Considering Measurement Uncertainty in H/WQ Model Evaluation

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Measurement Uncertainty in H/WQ Modeling

"Should it not be required that every… (field and modeling study) …attempt to evaluate the uncertainty in the results?"

- Beven. 2006. On undermining the science? *Hydrol. Process.* 20:3141-3146.

"The use of uncertainty estimation… (should be)…routine in hydrological and hydraulic science."

- Pappenberger and Beven. 2006. Ignorance is bliss: Or 7 reasons not to use uncertainty analysis. *Water Resources Res.* 42(5):xx-xx.

- Haan (1995) suggested that uncertainty analysis in H/WQ modeling represents intellectual integrity
- Reckhow (1994) emphasized the importance of communicating uncertainty to stakeholders and decision-makers to improve policy and management decisions

Measurement Uncertainty in H/WQ Modeling

- **An important source of uncertainty in H/WQ modeling is measurement uncertainty.**
- **However, when "measurement uncertainty" is included in uncertainty analysis**
  - **focuses almost exclusively on model inputs or parameter estimation (e.g. hydraulic conductivity, CN, fertilizer application)**
  - **does *not* address uncertainty in measured data, against which model outputs are compared (e.g. flow, water quality)**
- **This research focuses on uncertainty in measured data used to calibrate, validate, or evaluate H/WQ models.**

Measurement Uncertainty in H/WQ Modeling

- **Why is the uncertainty in measured H/WQ data typically not considered in model calibration, validation, and application???**
  - **Until recently…**
  - **Scientists had not established an adequate understanding of uncertainty in measured H/WQ data**
  - **No complete uncertainty (error propagation) analysis had been conducted on measured H/WQ data**
  - **No goodness-of-fit methods had been developed to explicitly consider measurement uncertainty**

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Objectives

- **Objective #1 – Briefly describe a method for estimating the "quality" of calibration, validation, and evaluation data**
  - **Fundamental scientific estimates**
  - **Methodology for project-specific uncertainty analysis**
  - **Focused on uncertainty in measured streamflow and water quality data (TSS, N, P) for small watersheds**

- **Objective #2 – Describe modified versions of several "goodness-of-fit" indicators that consider measurement uncertainty in H/WQ model evaluation**
  - **E_{NS}, *d*, RMSE, MAE**

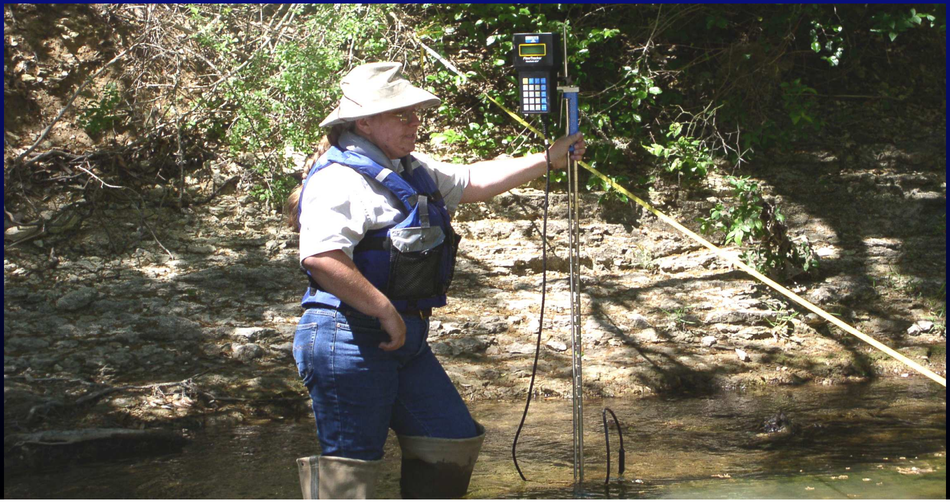
Objective 1 – Quality of Measured Data

- **Root mean square error propagation method (Topping, 1972)**
  - **includes all steps required to measure flow and water quality data**
  - **widely-accepted error propagation method**
    - **previously used for discharge, pesticides**
  - **combines all potential errors to produce realistic estimates of overall error (cumulative probable uncertainty)**
  - **assumes potential errors are bi-directional and non-additive**

$$E_P = \sqrt{\sum_{i=1}^{n}\left(E_1^{\,2} + E_2^{\,2} + E_3^{\,2} + \ldots + E_n^{\,2}\right)}$$

