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The Systems Approach: Historical Perspective, Need for a Paradigm Shift, and Relevance to PUB

For about 50+ years, computer-based modeling has been an integral part of Hydrologic Science. And, as computational power became progressively more accessible, the "*Systems Approach*" (study of '*structure→function'*, and '*function→structure*') steadily gained ground as a meaningful and systematic meta-scientific approach to building models … thereby enabling improved reasoning and more accurate predictions … and ultimately contributing to enhanced sophistication in the decision making process.

In the early decades (1960's-80's), given rather limited data, the main focus was on improving our conceptual understanding of watersheds, and the systems approach was employed mainly in the service of parameter estimation, … a task surprisingly found to be very difficult. In the 1990's, breakthroughs in global optimization theory finally provided the tools necessary to solve the "parameter optimization" problem, and enabled a shift towards the more interesting issues of *Informativeness of Data, Selection of Objective Function(s), Sensitivity Analysis, Uncertainty Analysis* and *Model Structural Inadequacy*. This led, inexhorably, to a gradual paradigm shift … away from "*Optimality*" as a goal … and towards a focus on "*Reducing Uncertainty*" and "*Achieving Model-System Consistency*".

Meanwhile, however, continued difficulties in reconciling models with available data has given rise to three major philosophical approaches – that of *Parsimony, Equifinality* and *Power*. The Parsimony perspective asserts that the information commonly available in data is only sufficient to identify catchment model structures of limited complexity. The Equifinality perspective asserts that the information commonly available in data is insufficient to distinguish between alternative catchment models (including model structures & parameter sets). Both of these dwell on the "*limited information content of available data*". In contrast, however, the Power perspective asserts that *current tools are not designed to properly extract all useful information* from the available data.

While I do not disagree, fundamentally, that Parsimony (carefully used) is a good idea, or that Equifinality is pervasive, I do claim that the the traditional systems methods used for model identification are fundamentally weak, and that this weakness must be resolved before assertions of Parsimony and Equifinality become properly relevant. A major reason for this weakness is that traditional methods for data assimilation are indirect or "*implicit*" … meaning that they do not *directly* quantify the information that is contained in the data (data must be placed in context to be meaningful), or that is represented by the models (models are, after all, a specifically coded form of information). In contrast, the *Diagnostic Evaluation* approach is based in *direct and explicit* definitions of the information in models and data (an undoubtedly challenging task). I am therefore now pressing for another paradigm shift … towards an *Information-based Framework* for model identification, one which draws both on modern *Systems* and *Information* theories, but also on the considerable conceptual (hydrological) knowledge that was historically developed and exploited before cheap computing made it so easy to play digital games.

What does any of this have to do with *Prediction In Un-Gauged Basins (PUB)*? Well, all PUB problems involve both catchment data and catchment models (spatio-temporal knowns), with the particular added challenge of developing additional models that characterize *Similarity* and *Regionalization*, thereby enabling the spatio-temporal transfer of known information to other locations/times. From this perspective, the metaphorical PUB Elephant is just another face on the perennial hydrological challenge of system identification … albeit writ large. In my opinion, it is only be a *direct characterization of Information* that we will be able to successfully address the challenges faced by PUB … (transferring structure and function information across space-time). The systems approach is, therefore, partcularly well suited to the coming PUB decade with its increased emphasis on natural and anthropomorphic non-stationarity of the Earth system.