Understanding Limitations in Environmental Models through Diagnostic Analysis in the Context of Global Change

Thorsten Wagener

Civil & Environmental Engineering, Penn State

Institute of Hydrology, University of Freiburg

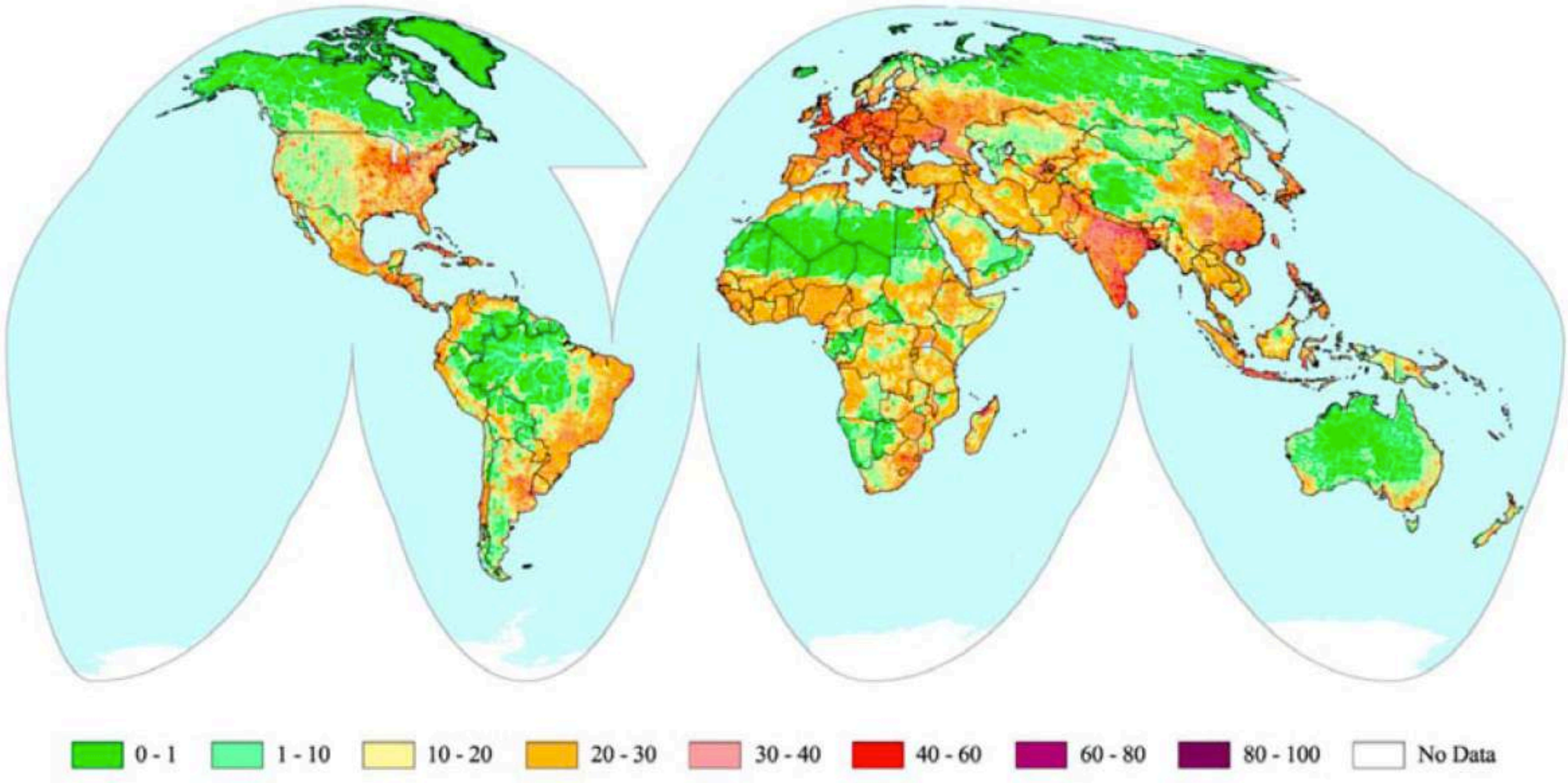
(Soon: Civil Engr., University of Bristol)

There is an increasing need for hydrologic predictions in support of a wide range of water resources services. These predictions need to be available everywhere and represent past, current and potential future conditions.

To achieve this, we need to ensure our models work for the right reasons, and use available data optimally.

Wagener, T., M. Sivapalan, P. A. Troch, B. L. McGlynn, C. J. Harman, H. V. Gupta, P. Kumar, P. S. C. Rao, N. B. Basu, and J. S. Wilson (2010), The future of hydrology: An evolving science for a changing world, *Water Resour. Res.*, *46*, W05301, doi:10.1029/2009WR008906.