Objective 1 – Quality of Measured Data

- Created several arbitrary "data quality" scenarios
  - best case, worst case, typical – based on QA/QC, available resources, and monitoring conditions
- Categorized uncertainty sources into procedural categories
  - Q measurement, sample collection, sample preservation and storage, laboratory analysis
- Calculated cumulative uncertainty in resulting data



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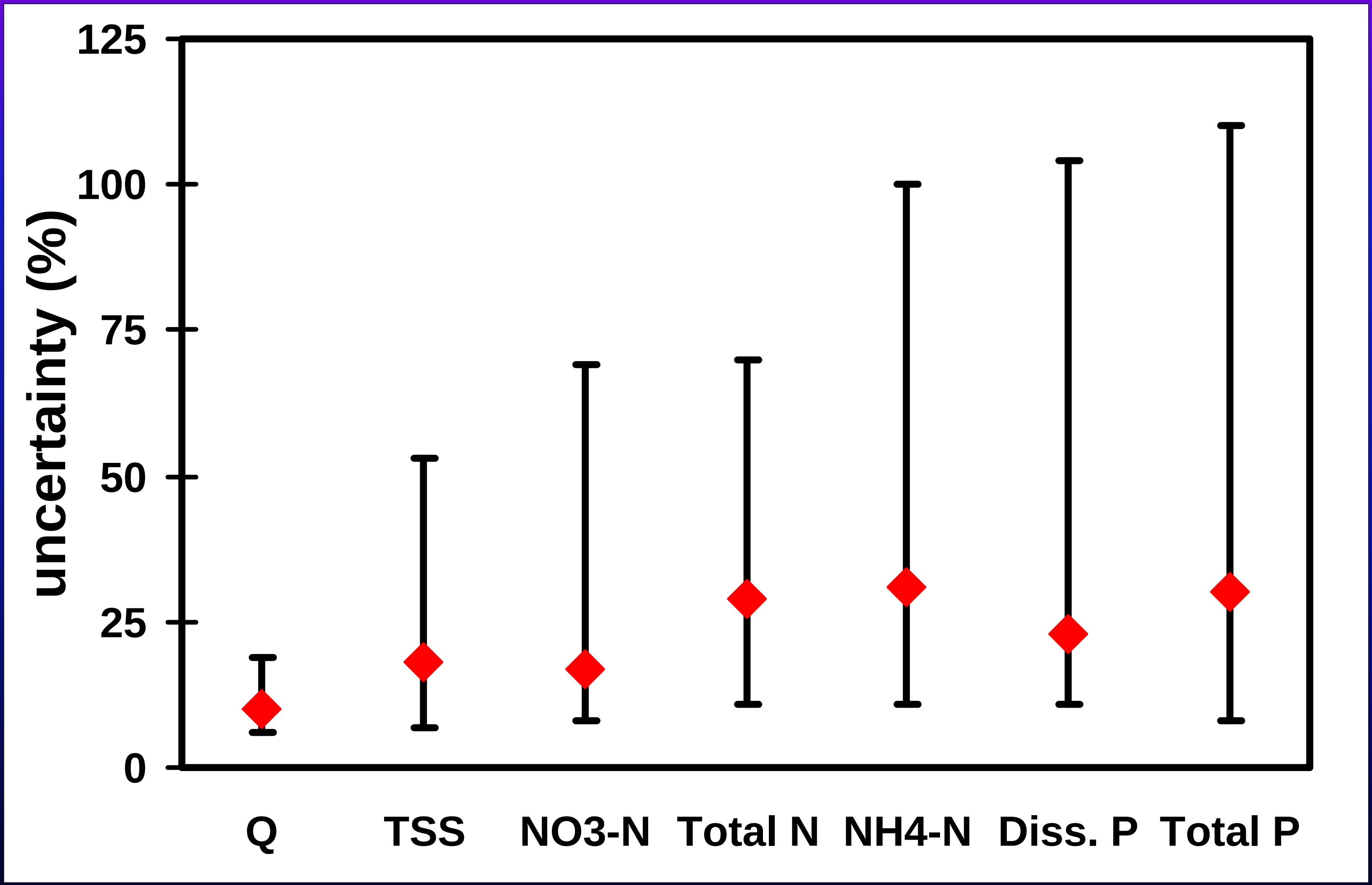
Objective 1 – Quality of Measured Data



