) 2. TOO VARIABLE (nonlinear or chaotic) 3. SCALE- too large and interconnected to observe 4. TRANSPARENCY -too opaque to observe 5.CAPACITY - can't observe/instruments (371)

Closure- "the process of defining and delimiting an investigation by imposing boundaries" (372) - inherent uncertainties that CANNOT be analyzed by SENSITIVITY analysis- (ignores Open Sys).

Taxonomy of Imperfect Knowledge

374 James D Brown

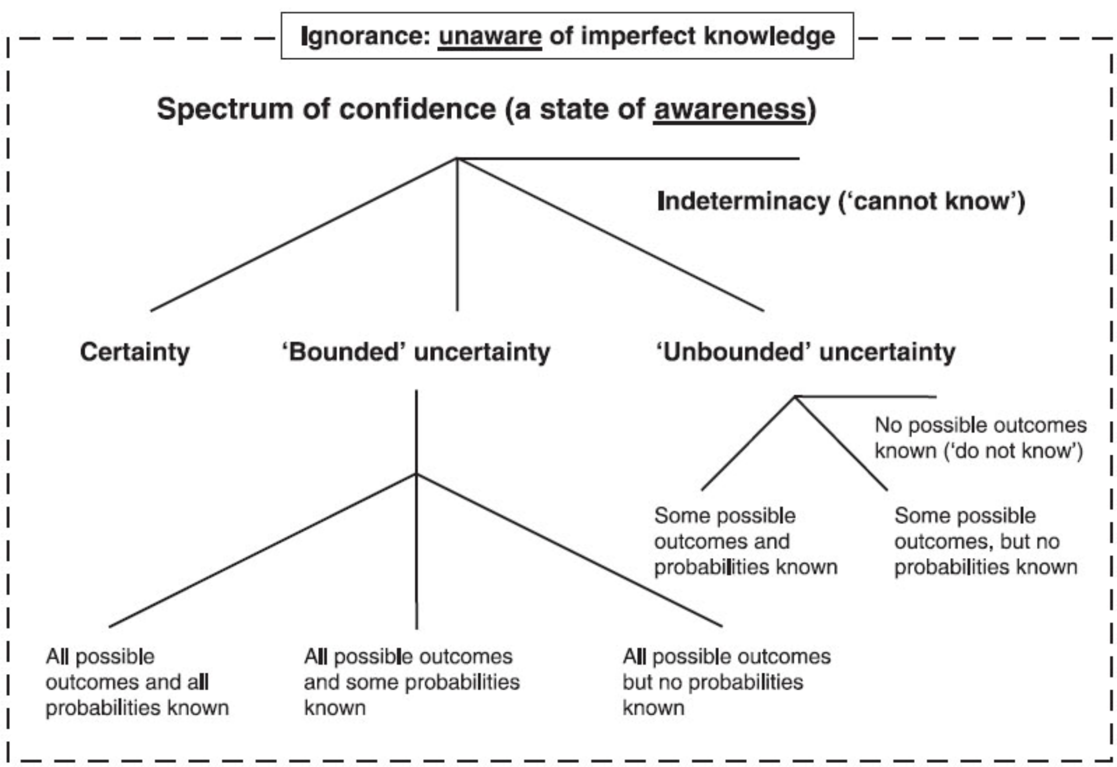


Figure 1 Our confidence may range from being certain to accepting that we cannot know, with uncertainty in between. Regardless of our confidence, we may be wrong (ignorance) and this may result in surprise. Uncertainty is bounded if we know all of the possible outcomes of an argument and is otherwise unbounded

Oreskes

"...(there is an) **implicit assumption that scientists have to make predictions**. Do they?....why predict?" ...for the **better parts of the last two centuries**, most **earth scientists eschewed temporal predictions,** viewing as beyond the scope of their science. Times have changed, and **earth scientists now routinely attempt to predict the future**...**these attempts rarely achieve their scientific or societal goals**." (23)

"..**two broad traditions have long competed in the philosophy of science**, two historically distinct visions of the scientific enterprise. One emphasizes **prediction (hypothetico-deductive)**, the other **explanation (inductive)**. **Physics and chemistry** (and more recently **molecular biology**) are highly compatible with the former, and perhaps best explained by it. **Geology and biology** (at the level of organisms and **ecosystems**) are better accounted for by the latter.. ..(**hypothetico-deductive) became dominant in the twentieth century** (31-32)

"...earth scientists are being increasing asked (by **policy makers) to predict** hurricanes, earthquakes, and the impact of human activities. This has led to an **explosive growth in the use of computer models**...to **generate temporal predictions**. In many cases this has led to the **same respect that the hypothetico-deductive model of science accords to logical predictions. But this respect is largely misplaced.** " (35)

" The hypothetico-deductive model presupposes that if, **if a theory fails its predictive test, then the theory is rejected**, or at least must be seriously revisited..."
this approach has **2 requirements**:
A. "the **time frame of prediction must be short enough** to allow us to compare the prediction with **events in the natural world**
B. "...to be of value in theory testing, the predictions involved **must be capable of refuting the theory that generated them.**"

"Nowadays the majority of predictions in the earth sciences are generated by computer models. There are **very few formal predictive laws in earth science**. ... **models**(consist of) a **complex amalgam of theoretical or phenomenological laws** (and the governing equations and algorithms that represent them), **empirical input parameters**, and a **model conceptualization.** When a computer model generates a prediction, **of what precisely is the prediction a test** ? The laws? The input data? The conceptualization? Any part (or several parts) may be in error, and there is **no simple way to determine** which one it is." (35/36)

"There can be **substantial social rewards for producing temporal predictions**...**If the value of predictions is primarily political or social rather than epistemic, then we need to be excruciatingly explicit about the uncertainties in the theory or model that produced them and acutely alert to the ways in which political pressures may influences to falsely or selectively portray the uncertainties**"(36)

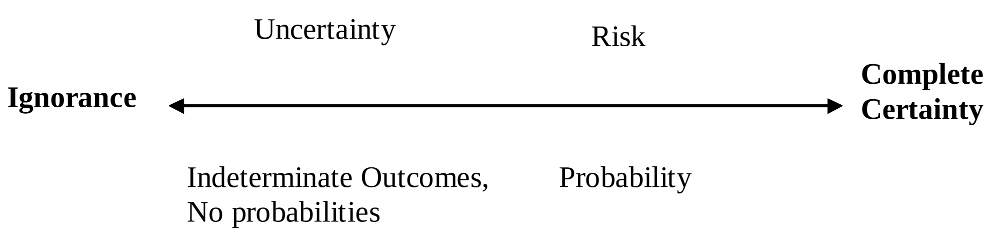
Water Resources

Cantor

"A desirable approach ...(to inform decision makers) would include delineating the **assumptions and limitations of utilized models,** and **expressing model results within a range (or including error bars). Sensitivity analysis** of modeling efforts can facilitate the expression of results". (282)