Such predictions are required in the context of a changing world (for which models have to account)



Human footprint index analysis showing that over 80% of the land surface is impacted by human activity (Sanderson et al. 2002, *BioScience*)

[Wagener et al. 2010 *WRR*]

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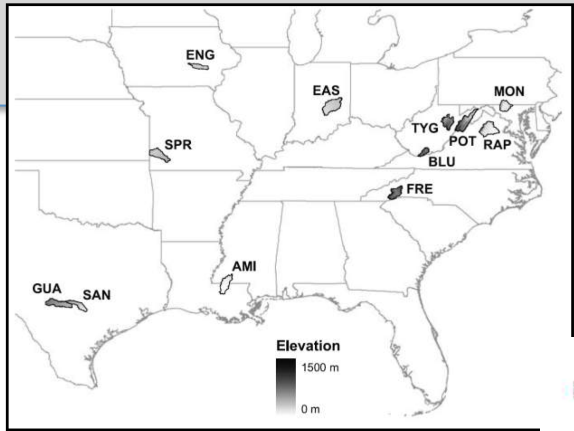
Current	Future
Humans are external to the hydrologic system	Humans are intrinsic to the hydrologic system, both as agents of change and as beneficiaries of ecosystem services
Assumption of stationarity: past is a guide to the future	Nonstationary world: past is no longer a sufficient guide to the future, expected variability could be outside the range of observed variability
Predicting response, assuming fixed system characteristics: boundary value problem with prescribed fixed topography, soils, vegetation, climate	Both system and response evolve: no longer a boundary value problem, boundary conditions and interfaces themselves evolve and are coupled. Becomes a complex adaptive system
Learning from studying individual places (often pristine experimental catchments) to extrapolate or upscale to other places	Comparative hydrology: learning from individual places embedded along gradients (e.g. changing climate, human imprint) and across spatial scales
Hydrologists as analysts of individual processes *or* features at small scales (akin to a microscope) or as synthesists of whole system behavior at large scales (akin to a telescope)	Hydrologists as both analysts *and* synthesists (akin to the *macroscope*) studying the coupled system across a range of time and space scales
Observations to characterize input-output behavior in individual (mostly) pristine places	Observations to track the evolution of both structure and response in coupled systems and subsystems
Observe and analyze pristine places and extrapolate to make predictions of human impacts	Observe and analyze real places where humans live and interact with the hydrologic system at range of scales
Model predictions derive credibility by reproducing historical observations	Model predictions derive credibility via more in-depth diagnostic evaluation of model consistency with underlying system and testing of behavior outside of observed range
Observation, prediction (modeling) and management are separate exercises (without feedbacks!)	Real-time learning: observations (sensing, including participatory human sensing), modeling and management are interactive exercises with feedbacks and updating

How can we understand how and why models work?

Diagnostic model evaluation



Understanding model behavior across environmental gradients

Identifying spatially distributed models

Predictions / Projections

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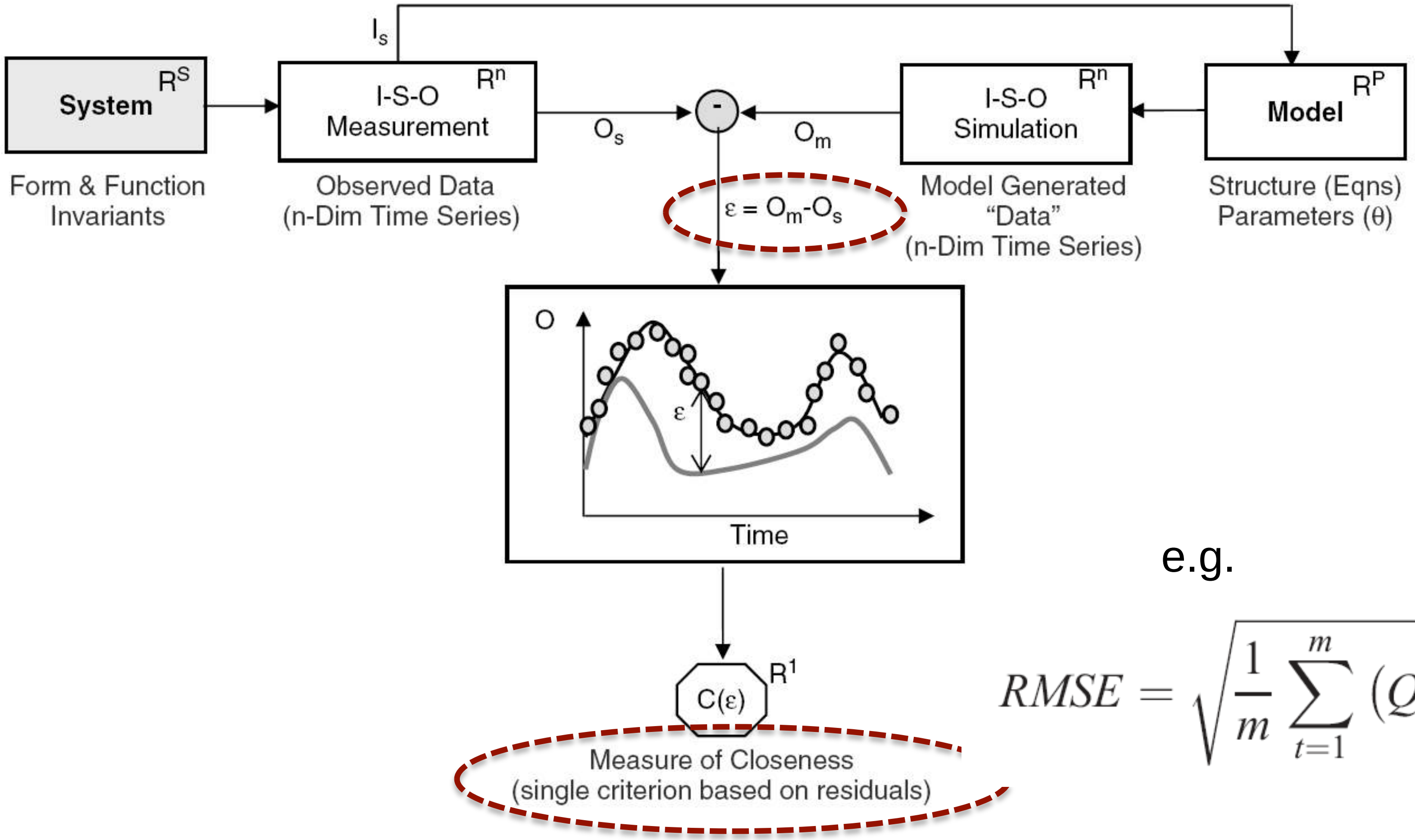
DIAGNOSTIC MODEL EVALUATION