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Objective 1 – Quality of Measured Data

	Q (%)	TSS (%)	NO_3-N (%)	Total P (%)
Worst case scenario	42	117	421	249
Typical scenario max.	19	53	69	110
Typical scenario avg.	10	18	17	30
Typical scenario min.	6	7	8	8
Best case scenario	3	3	4	3

Worst Case

Previous Data

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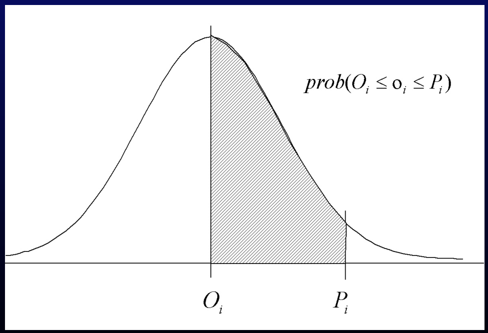
Objective 2 – Modified Goodness-of-Fit Indicators

- **Measurement uncertainty should be considered when evaluating H/WQ models**
- **Specifically, H/WQ models should:**
  - **not be expected to simulate/reproduce uncertain data values**
  - **produce output within the uncertainty range of measured data**
- **The error term ($e_i = O_i – P_i$) appears in several popular model goodness-of-fit indicators**
  - **e.g. E_{NS}, *d*, RMSE, MAE**
- **This error term should be modified to reflect measurement uncertainty**

Objective 2 – Modified Goodness-of-Fit Indicators

- **Developed two error term modifications, based on available measurement uncertainty information.**
  - **Modification 1 is most appropriate if:**
    - **only uncertainty boundary is known (+/- %)**
    - **probability distribution cannot be reasonably assumed**
  - **Modification 2 is most appropriate if:**
    - **distribution of uncertainty is known or reasonably assumed**



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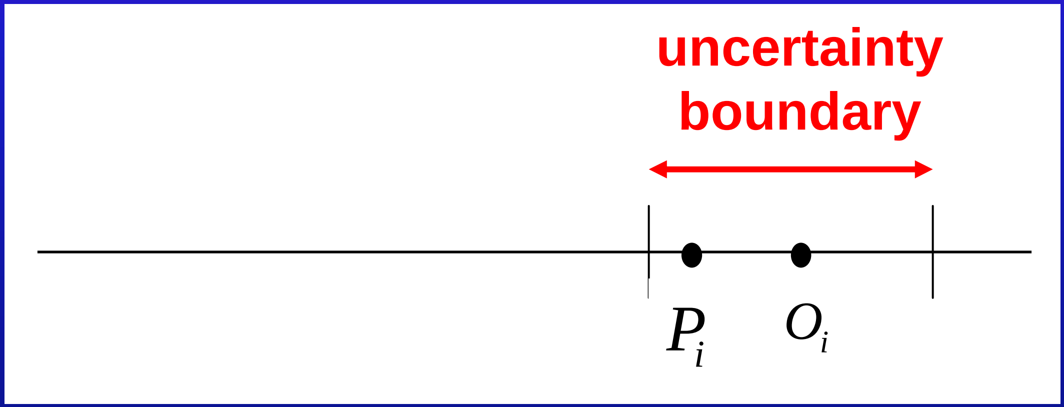
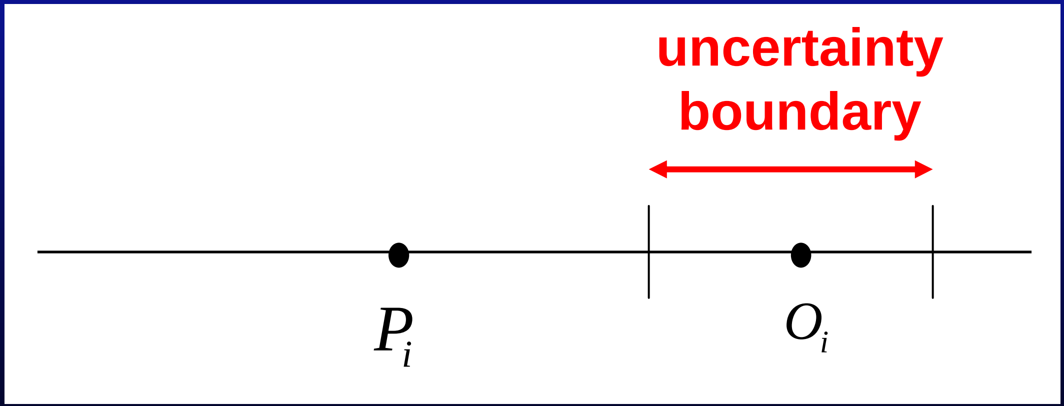
Objective 2 – Modified Goodness-of-Fit Indicators