Knowledge Continuum

Cantor (p. 269)



Ecology

Jordan and Miller

"... the hopes for an **improved ability to forecast** the effects of oil spills, wetlands drainage, pesticide leakage, and so forth have in the environment have **generally been unfulfilled**." (94)

"...**ecologists usually cannot predict within an order of magnitud**e, a margin of error so large that many scientists and citizens alike would hesitate to label predictions 'scientific'" (94)

DESCARTES (reductionism): "All sci. is certain, evident knowledge. We reject all knowledge which is merely probable, and judge that only those things should be believed which are perfectly known and about which there can be no doubt" (95)

Hard-Soft Sci: "... 'hard' sci. has more predictive power than 'soft' sci"...most would agree that the series, hard to soft would be approximately: physics-chemistry-biology-env sci (ecol., earth sci.)-economics-soc. Sci (Pol. Sci, Anthro)" (99/100)

"...ecologists should attempt to state what normally or usually happens in a given system. '**Normic Statements'** are not probabilistic, but they 'attempt to state what will happen in a particular case, given a series of conditional statements around circumstances' "- BUT this may be a **TAUTOLOGY-** was error in normic statement -the prob. the 'initial conditions.'? (107), (based on Pomeroy, L.R., Hargrove, E.C., Alberts, J.J. The Ecosys. Perspective. In: Pomerpoy,LR, Alberts,JJ, eds. Concepts of Ecosystem Ecology: a comparative view". NY: Springer-Verlag,1988:1-17.)

The **problem** lies with the traditional view of **95% confidence level approach for acceptability-** this simple approach is often not feasible

some models (global warming)- can improve(109)

Sci. Uncertainty is often an Excuse- when the real problem is- soc-econ-political

Self Serving Science
"Scientists, by continuing a charade that if they were only given more money and more facilities the, can solve the environmental crises, will only contribute to a greater discreditation of science" (115)

"Confront uncertainty. Once we free ourselves from the illusion that sci. or tech. (if lavishly funded) can provide a solution to resource or conservation problems, appropriate action becomes possible. Effective policies are possible under conditions of uncertainty, but they must take uncertainty into account." (115/6) quotes:(Ludwig, D., Hilborn, R., Walters, C. Uncertainty, resource exploitation, and conservation: lessons from history. Science 1993; 17, 36)

Carpenter
U.S. National Research Council has examined the challenges of environmental prediction and identified three classes of problems:
1. **Measurement**- insufficient observations and natural variability;
2. **Extrapolation-**time, scale-
3. **Inadequacy of fundamental knowledge** of underlying systems

"Most important environmental problems, however suffer from *true* uncertainty (ie. indeterminancy) or events with unknown probabilities". (126)

"More dangerous, however, is the **usual total disregard of variance, and the presentation of a single (expected or mean) value as a go-no go advisory from the impact assessor.** This is misleading at best..." (126)

"...the **so-called 95% confidence limit**...needs to be understood by scientists for what it is: **an artifact** of arithmetic in normal distributions of sets of repeated measurement". (however) "Some benchmark is required for expediency...(and) comfort of decision makers" (126) need for adaptive management (146-153)

Environmental Mapping and GIS

McMaster

"Generalization is one of the foundations of human inquiry. W/o generalization, the observations we make about the world around us remain isolated in space and time. Unless we are willing and able to generalize about these layers of experience, we cannot expect to learn from them" (Foreword)

Hist. Review of lit.

(from Muller, 191,458-9)

4 Generalization "requirements"

1. **Economic**- data collection, user needs
2. **Data Robustness**- **errors** in data collection; generalization "f**ilters out trends**"
3. **Multipurpose, multi scale**
4. **Display and Communication- graphic clarity** (4)

(from Wright, 1942) Generalization is a function of:

Simplification- raw data too intricate or abundant

Amplification- data too scanty (18)

Digital Generalization-

Reduce complexity; maintain spatial accuracy; attribute accuracy; aesthetics; logical hierarchy; consistency (68)

Mower

Natural Resources GIS

"...in a larger context, our clients also include upper-level managers, politicians, social interest groups...and many others w/ an interest in predictions affecting private and public lands" (3)

"**Perhaps the worst nightmare** of a natural resources manager is to **appear 'uncertain'** to the public, or to **admit there is error** in the decision process is being presented. At the same time, the **entire range of professionals** dealing with natural resources and environmental assessments, from ecologists to environmental engineers, **recognizes that environmental processes are inherently variable"(**3)

Environmental **disciplines evolved independently**, now with **GIS data sharing**- there are **communication conflicts**

Defs: **Accuracy**
Precision
Scale
Uncertainty/Risk Assessment (4/5**)**

Social/Political factors:

"...many people have difficulty accepting probabilistic forecasts" "They may demand certainty where none is possible or discount probabilistic evidence that does not agree w/ preconceived notions" (6)

(according to Lemons 1996) "**When rigorous treatment of sci. uncertainty is not included explicitly in problem analysis...natural resource managers often accept them as being more reliable than is warranted**" (6/7)

"The **tradition of "95% confidence for "sci" proof is often too stringent- creating a burden of proof of environmental harm that cannot be met.**" (7)

Pang

"...as the volume and richness of geo-spatial data increases... there inevitably will be more concern about the accuracy, timeliness and confidence of information being displayed- especially if the data is coming from multiple sources, or by their nature of collection contain some inherent uncertainty" (1)

In the literature there is no consensus \definition of uncertainty (Good lit. summary)

DEFS

ERROR - discrepancy between a given value and a "true" value
Inaccuracy- discrepancy between a given value and its modeled or simulated value
Validity- accuracy of data and procedures applied to the data (statistics, independent sources...)
Data Quality- data validity plus lineage

(NCGIA) DQ is based in 3 systems variables:
Source Error- "goodness"- statistical
Process Error- application, model resolution
Use error- purpose (analysis OR communication) see MacEachren)

Copied Fig 2. Contour Quality

MacEachren

"...**efforts to develop visualization methods** and tools that can help information analysts understand and cope with info. uncertainty have been underway for **over a decade**. Uncert. in geospatial info. has been given particular emphasis. Progress hads been made, but that progress has been reported in diverse outlets...(to date) **we do not have an understanding of the parameters that influence successful uncertainty visualization.**" (139)

5 COMPONENTS:

1. Conceptualzing Uncert.-

error- statistically known inaccuracy

uncertainty- is ill defined.