http://www.bytelove.com/images/uploads/Gadgets/linuxgear/x-ray-tux-sticker.jpg

Most (all?) models require some degree of calibration to observed data

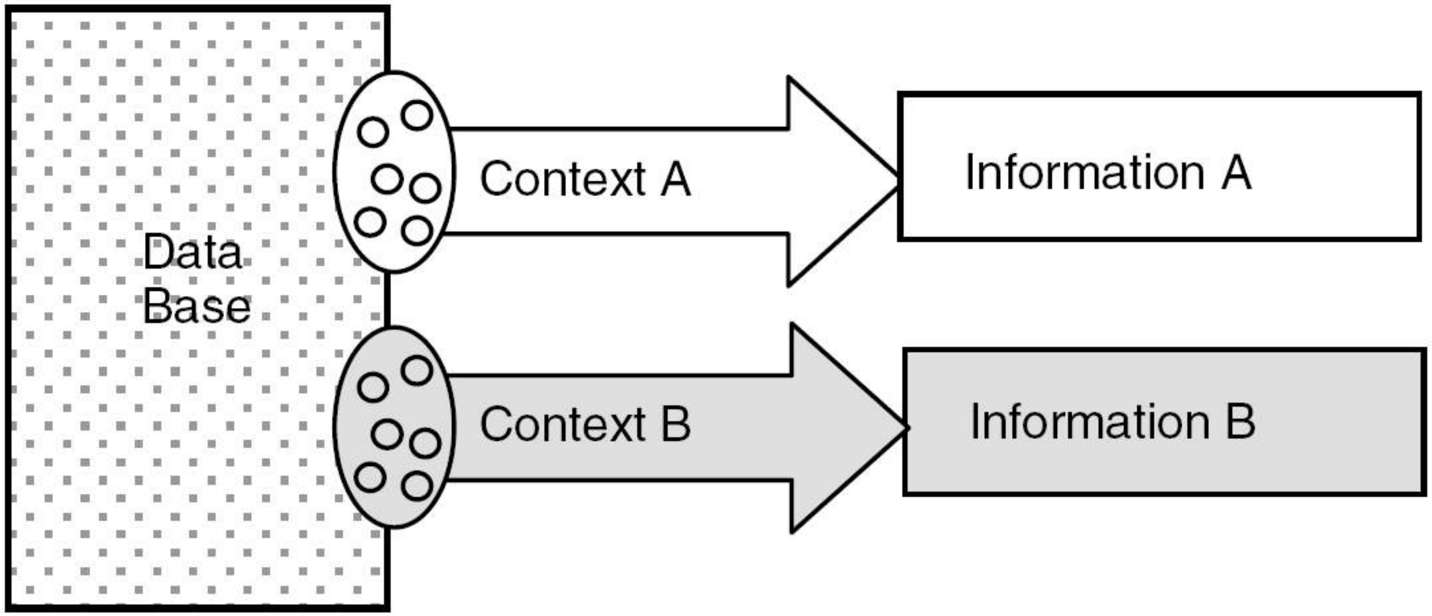


e.g.

$$RMSE = \sqrt{\frac{1}{m}\sum_{t=1}^{m}\left(Q_{s,t} - Q_{o,t}\right)^2}$$

[Gupta, Wagener, Liu 2008 *Hydrological Processes*]

