Utah Lake Water Quality Study
Science Panel Meeting
December 10-11, 2019
Salt Lake City, UT

Uncertainty Guidance

Utah Lake Nutrient Criteria Development Technical Support

Goals

- Review uncertainty guidance
- Discuss and provide feedback on operationalizing this guidance
- Discuss and develop recommendations for mechanistic model uncertainty analysis

Uncertainty Analysis

- Part of SP charge: develop a process to characterize uncertainty ("*the lack of exact knowledge*")
- Draft document sent out in June
- Goal: "*characterize scientific uncertainty including confidence of scientific findings and quantified measures of uncertainty, where possible*"

Utah Lake Water Quality Study—Uncertainty Guidance

June 5, 2019

PRESENTED TO

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Division of Water Quality
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PREPARED BY

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Two main metrics proposed

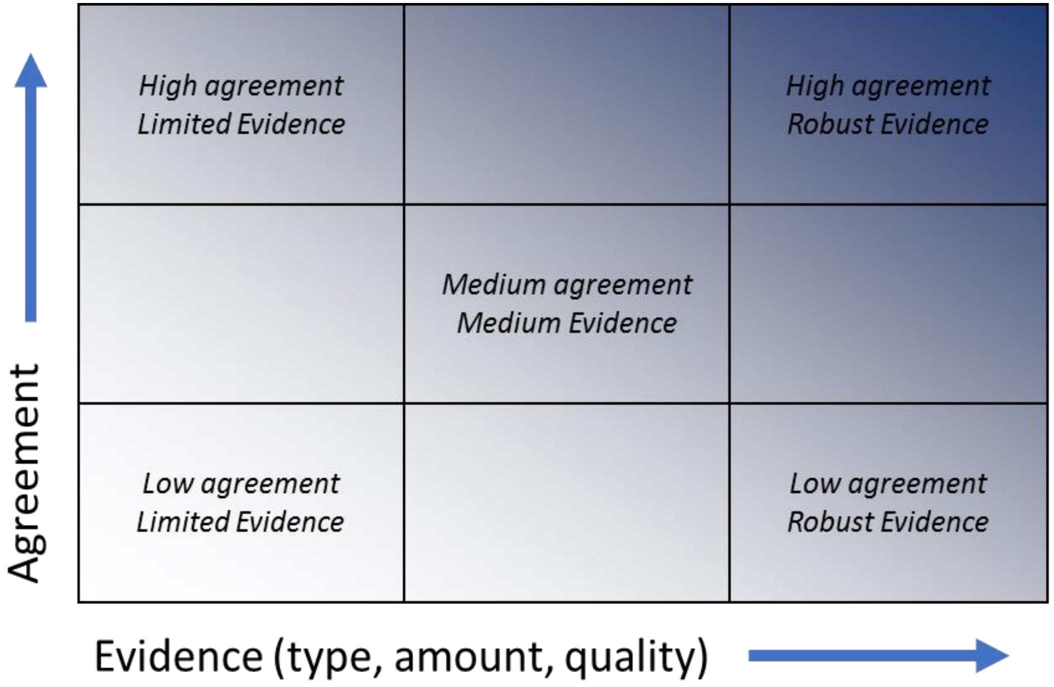
- Qualitative expressions of confidence
  - Use type, amount, quality, and consistency (or agreement) of evidence
  - Evidence is literature, statistical analysis, mechanistic model output, or expert judgment.

  - “The SP has medium to high confidence in this finding given the high agreement among the medium amount of studies”

- Quantitative measures of uncertainty expressed probabilistically (based on statistical analysis, model results, or expert judgment).
  - “The 95th percent confidence interval of TP associated with a target of 100,000 cyanobacterial cells per ml is 0.04 to 0.08 mg/l”

Uncertainty: Evidence and Agreement

- Evaluation based on:
  - Evidence
  - Agreement
- Statements convey:
  - Confidence – not statistical
  - Likelihood – can be statistical
- Based on IPCC



Uncertainty: Evidence and Agreement

- How to operationalize?
- Could develop strict rules for quality and agreement.