Semantics (Buttrenfield 1993)

Reporting **"accuracy"**- emphasizes "**good**" aspects of data certainty

Reporting "**error**" - emphasizes "**bad**" aspects

"...lack of methods for measuring and representing many aspects of uncertainty inb a GIS..." (140)

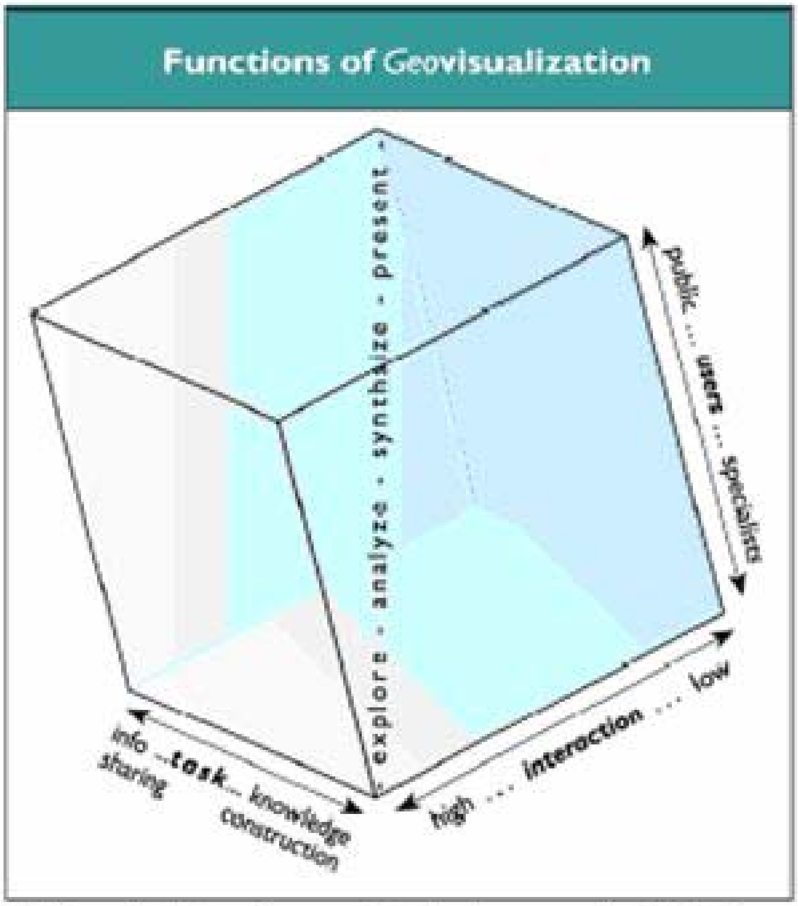
Some authors propose developing "**uncertanty libraries** (Lowell 1997), or an "**Encyclopedia of Ignorance**" (Couclelius 2003) (140)

2. **Decision Making with Uncertainty**

Uncertainty leads to bias toward initial potential solutions, and undervaluing negative evidence." **Expert decision makers** tend to respond to uncertainty by **incorporating probabilities into mathematical equations** (*this contradicts above definitions!*) ..(while).**naive decision makers.**..tend to rely on **past experiences and stereotypes**..." (140)

"...some **limited research** on **map readers suggests** that **representation of data uncertainty is helpful**.....however, there is l**ittle real-world verification**..." (140). "..the **research** seems to **take for granted** that visual depictions of uncertainty are useful for decision making" (141).

"...**humans are not typically adept** at **using statistical information** in the process of making decisions." (141)



I Four functions for geovisualization are depicted along the central diagonal of this geovisualization use space. The space is defined by: kinds of task, kinds of user, and level of interaction enabled in the interface. *modified from figure PIII.1* [1].

In his "Functions of Geovisualization " (above), MacEachren assumes that public users, including decision makers, want low interaction with highly simplified visualizations.

3. Typology of Uncertanty

many groups studying vproblem: geo-visualization; scientific visualzation; information visualization (143)

Geo-vis (**Spatial Data Transfer Stds**.)

lineage
positional accuracy
Attribute acc.
logical consistency
completeness

Fig. 2 Buttenfield 1988 (144)

(Thompson 2004) ads to list **credibility- correctness of past info (description, model predictions)** (146)

4. Methods for repesenting/interacting w/ uncert
5. Efforts to understand usability/utility (151-)
map interp. NOT equal to real world decsion

Challenges:(155-)
understanding components of uncertainty
" how knowledge of info uncertainty inflluences analysts, decision makers, decsion outcomes (156)
how/whether vis uncert aids **exploratory analysis**
interactive tools
assessing usability

Shi, Fisher, Goodchild

"...many types of spatial data involve human judgment...soils...landscape ecology..The concept of accuracy, which implies the existence of truth, that can be approached by better and more precise measurement, simply does not apply to many types of spatial data." (xvi)

Duckham

GIS error handling- "**common in the research** literature- largely **absent from GIS software**" (62)

"**error sensitive GIS**"- flexible core of error handling functions
"**error-aware" GIS**- extensions to help user understand (62)

Problems: -**cursory nature of metadata**
- "...Negative connotations of the word "error, outside the research literature, which may deter software developers and data producers from emphasizing error-handling capabilities". (62)

Reinke

" With the increase in **new users of GIS** and the rapidly growing number of data sets available...the **need for effective communication of spatial data quality is now vital.**" (76)

"While the methods employed to communicate data quality are dependent on the skill level of the user, the kind of data information the type of data being used, and the nature of the application, it is clear that **communication techniques need to be flexible**... ((76)

<u>Fig. 6.3 Proposed Model for Communicating Uncertainty in Spatial Databases to Users (79)</u>

Fig. 6.3 includes t**wo dimensions of Uncertainty in communication**-
"The first is the **degree to which the representation corresponds to the truth or what is taken to be the truth**, while the second is jointly termed **compatibility and consistency**, This examines the **needs of the user and the representation**." (79)

Need for **multiple representations for multiple users**(80)

<u>Table 6.1 Types of error during visualization of uncertainty in spatial data based on cartographic communication theories</u> (81)

Four steps in Communicating Uncertainty

1. **Notification**- presence or absence
2. **Identification**-nominal form (type of data quality info-positional, attribute...)
3. **Quantification** (nominal-ratio..)-needs to extended to data simulations ex. soil survey
4. **Evaluation**- "...user determines the significance that uncertainty has on the particular data set and application" (83)

visual assessment (decision making) is not the same as visual observation (correctly observing info) (96)

How do (output) data values vary by data quality- Sensitivity results in a **series of visualizations (**ex. fire risk based on varying quality terrain data) (97)

Environmental Impact Analysis

Cantor, L.