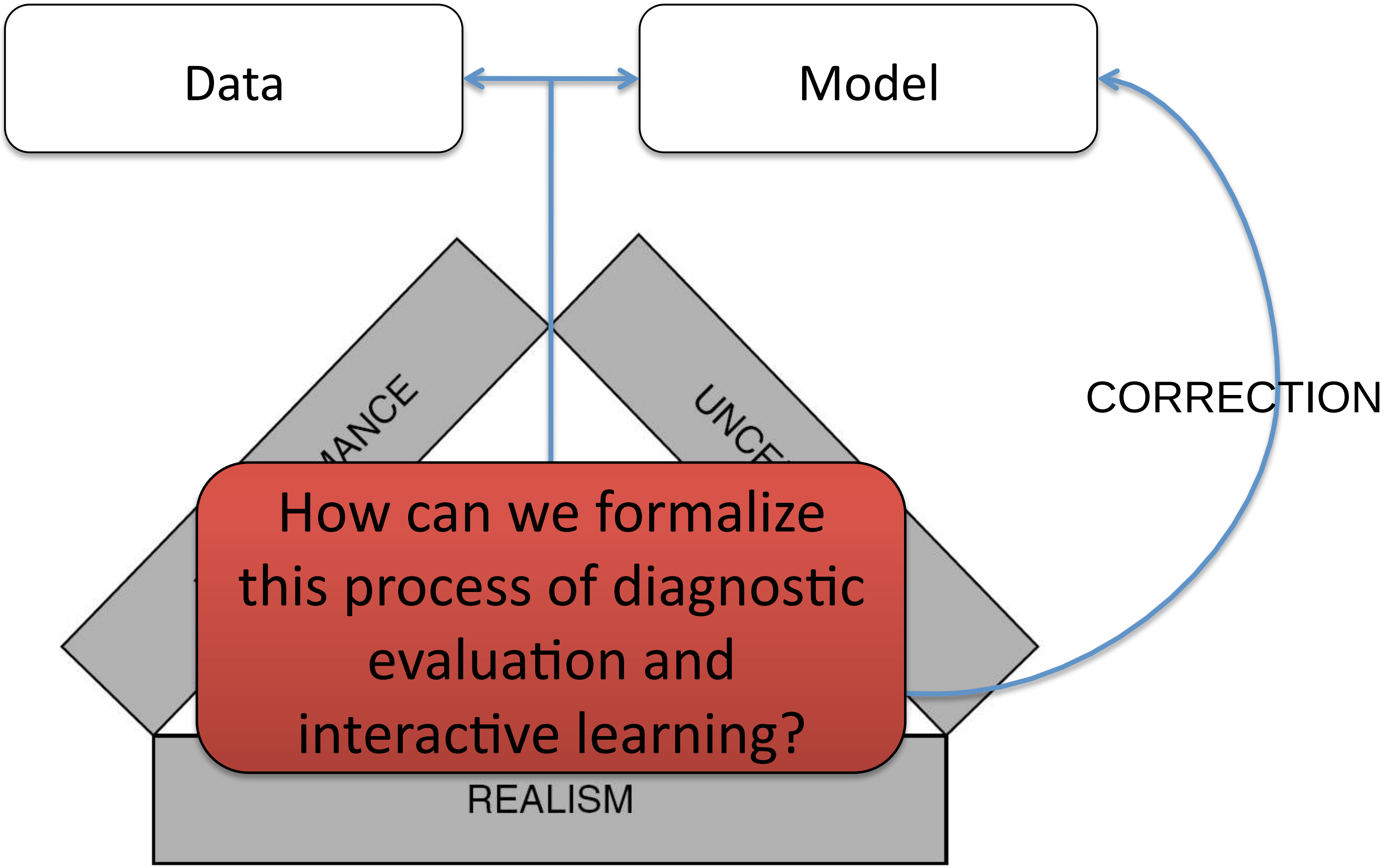
The measure of closeness (objective function) extracts information about model performance



However, traditional statistical measures extract little information useful for diagnostic evaluation!

[Gupta, Wagener, Liu 2008 *Hydrological Processes*]

Evaluation of environmental models has at least 3 dimensions



[Wagener 2003 *Hydrological Processes*]