		Agreement		
		Low	Medium	High
Amount		Half the lines of evidence agree	25% of the lines of evidence disagree	All lines of evidence agree

		Evidence Quality		
		Limited	Medium	High
Type		Other Scientific Studies of Lakes	• Mechanistic Model of Similar Systems • S-R analyses for similar systems • Reference based data • Scientific Studies from similar systems	• Mechanistic Models of Utah Lake • S-R analysis for Utah Lake
Amount	***Mechanistic Model***	1 model run	2-3 model runs	>3 model runs
	S-R Analyses	1 independent analysis	2-3 independent analyses	>3 independent analyses
	Scientific Literature	1-2 studies	2-4 studies	>4 studies
Quality	***Mechanistic Model***	75% Variables meet Very Good calibration criteria	75-90% Variables meet Very Good calibration criteria	>90% Variables meet Very Good calibration criteria
	S-R Analyses	• p<0.20 • Variance explained <30%	• P<0.10 • Variance explained 30 to 50%	• P<0.05 • Variance explained >50%
	Scientific Literature	• p<0.20 • Variance explained <30%	• P<0.10 • Variance explained 30 to 50%	• P<0.05 • Variance explained >50%

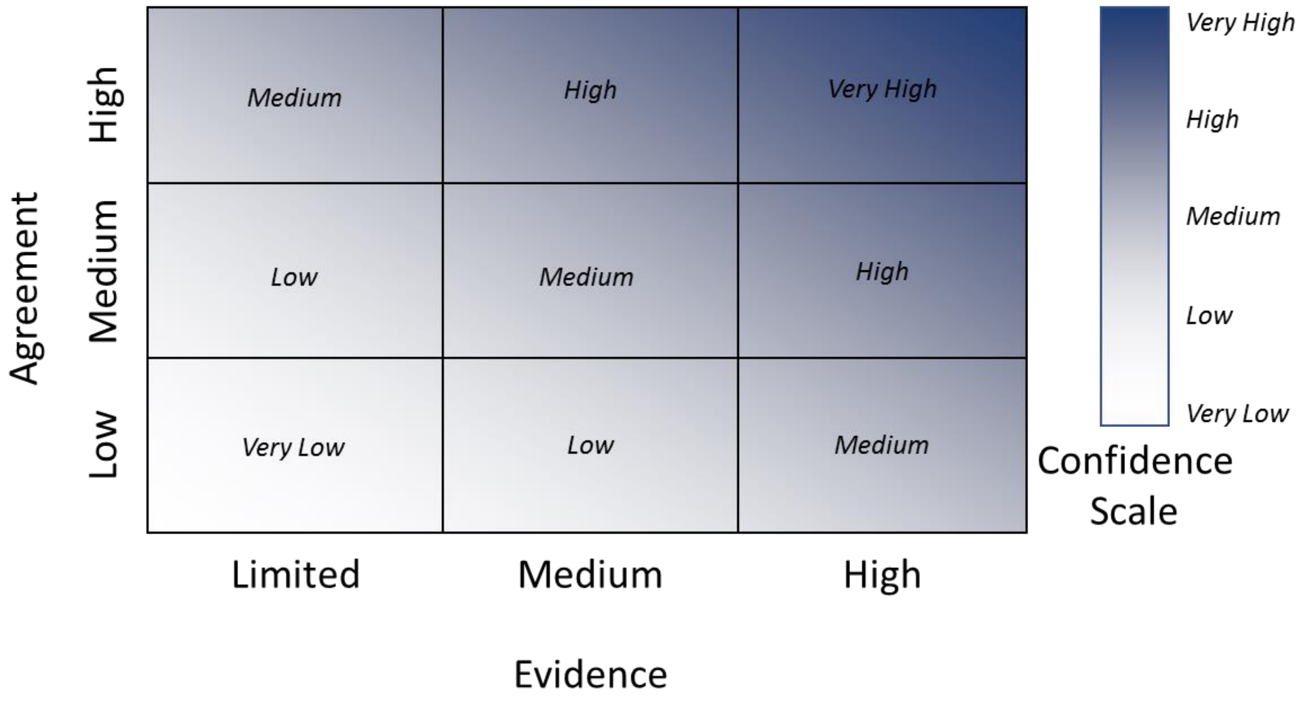
Uncertainty: Evidence and Agreement

"While there is only limited evidence to answer this specific charge question, the empirical and model data are in agreement with existing literature…"

- How to operationalize?
- Could develop strict rules
- Could forego discrete rules and use judgment as the situation dictates