Environmental Impact Analysis

Council on Environmental Quality CEQ Regs. 1502.24

Transparency: Agencies shall- prof. integrity, sci. integrity, identify methods, explicit ref. to sci. and other sources

1508.27 "**Consider the degree to which impacts are uncertain or involve unique or unknown risks**"

1502.22 when there is incomplete or unavailable info-

(a) get info (if reasonable)
(b) statement of incompleteness, relavance
(c) sci. evidence, evaluation based on theory (298)

A study (Ref.4,) in the mid 1980's found that "The **delineation of uncertainties was identified as an aid to decision makers**."(300)

A euro study (Ref.15, p.5) "In env. predictions, the **identification of the quantity and sources of uncertainty** (are) an important step in the application of methods. The **results of predictions should indicate the margin of uncertainty** involved". (300)

Prediction and **forecasting** are often used **synonymous**ly (306)

(World Health Org., Ref 14) "in environmental impact it would be **desirable to specify the range in magnitude of effects (impacts) and the possible errors in the prediction.**..However, uncertainties in impact prediction have led to **qualitative descriptions** of impacts, and the use of phrases such as **"might" or "possible"**

"The probability of occurrence should be noted if possible. ...example 95% of time noise between 65-70 dBA." (306)

Culhane

Communication and Rhetoric

Adler

"C. On Information and Environmental Conflict Resolution

1. **Conflicts over information, data, ideas, and knowledge are an inevitable** and integral part of most environmental conflict resolution processes. This holds true whether the conflicts are "upstream" in the policy formation or rule making stages or "downstream" in enforcement proceedings.

2. **Environmental disputes are rarely caused by scientific or technical information per se**. Most often, they tend to be about (a) perceived or actual competition over **interests**; (b) **different criteria** for evaluating ideas or behaviors; (c) **differing goals**, values and ways of life; (d) **misinformation, lack of information, and differing ways of interpreting or assessing data**; and/or (e) **unequal control, power**, and authority to distribute or enjoy resources.

3. In environmental conflicts, **scientific and technical issues are embedded in a political context where value choices are at play**. These underlying values are the ultimate arbiters of political decision-making, even when a plethora of scientific information is available. Substituting **scientific and technical information cannot finesse value choices**. However, information can more fully inform the value choices that need to be made.

4. **Not every environmental case is actually science-intensive**, nor is scientific and technical controversy the primary "story" in many seemingly science-intensive cases. **Parties often use scientific and technological issues as a strategic or tactical "weapon"**. Even when it is not a camouflage for other issues, **parties typically bring information to the table that bolsters their position.** Consensus-based environmental conflict resolution is a search for jointly usable information, which requires a joint inquiry.

5. **Jointly usable information requires trust in information and the methods** by which it is produced. Trust tends to diminish when parties perceive that the science has been generated from a particular point of view or with a particular outcome in mind. Conversely, trust can often be built if the questions asked and the methods employed in information gathering are jointly negotiated.

6. **Scientific and technological complexity plays a role in escalatory conflict dynamics.** The intricacy and technicality of some information can exacerbate a dispute by creating "mystery", by obfuscating options, or by alarming or overwhelming people with too many countervailing ideas.

7. **Parties are entitled to have the lid of the "black box" of science opened for them**, and illuminated, if they so choose. In joint gain proceedings, parties have a right to understand the science that informs their choices rather than being asked to trust the experts.

8. Some of the **confusion and complexity of environmental conflicts** are attributable to the presence of **multiple parties and multiple issues and the innate intricacy of systems** that have interconnections, emergent properties, and ripple effects that are not immediately apparent. **Reductionist thinking** ("here is the problem and these are the options") **does not sufficiently take into account the potential for unintended consequences that may not be readily or easily forecast**.

D. On Research and Information Gathering

1. **Stakeholders should drive the technical process** and determine the kinds of questions they need answered, when, and at what level of detail.

2. **Overly simplified or excessively summarized information often discounts the potential impacts of the policy choices that are at stake** in environmental disputes. Adequate detail is critical to assessing the strengths and weaknesses of each policy choices involved.

3. **Information and research costs money**. The better the research, the more it may cost. In mediated environmental conflict resolution, the rigor and depth of the scientific and technical information used in the search for consensual solutions **should ideally be matched to the seriousness of the problem at hand and the significance of the risk associated with bad decisions**. Scale and level should ideally be appropriate so as to avoid the costs of doing too much information gathering or the dangers of too little.

4. Either within the conflict resolution process itself, or as a product of it, **more research is warranted when potential impacts are great or uncertain**. This research can be part of the dispute resolution process, or can be built into an agreement. If parties choose not to have this research done, or cannot have this research done, it may be helpful to indicate an explanation to future stakeholder groups so they understand why.

5. **Some disputes have urgencies that require action prior to doing all the research** that would be desirable. In these instances, agreements that impact others not at the table but affected by the decision should spell out why a decision was made and offer clear assessments of the risks and benefits of doing so.

6. The **process of generating, compiling, analyzing and ultimately utilizing technical information should, wherever possible, be coordinated with the stakeholder process** and avoid either getting too far ahead of decision-making or being seriously delayed by it.

E. On Modeling

1. **Many environmental conflicts benefit from some form of modeling** in order to define problems, review impacts, or illustrate choices. **The promise of models may seduce policy makers and disputants into believing that the models are infallible**. However, **all models have uncertainty; it is misleading to believe that a number generated by a model is a singular value that predicts a future state with absolute certainty. Stakeholders must understand (and scientists must be assisted to honestly portray) that there is a range of quantities that surround any number output from a model. This variance reflects, among other things, the assumptions of the modelers and the complexity of the natural system.** Models will help differentiate answers, but **will not enumerate the one true and correct answer**. Models are **rarely fully predictive**; they are best thought of as **illustrative**. Models serve best when stakeholders understand that models describe ranges of options and are merely tools -- albeit sophisticated tools -- to aid in making informed choices.

2. **Scientists working for opposing parties may bring different models to the table based on differing assumptions about inputs, interactions between variables, and outputs.** The models then **are staged to be in opposition to one another, when in reality they simply miss or talk past each other because they are, at their core, incomparable.** This also occurs when **scientists of different disciplines modeling the same natural system view that system from different perspectives.** For example, an earth scientist analyzes global climate change through the lens of geologic time. On the other hand, an atmospheric scientist may make many detailed measurements of the present day climate and believe that such measurements are the key to predicting climatic change. Both approaches are correct. However, the results of the two models may yield different conclusions and advocates of each approach may disagree. It is the responsibility of the mediator to help parties and scientists integrate and understand each other's work and perspective, and learn how each perspective can benefit from the other.