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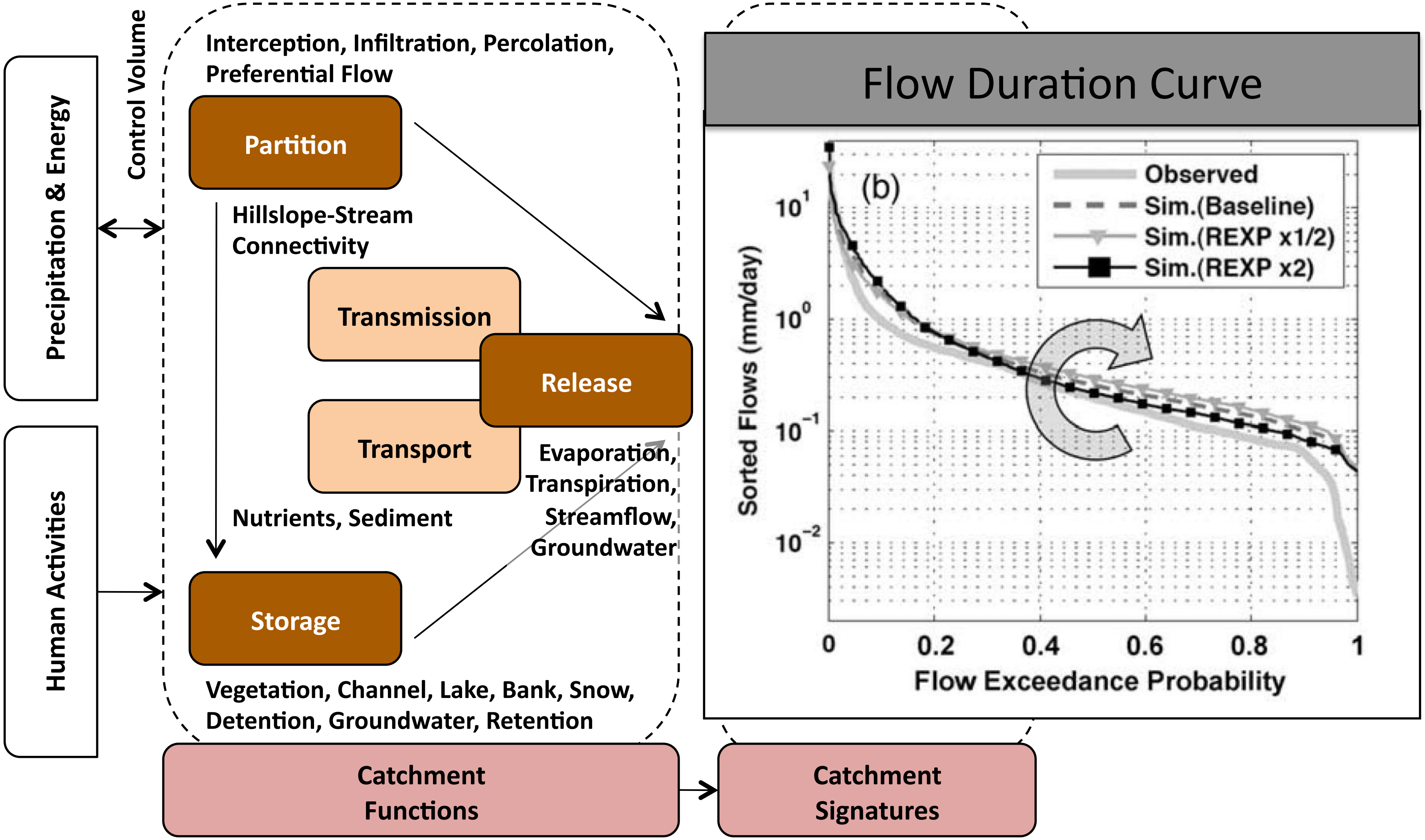
[1] We can use signatures to provide insight into how the system functions



[Yilmaz et al. 2008 WRR; Wagener et al. 2007 *Geography Compass*]

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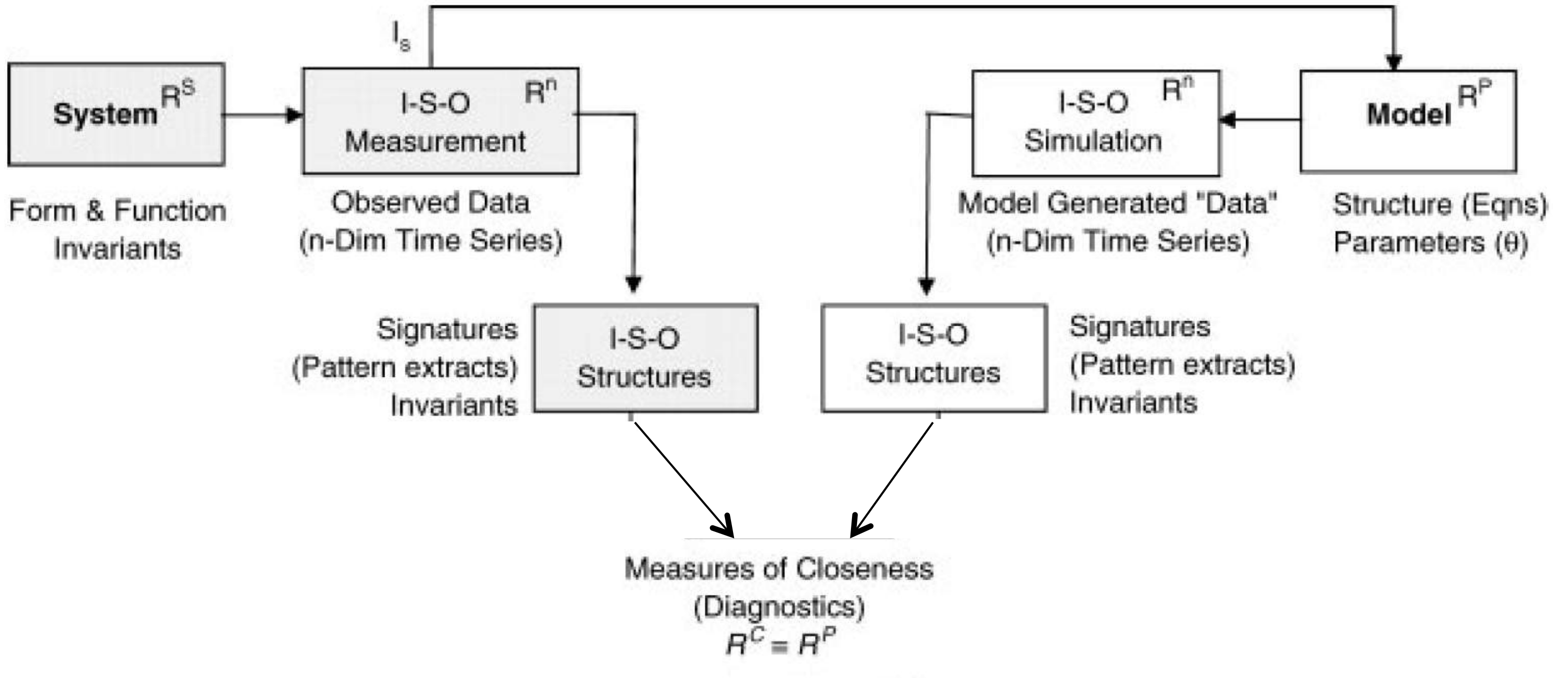
Comparing signatures and understanding how the model produces them can be diagnostic…