Modification 1- if only uncertainty boundary is known



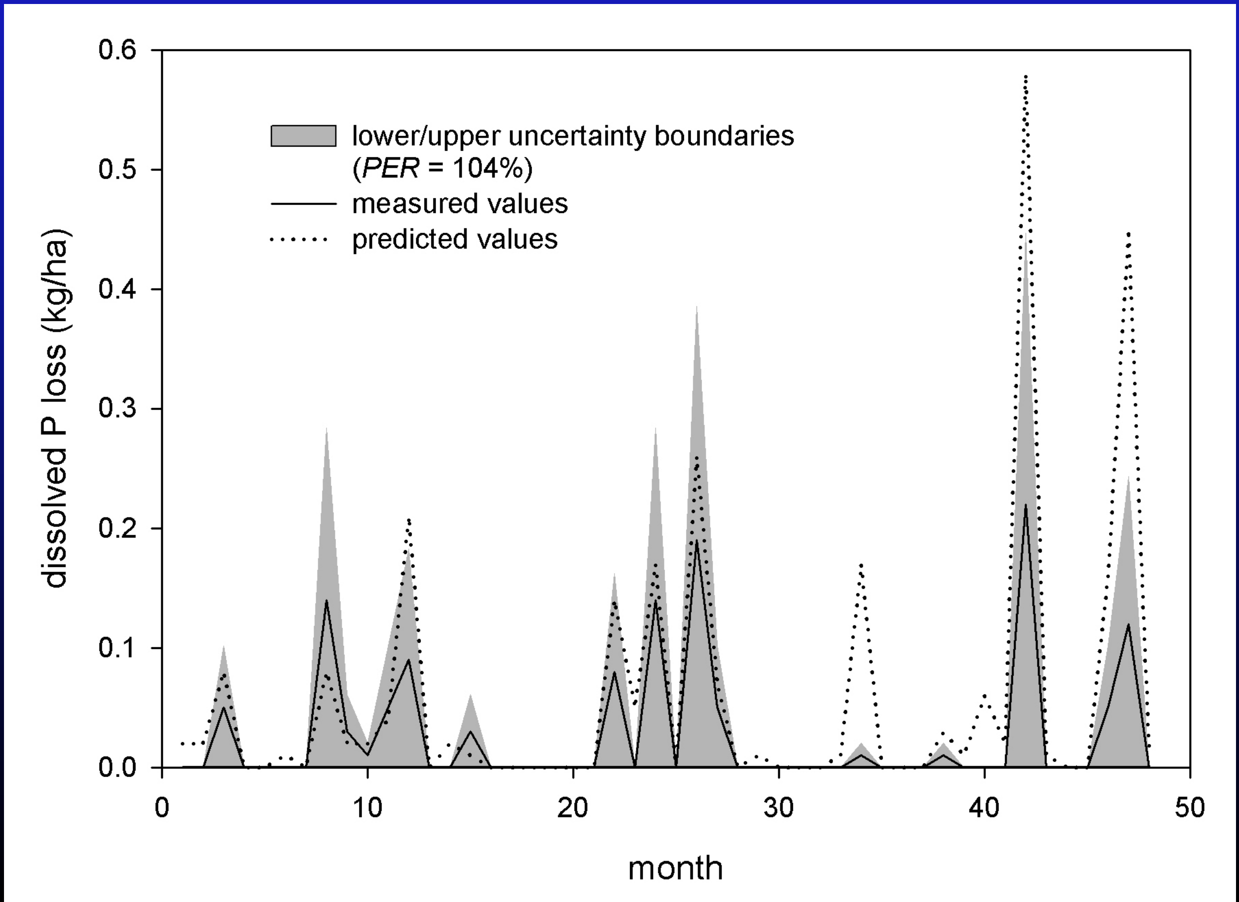
$$e_i = 0$$



$$e_i = boundary - P_i$$

Objective 2 – Modified Goodness-of-Fit Indicators

- **Modification 1 - provides conservative goodness-of-fit estimate**
  - **Goodness-of-fit improves substantially because minimize e_i**
  - **Facilitates visual assessment**