3. Ideally, a mediator works with opposing scientists and stakeholders at the outset to have them develop a joint concept for how modeling should be accomplished. This **early agreement regarding modeling must include**, at a minimum, agreements regarding the **question to be answered** by the model, **the inputs for the model**, the **assumptions** that modify and affect the model, and the **expected outputs** from the model. **Some scientists may also be unwilling or unable to combine their work in a single modeling effort**. **Cost** considerations, **legal** mandates, **pride of authorship**, or simply the **timing** of the intervention may all **prevent the joint development of models**. In these circumstances, it is **critical that assumptions used in all models be transparent**, so that stakeholders can make their own choices on how to combine the information from opposing models in their decision-making process. This is something that a mediator or facilitator can more safely urge than an opposing party.

4. Recently, scientists and policy makers have developed methods for allowing modeling and decision-making to be more **iterative**, and to truly inform each other as each

progresses. In disputes involving public or environmental health, scientists may be asked to apply “risk based” analysis to their modeling, carefully identifying who or what may actually be impacted under any given scenario. For resource allocation or environmental restoration issues, scientists may be asked to construct an **adaptive management plan that allows policy choices to be refined as knowledge is accumulated about a given resource**. Mediators should help stakeholders and the scientists serving them to determine when it is appropriate to move to a risk-based analysis or an adaptive management analysis.” (17-19)

Innes

"What planners do, mostly, is talk and interact, but this is not just talk. It is through communicative practice, primarily that planners influence public action...(the) concept of communicative rationality to replace instrumental rationality,

"... three primary points.

(1) "**information** in communicative practice ***influences practices and institutions,* rather than primarily because a decision-maker uses it as a scientist would as evidence for choosing a policy alternative**.

(2) "the ***process by which the information is produced and agreed upon is crucial*.** It will **not become embedded** in those understandings and institutions **unless** there is **substantial debate among key players and a social process for developing shared meaning and legitimacy** for the information.

(3) "...***many types of information count, and not solely "objective" or formal information*. Storie**s count, as do **practical experienc**e and **intuitive knowledge**." (Abstract)

Jakobsen

"**Ecosys. management** is ...characterized by a **science-based integration of ecological, social, and economic elements..**.**collaborative** decision building... (crossing) traditional boundaries...between disciplines, agencies, governments, and interests...communication is essential."(591)

"In the context of team work, **integration** can be defined by as the "capacity (of team members) to '**enter into the mind-set of others**' (Kasl, 1997,242)".
"...the **literature on the barriers and facilitators** to interdisciplinary integration is **largely anecdotal or non-empirical discussions** (Clark 199, Norgaard 1992)" (592)

A Case study of Cross Disciplinary Integration in the Assessment Phase of the Interior Columbia Basin Ecosystem Management Project "contextual constructivist, qualitative, inductive approach..(with) active inclusion in the research process of those involved in the experience under study." "..exploratory single case study (holistic) research design...)(594)

Fig.1 Important Communicative Interactions (593)

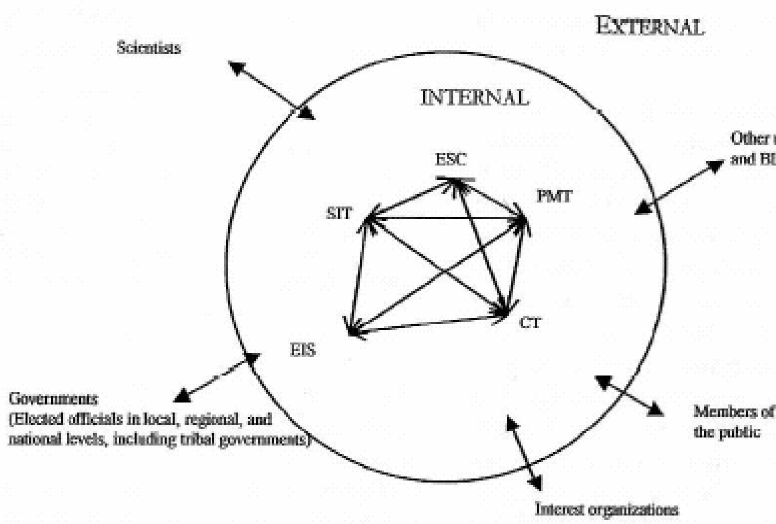


Figure 1. Important communicative interactions in the ICBEMP assessment phase. *Internal* includes groups or individuals internal to the ICBEMP assessment organization; *External* includes groups and individuals external to the ICBEMP assessment organization. Arrows indicate emerged communication pathways between actors that were important for carrying out the ICBEMP assessment. Abbreviations for internal groupings are *ESC* (Executive Steering Committee), *PMT* (Project Management Team), *SIT* (Science Integration Team, including 7 disciplinary subteams), *EIS* (Environmental Impact Statement team), and *CT* (Communications Team).

" only the ICBEMP planning module had a legal requirement for public involvement, ...(however it) included stakeholder participation throughout the entire process"
This case study focuses on the "internal communication process" within the scientific assessment (Fig.1).(593)

Assessment of "**Trustworthiness**"
- Credibility
- Transferability
- Dependability
- Confirmability (597)

Results:
- Facilitators/ Barriers:
  - Individual **Traits of Scientists**
  - **Cross disciplinary literacy/illiteracy**
  - **Interdisc. training**
- Differences in underlying values and methods between disciplines
- **Organizational structures**
- **Inefficient info. exchange**
- "**Closedness of communication process**" (598)

Social scientists felt ignored by natural scientists. "...**modeling** happened...in a black box"

Clear Power hierarchy: landscape ecologists- GIS- Terrestrial-Aquatics-Economics-Social Scientists

" **' The power that was represented in the maps, data sets, and projections (in a modeling sense) were obvious to other teams, to the agencies that were attempting to make decisions, and to the public we communicated with regularly. In that sense the social and economic subteams found themselves in a constant game of catch-up, because the information, data, and tools they brought to the process were not as powerful in their communicative ability (verbal or written)...as...the dominant players"** (600).

Conclusions for interdisciplinary science

need for "...effective or appropriate way of **group interacting**..(including) equipment or tools (eg. GIS)

"...explicit development of **shared cognition or understanding among team members**.."

"**Formal training in literacy (vocab. theoretical assumptions..) and techniques** (conceptual modeling, GIS, etc) in the beginning..."