…if we can assess whether the model reproduces the functional behavior of the system in a way consistent with our theory

[Gupta, Wagener, Liu 2008 *Hydrological Processes*]

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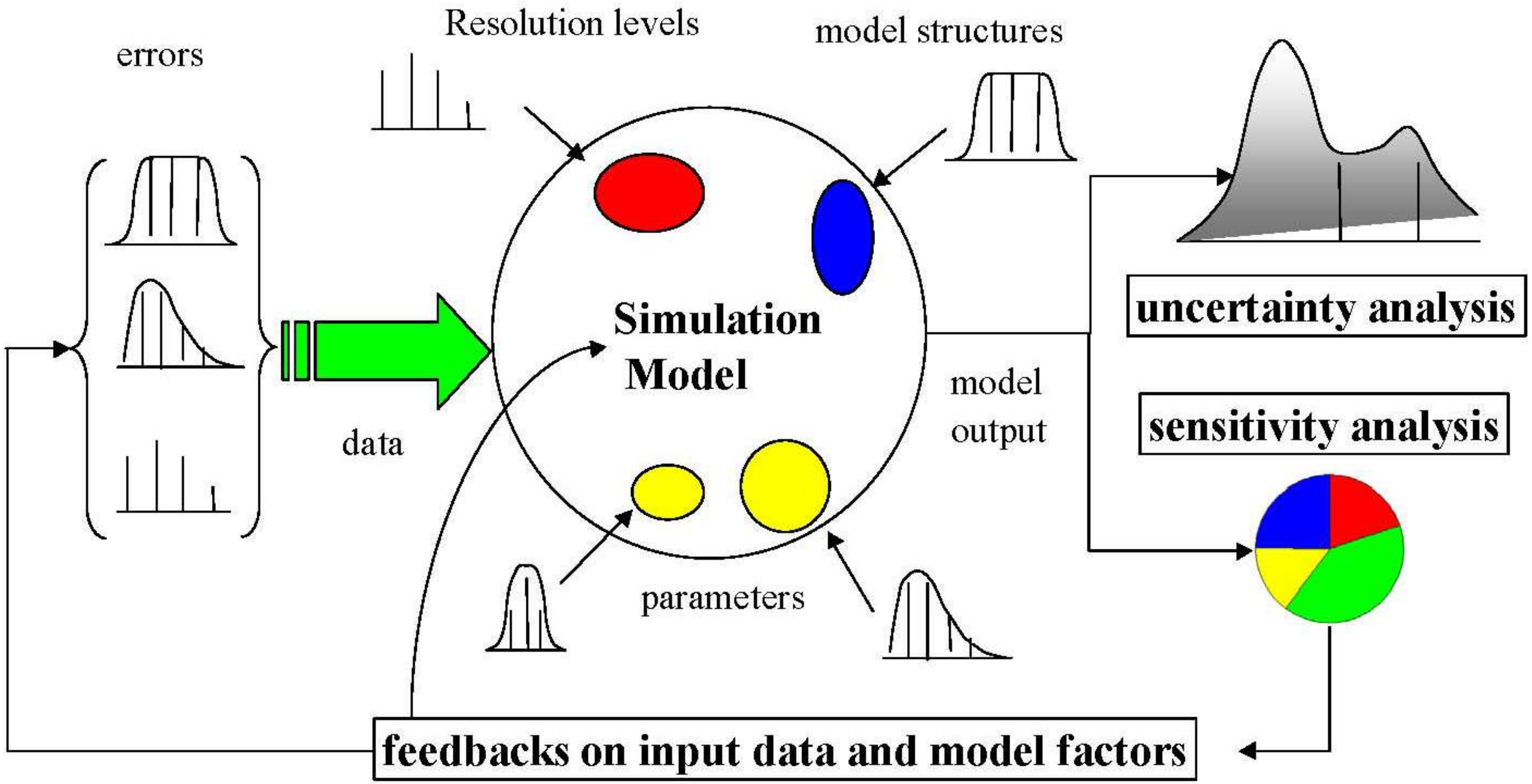
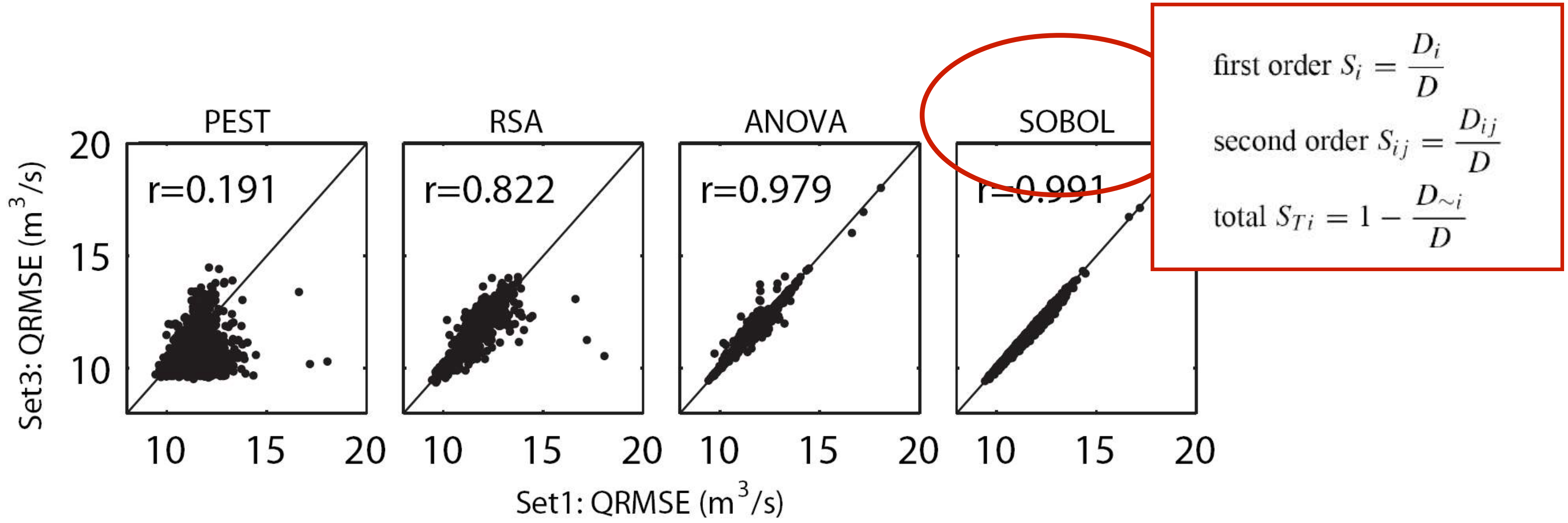
[2] We can use sensitivity analysis to understand how the model produces these signatures (= realism)