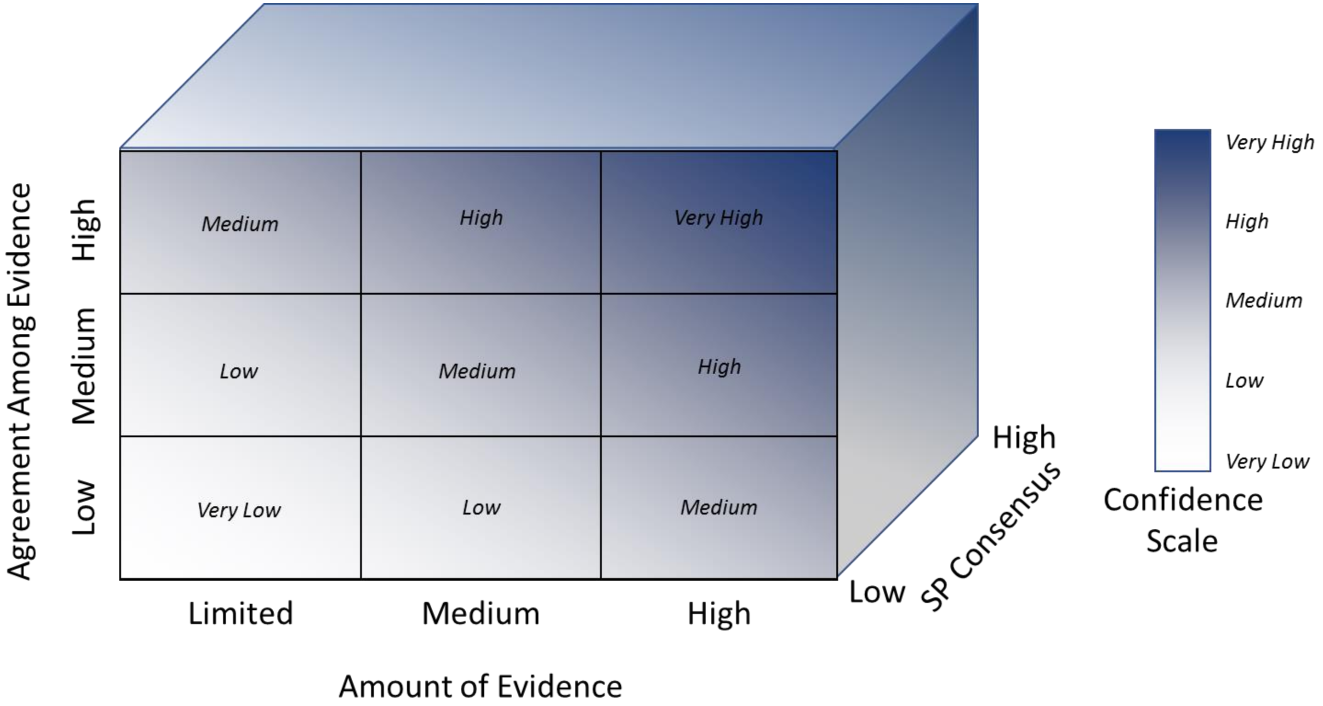
Uncertainty Analysis: Confidence

- Any finding should include expression of confidence.
- Based on evidence and agreement
- Aside is one discrete rubric that could be used



Uncertainty Analysis: Confidence

- Consensus among SP member could be added
- Lack of consensus decreases confidence
- Could also be incorporated into agreement