Field trips

Qualified communication specialists (603)

Decision Making

Ozawa

In conventional decision making (1970s-'80's), **science is used as "conquer or perish"**. Both sides marshal sci. analyses. "**Decision makers respond initiating a variety of procedures designed to resolve tech. disagreements and either establish the superiority of one policy option over others, (because of its consistency w/ the 'correct' understanding of tech. parameters),or establish the tech. constraints w/in which political claims can subsequently be settled. In neither case is the political nature of the sci. argument itself considered**" (xi)

(Hiskes and Hiskes, 1960's) **dominant popular understanding of science="Logical Positivism Empiricism".**

1. data, experiment, observations= "objectivity";
2. science ha one universal, valid logic;
3. "through the rigorous application of logic to data, science gradually makes progress toward the ancient ideal of "theoria"- absolute understanding w/o ambiguity (6)

Traditional public decision controversies are **adversarial** involving sci/tech issues, each side marshals its sci/tech arguments. "comments, public hearings..(have the) primary function to persuade decision makers- not to educate or establish a common understanding of important elements of decisions" (33).

These adversarial approaches "...share serious constraints on communication that obstructs the revelation of disagreement on the sci. or technical components -written comments submitted to decision makers are strictly **one-way channels of communication.**(34)

(Mazur, A.1981. The Dynamics of Technical Controversy. Wash. D.C. Communications Press Inc.) "**Rhetorical devices are a major source of public confusion on the tech. merits of decision alternatives.**" (Ozawa 34)

Newer philosophies of science, Kuhn, social studies/construction of science, fact value dualities... transcend positivism(46)

Need for more transparency: **explicit examination of assumptions and methods,** expert and non-experts, and risk assessment (52)

Ozawa proposes a new **Collaborative** decision approach: "**Proceeding Despite Uncertainty**"
"**Run models with high, medium, and low values**" (72)- a form of sensitivity analysis
"**Different sci. methods, and tech opinions can be legitimate, given the existing state of knowledge."** (73)
Caution- in the Indian fishery case, **collaboration in the modeling process did not lower mistrust.** (95)

In **collaboration**:
"**Voice is the ability to express concerns and interests in language that is comprehensible to decision makers**"
"**Standing** is the necessary legitimacy conferred either explicitly through statutory language identifying those groups holding legal recognition as affected parties, or less formally, through public consensus earned by generating widespread public support". (100)

Stewart

:When there is enough data available, (**frequentist view**) then statistically there are two types of error of concern to Decision makers:
Error Duality- False Positive- False Negative
Scatter plots- Low to high correlation Prediction- Event
Taylor -Russell Diagram
Taylor-Russell Diagram with decision Table

(see **Stewart** above "(**How Well) Can we Predict**" section)

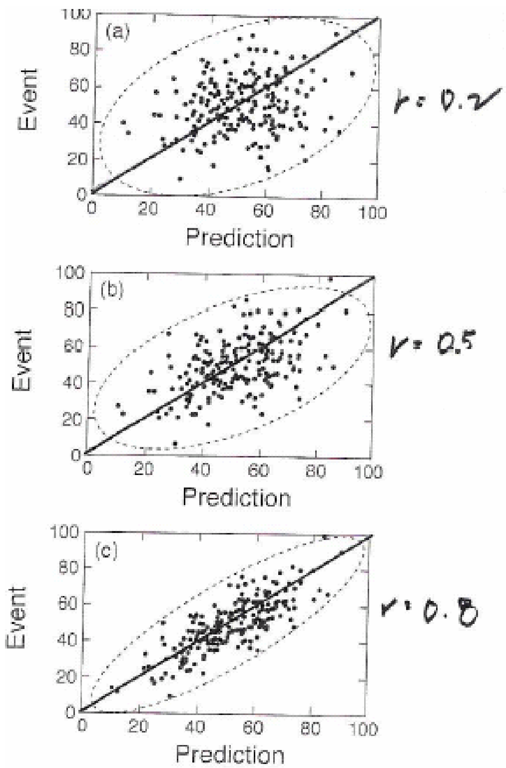


Fig. 3.1 Scatterplots representing various levels of uncertainty.

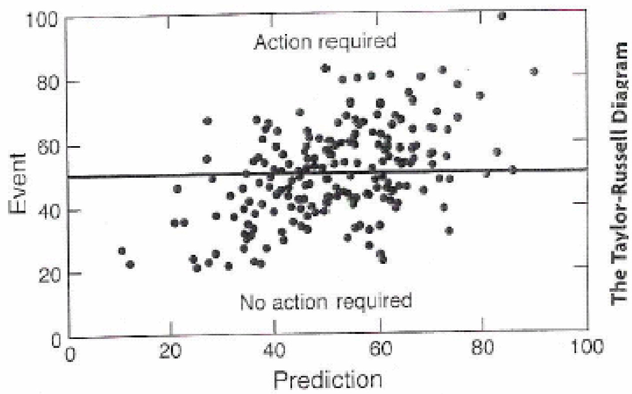
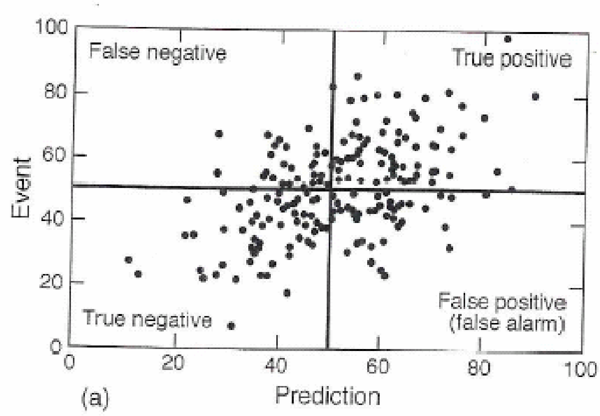


Fig. 3.2 The action/no-action criterion.



(b)

	Decision: Negative	Decision: Positive	
Event Positive	False Negative 30	True Positive 69	99
Event Negative	True Negative 59	False Positive 42	101
	89	111	200

Fig. 3.3 (a) Taylor-Russell diagram with (b) decision table

STEWART, T. "UNCERT., JUDGMT, AND ERROR IN PREDIC." IN SAREWITZ, D. ET. AL EDS (2000) PREDICTION: SCIENCE, DECISION MAKING & THE FUTURE OF NATURE. WASH. D.C., ISLAND PRESS.