Both sensitivity analysis and signatures form elements of a diagnostic model evaluation strategy

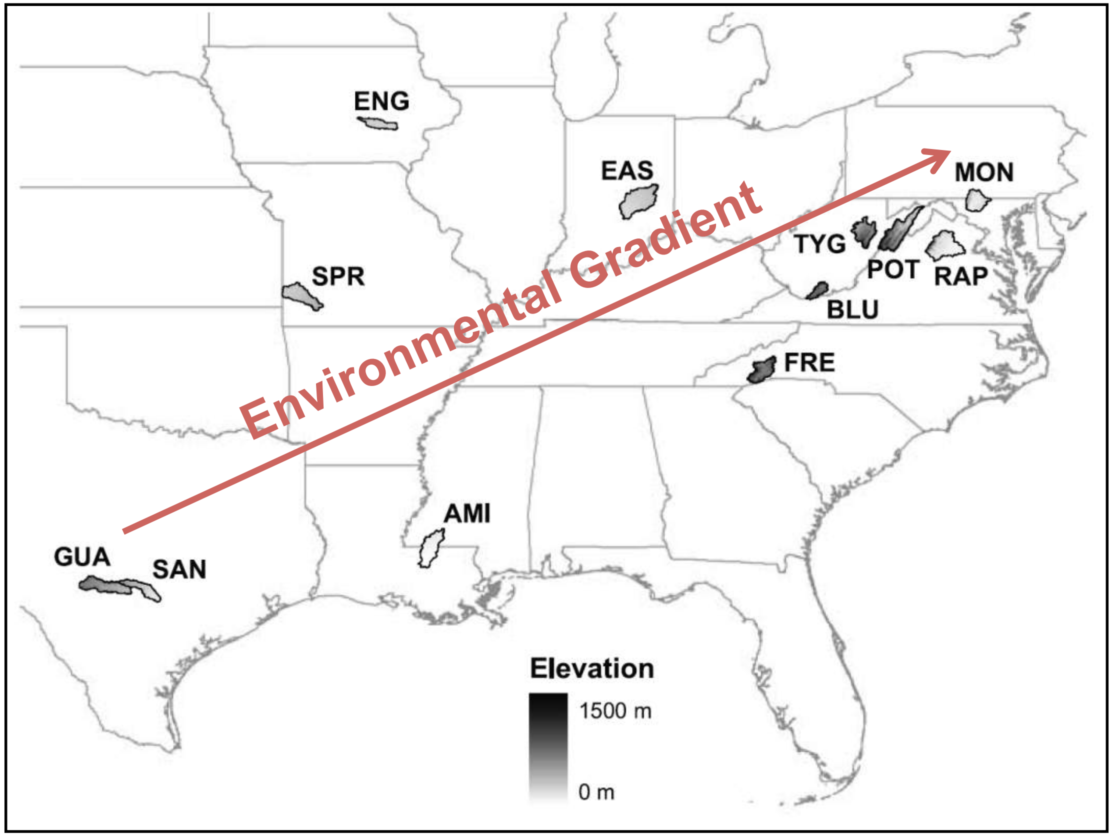
[http://upload.wikimedia.org/wikipedia/en/0/01/Sensitivity_scheme.jpg]