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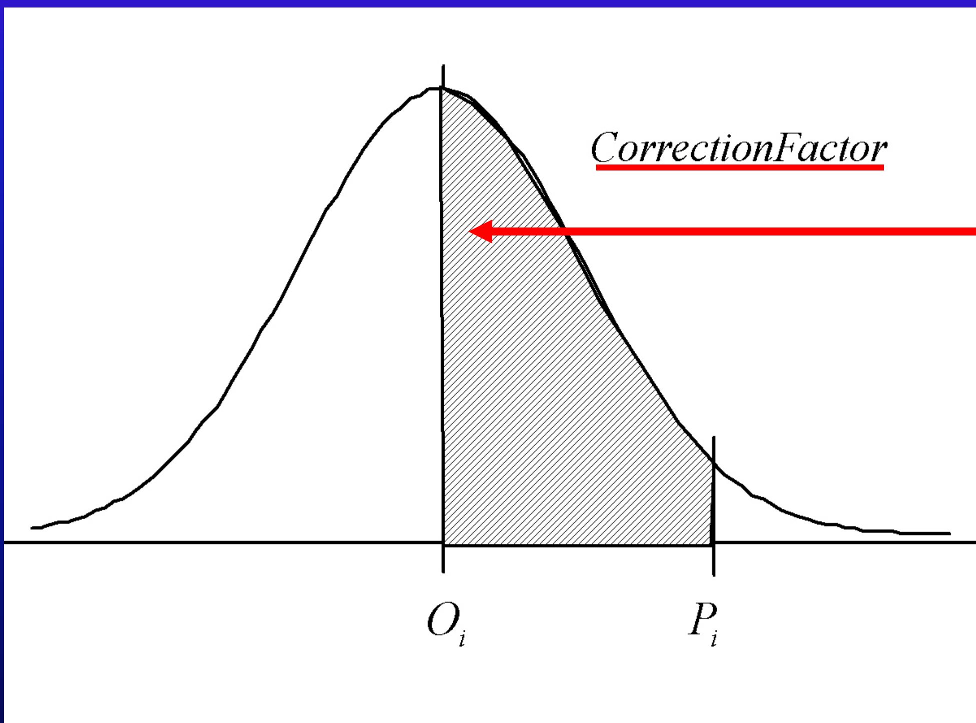
Objective 2 – Modified Goodness-of-Fit Indicators

Modification 2 - if distribution of uncertainty is known



$$e_i = \frac{CF_i}{0.5} \times (O_i - P_i)$$

In Modification 2, the probability distributions represent possible measured values for each point (O_i) not for the entire population of measured data.