Stewart pp.43-7

Policy Tradeoffs-**Reducing false positives (hurricane evacuations) often leads to an increase in false negatives** (hurricane damage) (48)

(Hammond(1996) Human Judgment and Social Policy- Irreducible uncertainty, inevitable error, unavoidable injustice. NY: Oxford U. Press) *.* **Each quadrant in the Taylor Russell diagram "develops its own constituency, and that in the presence of irreducible uncertainty, the decision cutoff will cycle back and forth over time**. Assuming that a prediction is necessary for a decision, the only way to **break the cycle is to simultaneously reduce both error types at the same time..(is to) reduce the uncertainty in the forecast"** (49)

Human judgment isn't very consistent-
The **judgment environment** plays an important role:
the n**ature of the system** being analyzed (external environ.)
the **information systems** quality (**ext. sys + info sys=** ***task uncertainty)*** Task uncertainty puts an upper bound on the accuracy of forecasts *(54)*
procedural, social, bureaucratic context (52)

PRIMACY OF FEEDBACK FOR LEARNING- often missing
(medicine, infrequent events...)

"In cases **where (systems) feedback is limited** or non-existent, **scientists** maybe **reluctant to make predictions, but they will be pressured to do so** because policy decisions cannot wait, and **policy makers need the judgments of informed experts.**" .."Unfortunately, logical coherence and consistency with natural laws leaves lots of room for a **wide range of predictions**.This creates ample opportunity for informed experts to disagree...**leaving policy makers in a quandary** and often results in opposing credible experts effectively **canceling each other ou**t." (53)

"Since uncertainty has such profound consequences for those that make predictions, and those that use them, **the measurement of uncertainty should play a critical role in the use of predictions in decision making**....**Assessing uncertainty can be extremely difficult,..(sometimes) more tech. complex than making the prediction**...(it is) an increasingly **important role for scientists**".

Sarewitz
"The difficulty of turning reasonably reliable knowledge about the future into positive action....(is) the central theme of this book. The value of predictions in public policy is not simply a technical question- it is **much more than a problem of reducing uncertainties, of getting the numbers 'right'**. Rather it is a complex mixture of interdependent scientific, political, and social factors. That being said, we must further muddy the waters by observing that even the very idea of **technical 'reliability' can be damnably difficult to evaluate at the time a decision must be made."** (2)

(quoting **Dewey**, J. 1991- *How We Think,* Amherst, NY: Prometheus Books, 16*)*) " The very essence of civilized culture is that we....deliberately institute, in advance of the happening of various contingencies and emergencies of life, devices for detecting their approach and registering their nature, for warding off what is unfavorable, or at least for protecting ourselves from its full impact, and for making more secure and extensive what is favorable." (3)

"Science, with its promise of prediction, seems to be a perfect mate for decision making, with its forward-looking essence. Environmental policy making tests this marriage. .. In fact, the relationship is rocky...each activity is complex and difficult in its own right. The theoretical and technical **difficulties of predicting complex natural systems are immense**, and the **magnitudes of uncertainties associated with such predictions may be not only large, but themselves highly uncertain.** ..the process of making environmental decisions, which often brings together a mix of violently conflicting interests and values, has given rise to some of the most intractable political disputes of the last half century." (4)

"Scientists, decision makers, and analysts have often **suggested** that effective **linkage between science and environmental decisions** depends on the achievement of two goals: First, s**cientific uncertainties must be reduced**, (that is predictions need to become more accurate); and second, **technical experts must effectively communicate the nature of these uncertainties to people who must take action.** This intuitively attractive perspective treats uncertainty as something to be overcome, and prediction as a technical product that must be successfully integrated into decision making ***prior* to taking effective action**. It also explicitly justifies tens of billions of dollars of publicly funded scientific research...

All the same, **it is often impossible to assign meaningful uncertainties to predictions of complex natural processes**...(such as) hurricanes.." (6)

"Case studies of this book indicate **little obvious correlation between the quality of a prediction as judged by scientific stds. and the success of decisions as judged by the achievement of desired societal outcomes**...earth quakes, acid rain...)

Sarewitz

"In modern society, **prediction serves two important goals**. First, prediction is a **test of scientific understanding,** and as such has come to occupy a position of **authority and legitimacy**. Scientific hypotheses are tested by comparing what is expected to occur and what actually occurs.

"Second, prediction is also a potential **guide for decision making.** Today as decision makers debate alternative courses of action, such as the need for a new **law** or design of a new **program**, they are actually making predictions about the **expected outcome...and its future impact on society.**

."....Persistent and pervasive calls for scientific prediction as a basis for environmental policy making suggest a **confusion about these two motives**...

"The **essential context for prediction in traditional science is reductionism:** the effort to break down reality into describable **component parts** or processes with the ultimate objective of **specifying the "laws of nature".** Such laws are fundamentally predictive, because they describe the **behavior of phenomena that is *independent of time and place*** *(Popper)*...In reductionist science, prediction pertains to the invariant behavior of the individual parts, **not to the interaction among natural systems that contain these parts** (Wilson)." (11-12)

"...disciplines of the **natural earth** (and atmospheric) **sciences**, ...have **not traditionally** been i**nvolved with prediction**. Rather, such disciplines have been the source of **verbal, graphical, and mathematical portrayals of nature that yield insight into earth processes**....For example historical **interpretation of earthquake** occurrence, combined with present- day **monitoring**, has **led to successful strategies** for mitigating earthquake losses through appropriate **engineering**, land-use **planning**, and **emergency management**. Such strategies **do not require the prediction of a specific earthquake to deliver social benefit"** (12)

" Over the **past several decades** however**, prediction has increasingly become the goal of the integrative earth science disciplines**.

... proliferation of **new technologies...**proliferation of **massive volumes and new types of data...**rapidly **increasing computer-processing capabilities..** have allowed earth scientists to **develop more intricate conceptual and numerical models...**ranging from the flow of t**oxic plumes in groundwater** to the **global circulation patterns of the atmosphere and oceans."** (13**)**

"While such models can be used to **test the validity of hypotheses** about earth processes, they are **also being used to predict the behavior of complex natural phenomena as input to policy decisions.** ***This type of prediction is fundamentally different from the predictive aspect of traditional, reductions scientific inquiry*****.**

Two analysis/prediction approaches:

"1. EVOLVING PROCESSES- mathematical characterizations of the **significant components of a system** and the **interactions** of those components **according to governing laws (first principles),** to yield a **quantitative predictive model;**

2. EPISODIC, TEMPORALLY DISCRETE- identification of specific environmental **conditions** that are **statistically significant precursors** of a **particular type of event."** (15)

Many earth science predictions (global warming, flood damage) require a mixture of physical and social predictions. The latter are of highly varying quality. (16/17)

"This new, **political role for prediction is seductive**.If predictive science can as well improve policy outcomes by guiding policy choices, the it can as well **reduce the need for divisive debate and contentious decision making** based on subjective values and interests. Prediction, that is, can become **a substitute for political and moral discourse**. By offering to improve policy outcomes, scientific predictions also offer to **reduce political risk**, and for policy makers worried about public support and **reelection**, avoiding political risk is very appealing indeed. This appeal has an additional attribute: The very **process of scientific research aimed at prediction can be portrayed as a positive step toward** solving a policy problem, **Politicians** may therefore be see **support of research** programs that promise to deliver a predictive capability **as an alternative to taking politically risky action** in the present." (17/18)