We found the global variance-based approach by Sobol to be robust and effective



We compared four different sensitivity analysis approaches. The perfect approach would result in all points falling on a line.

[Tang et al. 2007 *Hydrology and Earth System Sciences*]



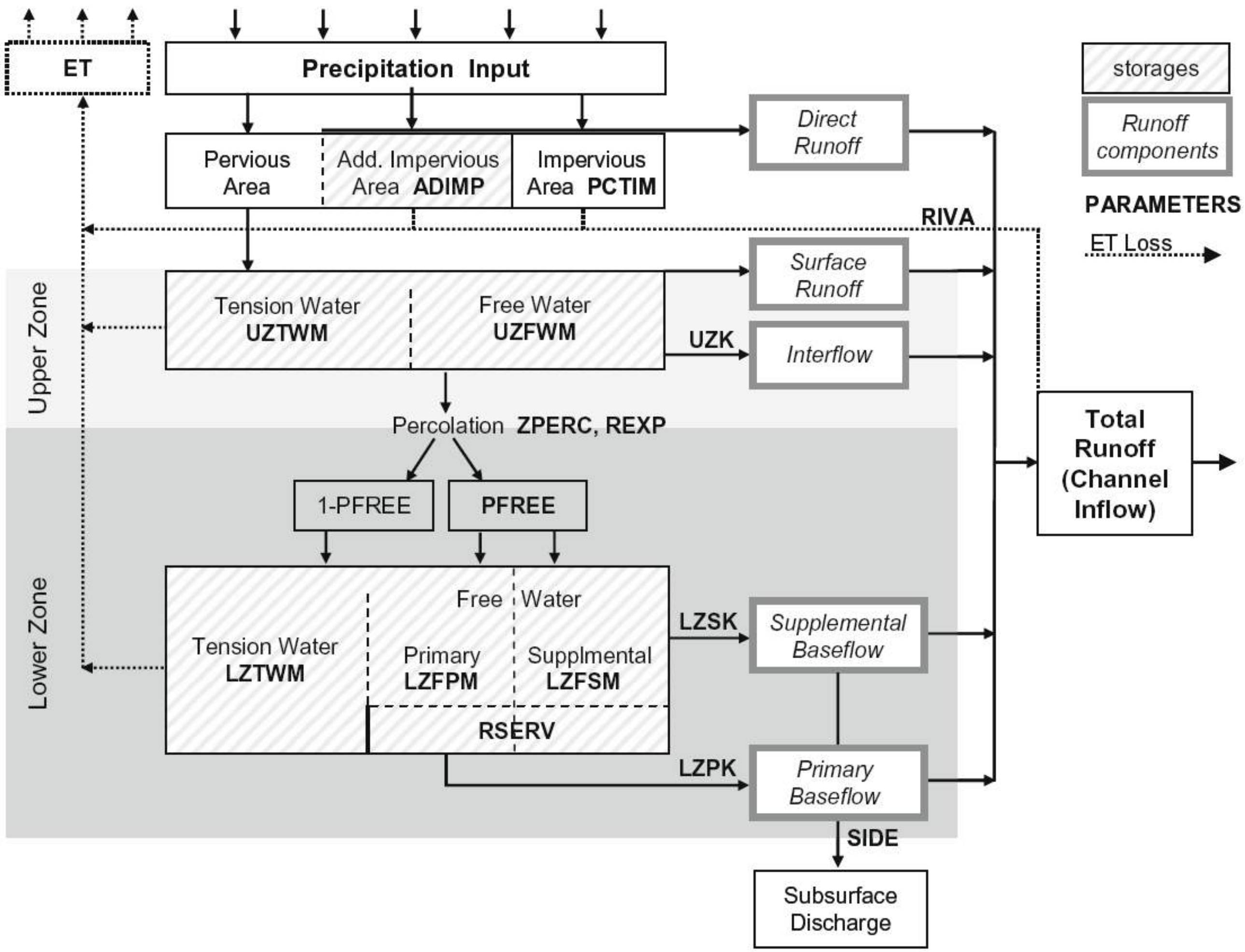
UNDERSTANDING MODEL BEHAVIOR ACROSS ENVIRONMENTAL GRADIENTS

The model evaluated is a popular lumped watershed model, i.e. the Sacramento model

Soil

Percolation

Groundwater



[van Werkhoven et al. 2008 *WRR*]

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