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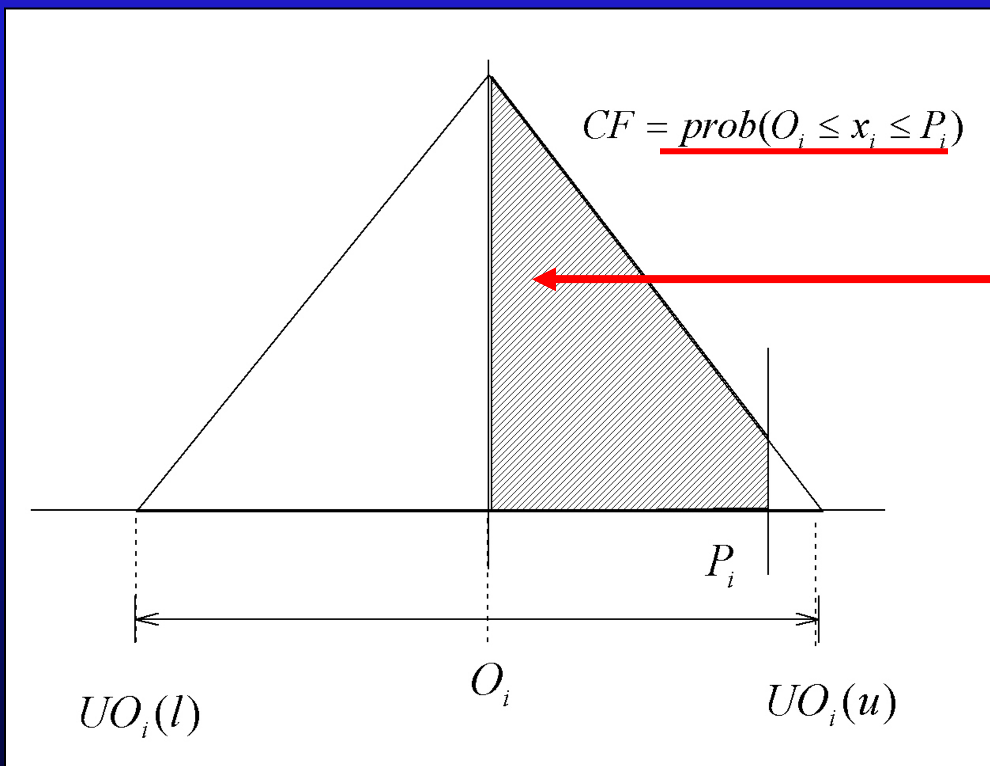
Objective 2 – Modified Goodness-of-Fit Indicators

Modification 2 - if distribution of uncertainty is known



$$e_i = \frac{CF_i}{0.5} \times (O_i - P_i)$$

Objective 2 – Modified Goodness-of-Fit Indicators

- **Modification 2 – provides more realistic estimate of e_i when distributional information of measurement uncertainty known or reasonably assumed**
  - **Goodness-of-fit increased only slightly for measured data with little uncertainty.**
  - **Modest improvement when data with substantial uncertainty were compared with both poor and good model predictions.**
  - **Important result - poor performance shouldn't appear satisfactory because of measurement uncertainty, especially for large model structure errors**

Recent Model-Related Uncertainty Pubs.

Harmel, et al. 2006. Cumulative uncertainty in measured streamflow and water quality data for small watersheds. *Trans. ASABE* 49(3): 689-701.

Shirmohammadi, et al. 2006. Uncertainty in TMDL models. *Trans. ASABE* 49(4):1033-1049.

Harmel and Smith. 2007. Consideration of Measurement Uncertainty in the Evaluation of Goodness-of-Fit in Hydrologic and Water Quality Modeling. *J. Hydrology* 337:326-336.

Moriasi, et al. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50(3):xxx-xxx.

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Conclusion and Acknowledgments

- **Conclusions related to H/WQ modeling…**
  - **no longer acceptable to not consider uncertainty in H/WQ modeling**
  - **advantageous for modelers to quantify the "quality" calibration, validation, and evaluation data**
- **Insight and groundbreaking work by many contributed to the foundation for this research.**
  - **Richard Cooper, Ken Reckhow, Keith Beven, Florian Pappenberger, Dmitri Kavetski, Ann van Griensven (and her colleagues), Bruce Beck, Tom Haan, Dan Storm, Raymond Slade.**

Upcoming Research on H/WQ Data Uncertainty

- Refine the uncertainty estimation method to facilitate estimation in measured H/WQ data
  - Procedure, field/data form, simple spreadsheet
- Push for increased emphasis on sample collection in QA
- Emphasize benefits of uncertainty estimates accompanying measured H/WQ data sets
- Apply modified goodness-of-fit indicators in H/WQ modeling and other fields
- Incorporate uncertainty estimates and modified goodness-of-fit indicators in SWAT,EPIC/APEX interface

Any Questions??

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