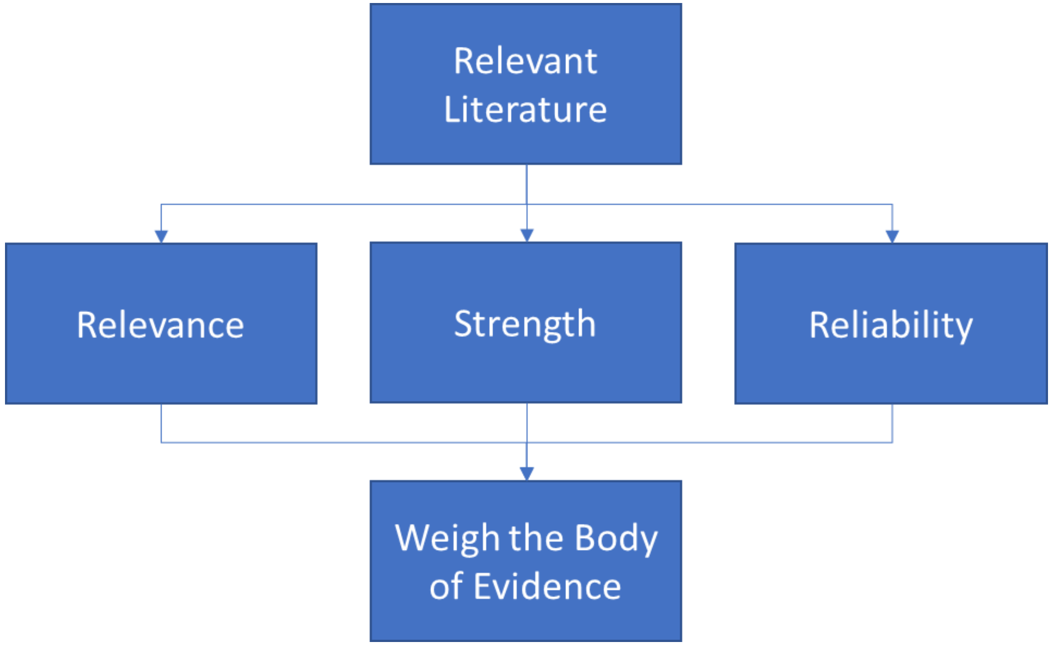
Uncertainty Analysis: Likelihood

- SP should communicate likelihood where necessary
- Derived from statistical models or elicitation
- Example from IPCC

Language	Probability
Virtually certain	99-100% Probability
Very likely	90-100% Probability
Likely	66-100% Probability
About as likely as not	33 to 66% Probability
Unlikely	0-33% Probability
Very unlikely	0-10% Probability
Exceptionally Unlikely	0-1% Probability

Uncertainty Analysis

- Evaluating different lines:
  - Empirical Analyses
  - Mechanistic Models
  - Literature



How to weigh literature – from USEPA 2016

Uncertainty Analysis

- Traceable Accounts
- Any conclusion and statement of confidence and likelihood should be accompanied by a traceable account
- This has proven useful in other similar endeavors

Operationalizing Uncertainty Analysis

- Discussion
  - Does this make sense? Is it way off? Is it confusing?
  - Is it specific enough? Does it need to be more prescriptive?
  - How can it be improved? Do you have examples from other experience?
  - What information is missing?
  - Would it help to work through examples?

  - Are the SC questions formulated in a way that can be addressed as to confidence or likelihood?
    - E.g., *What was the historic condition of the lake?*
    - Versus "*Was the lake historically eutrophic defined using Carlson's TSI and/or OECD thresholds for trophic state?*"

Uncertainty Analysis: Mechanistic Modeling

- Goal: recommendation to model team on uncertainty analysis approaches

- Deterministic models are different

- Natural variability in drivers
- Uncertainty in model equations
- Lack of knowledge of important pathways

- Types of Uncertainty (USEPA 2009)
  - Model framework uncertainty (e.g., missing calcite scavenging)
  - Model input uncertainty (e.g., sparse data on atmospheric deposition)
  - Model niche uncertainty (e.g., using a deep water model for Utah Lake)

Uncertainty Analysis: Mechanistic Modeling

Source of Uncertainty	Strategy	Advantages	Limitations
Model Framework	Expert Opinion	experts who have devoted their careers to study these questions might be better sources of information; can integrate all lines of evidence	Can easily be criticized as subjective
	Estimation by Comparing Different Model Structures	Provides direct evidence by comparing results of models	Requires use of more than one model
	History of use. Others?		
Model niche	Same?		