Will research based predictions improve policy outcomes? Not necessarily.
6 Framework Concerns:

A. Are process of policy interest fit **easily predictable geographic and time scales**? (earthquakes)

B. Is **accurate prediction necessary** to r**espond to socio-econ, problems** created by natural phenom- ex. effective **land use controls** (floods)

C. Is the lack of predictive capability used as to **defer political action**? (global warming)

D. "Predictive information may be subject to **manipulation and misuse, because limitations and uncertainties with predictive models are often not apparent to nonexperts, and because the models are often applied in a climate of political controversy and/or high economic stakes**...For example, in the cases involving mining on federally owned lands and replenishment of beaches, mathematical models are used to predict costs and impacts. the scientific assumptions that guide the use and interpretation of such models may be influenced by powerful economic and political interests" (19)

(Rushefsjky,M. (1984) The misuse of science in gov. decision making. *Science, Technology, and Human Values*, 9(3): 47-59) E. Are **criteria for policy success different than for science success?** (global warming). "...scientifically reputable predications that are not developed with the needs of policy makers in mind can in fact backfire and inflame political debate (oil and gas resource appraisals)

F. Do efforts to improve predictions **divert resources** ($, staff) from other types of activities such as **monitoring**?(19/20)

Notes

All Clean Air Act actions and most Clean Water Act actions are exempt from NEPA by statute. (Bass, 36).

Adler, P., et al. *Managing Scientific and Technical Information in Environmental Cases: Principles and Practices for Mediators and Facilitators*. Resolve, Inc. www.resolve.org U.S. Institute for Environmental Conflict Resolution (Tuscon) www.ecr.gov; Western Justice Center Foundation, Accessed 2005. Available from www.mediate.com/articles/pdf/envir_wjc1.pdf.

Bass, R, et al. *The Nepa Book: A Step-by-Step Guide on How to Comply with the National Environmental Policy Act.* 2nd ed. Point Arena, CA: Solano Press, 2001.

Brown, J.D. "Know;Ledge, Uncertainty and Physical Geography: Towards the Development of Methodologies for Questioning Belief." *Transactions Institute of British Geographers* NS 29 (2004): 367-381.

Cantor, L. "Scientific Uncertainty and the Evironemtal Impact Assessment Process in the U.S." In *Scientific Uncertainty and Environmental Problem Solving*, ed. J. Lemons, 298-326. Cambridge MA: Blackwell Science, 1996.

________. "Scientific Uncertainty and Water Resources Mangement." In *Scientific Uncertainty and Environmental Problem Solving*, ed. J. Lemons, 264-297. Cambridge MA: Blackwell Science, 1996.

Duckham, M. and J. McCreadle. "Error Aware Gis Development." In *Spatial Data Quality*, ed. W Shi, Fisher, P., Goodchild, M. New York: Taylor and Francis, 2002.

Innes, J. *Information in Communicative Planning*. Accessed 2005. Available from www.rmi.org/images/ER-InOpp-InfoCommPlng.pdf.

Jakobsen, C and W. McLaughlin. "Comminication in Ecosystem Management: A Case Study of Cross Disciplinary Integration in the Assessment Phase of the Interior Columbia Basin Ecosystem Management Project." *Environmental Management* 33, no. 5 (2004): 591-605.

Jordan, C. and C.Miller. "Scientific Uncertainty as a Constarint to Environmental Problem Solving: Large Scale Ecosystems." In *Scientific Uncertainty and Environmental Problem Solving*, ed. J. Lemons, 91-117. Cambridge MA: Blackwell Science, 1996.

Karplus, W. "The Spectrum of Mathenatical Models." *Perspectives in Computing* 3, no. 2 (1983): 4-13.

Lemons, J. "Introduction." In *Scientific Uncertainty and Environmental Problem Solving*, ed. J. Lemons, 1-11. Cambridge MA: Blackwell Science, 1996.

MacEachren, A., et al. "Visualizing Geospatial Uncertainty: What We Know and What We Don't Know." *Cartography and Geographic Information Science* 32, no. 3 (2005): 139-160.

McMaster, R. and K.S. Shear. *Generalization in Digital Cartography*. Wash. D.C.: Assoc. of American Geographers, 1992.

Mower, H.T. ""Accuracy Assurance: Selling Unceratinty to the Uncertain"." In *Spatial Accuracy Assessment: Land Information Uncertainty in Natural Resources*, ed. K. and A.Jayton Lowell, ???? Chelsea, MI: Ann Arbor press, 1999.

"National Environmental Policy Act." In *42 U.S.C. 4321-4347*, 1970.

Oreskes, N. "Why Predict? Historical Perspecs on Prediction in Earth Science." In *Prediction: Science, Decision Making, and the Future of Nature*, ed. D. Sarewitz, Pieke Jr, R., Byerly Jr., B, 23-40. Wash, D.C.: Island Press, 2000.

Ozawa, Connie. *Recasting Science: Consensual Procedures in Public Policy Making*. Boulder, CO: Westview Press, 1991.

Pang, Alex. *Visualizing Uncertainty in Geo-Spatial Data*. 9/20/01. Accessed Web:. Available from www.spatial.maine.edu/~worboys/SIE565/papers/pang%20vis20uncert.pdf.

Reinke, K. and G. Hunter. "Spatial Data Quality." In *Spatial Data Quality*, ed. W. Shi, Fisher, P., Goodchild, M., 76-101. New York: Taylor and Francis, 2002.

Sarewitz, D., Pieke Jr, R., Byerly Jr., B. "Introduction: Death, Taxes, and Environmental Policy." In *Prediction: Science, Decision Making, and the Future of Nature*, ed. D. Sarewitz, Pieke Jr, R., Byerly Jr., B, 1-21. Wash. D.C.: Island Press, 2000.

________. "Prediction in Science and Policy." In *Prediction: Science, Decision Making, and the Future of Nature*, ed. D. Sarewitz, Pieke Jr, R., Byerly Jr., B, 11-22. Wash. D.C.: Island Press, 2000.

Shi, W., Fisher, P., Goodchild, M., ed. *Spatial Data Quality*. New York: Taylor and Francis, 2002.

Stewart, T. "Uncertainty, Judgement, and Error in Prediction." In *Prediction: Science, Decision Making, and the Future of Nature*, ed. D. Sarewitz, Pieke Jr, R., Byerly Jr., B, 41-57. Wash. D.C.: Island Press, 2000.

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