Uncertainty Analysis: Mechanistic Modeling; Predictive Uncertainty

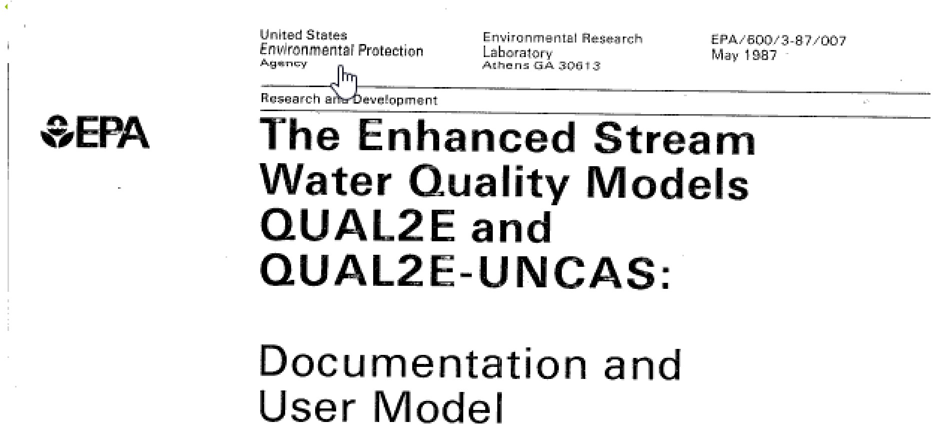
Source of Uncertainty	Strategy	Advantages	Limitations
Input/Parametric Uncertainty	Corroboration/Data-based approaches	how well the model conforms to reality: Model fit, probability distribution of outputs, performance criteria, expert elicitation	Limited to predictive uncertainty vs. model uncertainty
	Expert Opinion	Allows evaluation of all lines of evidence	Subjective
	Multiple Models	tests independent selection of various parameterizations, input	Time/labor intensive
	Sensitivity Analyses	Indicates how changes in inputs/assumptions affect predicted behavior	Simple and not computationally intensive; Inputs/parameters assumed independent

Source of Uncertainty	Strategy	Advantages	Limitations
Input/Parametric Uncertainty	Monte Carlo Simulations	Robust approach; long history of use. Useful for input and parametric uncertainty.	Computational intensive; no link to observations; requires specification of the covariance structure
	Bayesian Monte Carlo (BMC)	Generates uncertainty estimates combining prior information on parameter uncertainty with observed variation in water quality; Combines Monte Carlo analysis with Bayesian inference to determine the ability of random selected parameter sets to simulate observed data.	Best for parametric uncertainty. Computationally intensive
	Markov Chain Monte Carlo	Similar to BMC but not based on specifying prior distribution (uses	Best for parametric uncertainty. Computationally Intensive
	Bayesian Model Averaging	Used primarily for model selection or for combining predictive distributions from different sources	the application of BMA is not always straightforward; computationally intensive
	Others??		

Uncertainty Analysis: Mechanistic Modeling

Monte Carlo

- Start with calibrated model and selected parameters
- Assume a distribution of the model parameters (e.g. uniform; Gaussian, etc.)
- Randomly select from the distributions of model parameters and run the model using the randomly selected parameter values
- Do this LOTS of times to get a probability distribution of the model predictions


United States Environmental Protection Agency

Environmental Research Laboratory Athens GA 30613

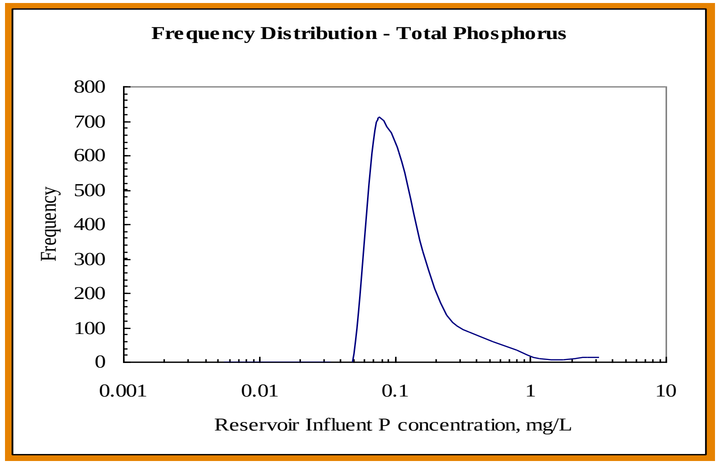
EPA/600/3-87/007 May 1987

Research and Development

EPA

The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS:

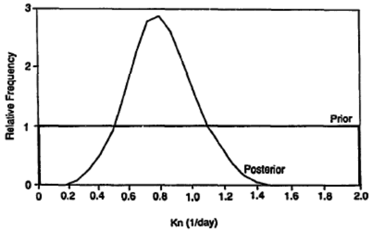
Documentation and User Model



Uncertainty Analysis: Mechanistic Modeling

Bayesian Monte Carlo

- Start with calibrated model and selected parameters
- Determine or assume a distribution of the model parameters (e.g. uniform; Gaussian, etc.)
- Compute likelihood of a parameter value given observed data (how well the model describes the observed data or what parameter value would make it most likely to observe the data we have observed)
- Using the likely results, compute a new (improved), or posterior distribution of the parameters
- Using the portions of the MC simulations that were run using the more likely parameters, you can select the best parameters (most likely) for the calibration and can also using this subset of the MC simulations compute the confidence intervals of the model predictions



Ecological Modelling, 62 (1992) 149–162
Elsevier Science Publishers B.V., Amsterdam

Development of Bayesian Monte Carlo techniques for water quality model uncertainty

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(Accepted 11 December 1990)

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Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/envsoft

A framework for uncertainty and risk analysis in Total Maximum Daily Load applications

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Uncertainty Analysis: Mechanistic Modeling

Bayesian Model Calibration/Markov Chain Monte Carlo

- MCMC is also a Bayesian strategy to compute the posterior distribution. It differs from BMC in that it uses a different startegy to obtain the posterior distribution. instead of obtaining the parameter samples from the prior, it directly samples the posterior using subject to some rule for determining what makes a good parameter value. The trick is that, *for a pair of parameter values,* it is possible to compute which is a better parameter value, by computing how likely each value is to explain the data. That is using a clever way to determine the posterior distributions
- Then from the subset of MC simulations you can compute the "best" set for calibration and can determine the frequency distribution of the model predictions (as in BMC)

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A COMPARISON OF BAYESIAN METHODS FOR UNCERTAINTY ANALYSIS IN HYDRAULIC AND HYDRODYNAMIC MODELING[1]

René A. Camacho, James L. Martin, William McAnally, Jairo Díaz-Ramirez,

Ecological Modelling 242 (2012) 127–145
Contents lists available at SciVerse ScienceDirect
Ecological Modelling
journal homepage: www.elsevier.com/locate/ecolmodel

A Bayesian synthesis of predictions from different models for setting water quality criteria

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Contents lists available at ScienceDirect
Environmental Modelling & Software
journal homepage: www.elsevier.com/locate/envsoft

Integration of numerical modeling and Bayesian analysis for setting water quality criteria in Hamilton Harbour, Ontario, Canada

Maryam Ramin[a], Serguei Stremilov[a], Tanya Labencki[b], Alexey Gudimov[a], Duncan Boyd[b], George B. Arhonditsis[a,*]
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Uncertainty Analysis: Mechanistic Modeling

Model Averaging

- Bayesian model averaging extended to deterministic models
- a standard method for combining predictive distributions from different sources
- For any forecast set, there is a "best" model
- Quantifying uncertainty about what is "best" input set using BMA

MAY 2005 RAFTERY ET AL. 1155

Using Bayesian Model Averaging to Calibrate Forecast Ensembles

ADRIAN E. RAFTERY, TILMANN GNEITING, FADOUA BALABDAOUI, AND MICHAEL POLAKOWSKI

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(Manuscript received 18 December 2003, in final form 29 September 2004)

ABSTRACT

Source of Uncertainty	Strategy	Advantages	Limitations
Input/Parametric Uncertainty	Monte Carlo Simulations	Robust approach; long history of use. Useful for input and parametric uncertainty.	**Computational intensive**; no link to observations; requires specification of the covariance structure
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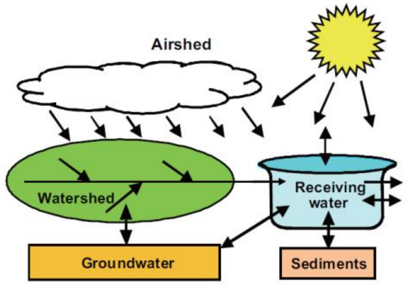
	Others??		

Uncertainty Analysis: Mechanistic Modeling

- All approaches can be used independently or combined (e.g. expert opinion on how to weigh each)
  - Do all?? Some?? Which??



- An additional issue is addressing uncertainty in individual models vs. integrated system (how uncertainty propagates though a series of models)?
- What to recommend to model team?

Uncertainty Analysis

- Next steps:
  - Mostly guiding principles – more details will emerge with work
  - Feedback from Science Panel
  - Revise and Finalize