Systems Archetypes and Generic Structures for Reservoir Management

Babak Bahaddin
University at Albany
bbahaddin@albany.edu

Saeed Langarudi
lang@nmsu.edu
Water Resources Research Institute,
New Mexico State University

David Andersen
david.andersen@albany.edu
University at Albany

Keywords: Archetypes, Generic Structures, Reservoir Effect, Supply-Demand Cycle

In the recent movements among water scientist, feedback mechanisms are progressively becoming prominent. Following this trend and in their recent article, Di Baldassarre et al. [2018] introduce two long-term dynamics in reservoir management, the supply-demand cycle and reservoir effect which are caused by feedback mechanisms between human and natural systems. However, after acknowledging the difficulties in quantifying such causal relationship, the authors call on water managers, social scientists, policymakers, economists, ecologists and hydrologists to collaborate and develop analytical tools capturing the long-term dynamics produced by the interactions of physical, social and technical processes. Inspired by this call, this paper constitutes a first step to bridging qualitative water resources analysis and quantified simulation models. To this end, we have used system dynamics modeling and its embedded concepts such as systems archetypes and generic structures to study human-nature interaction in the context of water resources management.

The *supply-demand cycle* takes place when increasing water supply enables agricultural, industrial, or urban expansion, which in turn leads to increasing competition for water resources [Kallis, 2010, Scarrow, 2014]. The *reservoir effect* states that the construction of the reservoirs reduces the incentive for adaptive actions at individual or community levels. The lack of incentive for adaptive actions reduces the resiliency of the system against the negative impacts of water shortages during severe droughts. Di Baldassarre et al. [2018] portray these two mechanisms with a simple causal loop diagram (Figure 1). These mechanisms could be represented using systems archetypes analogies. The paper explains how supply-demand cycle and reservoir effect can conveniently match the structure of the *Fixes that Backfire* archetype. Besides the fixes that backfire archetype, other archetypal structures are explained in the paper which could be used for explaining the post-dynamics of expansion in water supply infrastructure

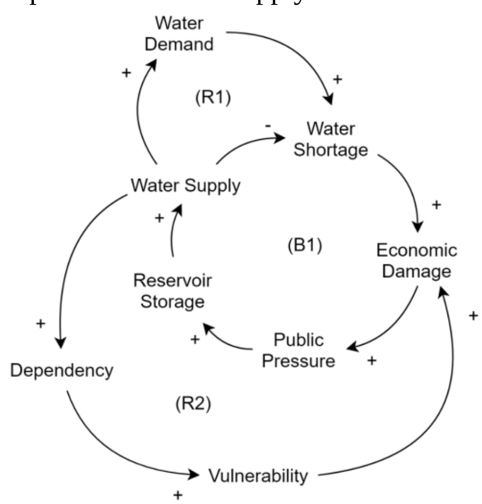

Figure 1) supply-demand cycle (upper loop) and reservoir effects (lower loop) -- adopted from De Baldassarre et al (2018).

While archetypes can be helpful for getting structural insights, they cannot provide behavioral analysis. To overcome the limitations of system archetypes, simulation models can be generated. These mathematical models include all key variables and their causal relationships that are necessary to generate the behavior of desired variables. In this paper, we created one exemplary generic structure that includes both the supply-demand cycle and also the reservoir effect. With the help of this generic structure we were able to simulate the model and generate the overtime behavior of each variable. This model helped us to test our initial hypotheses with different what-if scenarios. The behavior of the main variables are shown below.

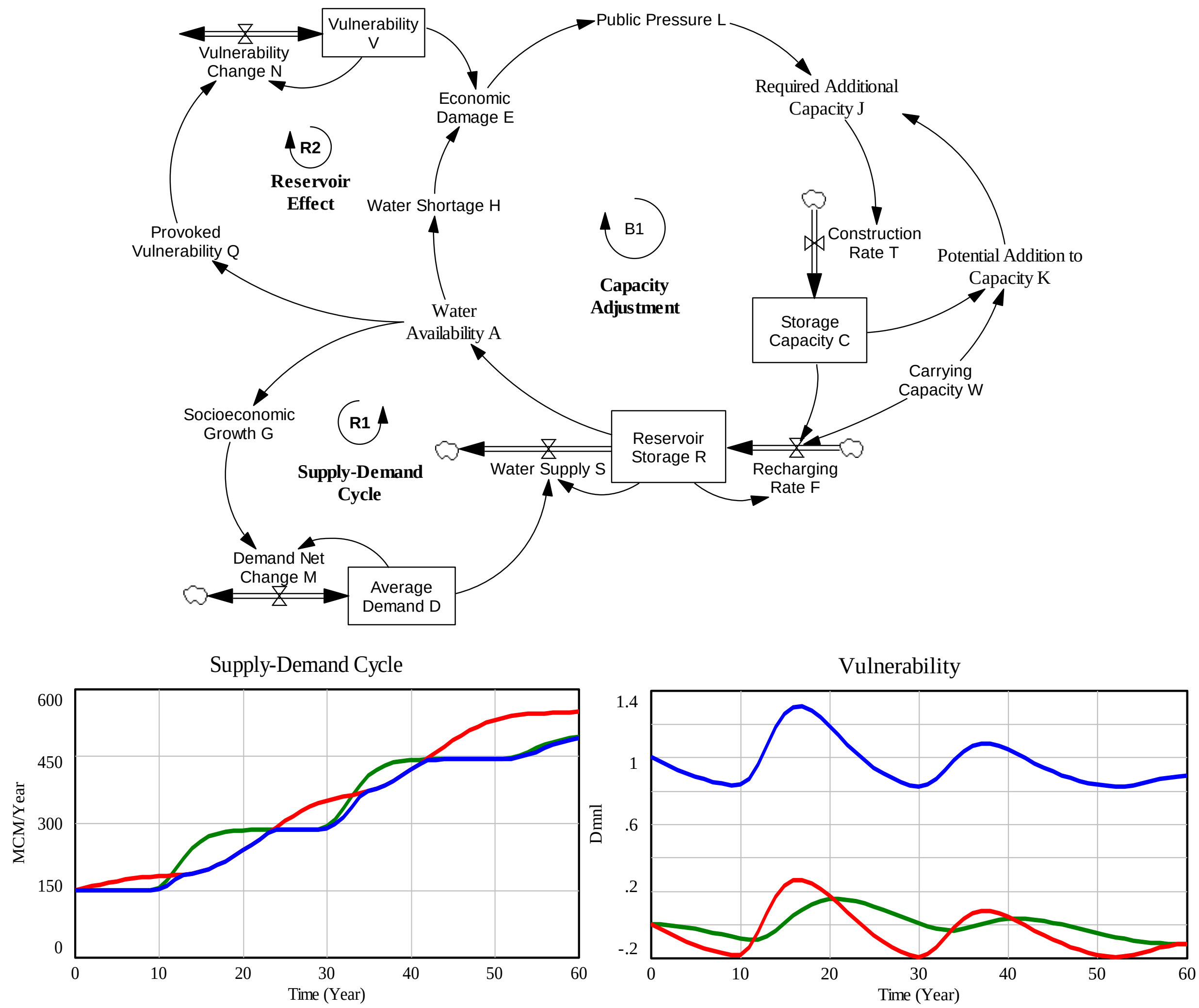

Figure 2) stock-and-flow diagram of the supply-demand cycle and reservoir

Despite the value archetypes as a first approach to understanding systems (Senge et al, 1994), it is crucially important to note that archetypes merely constitute a hypothesis concerning the structure link. For the rigorous testing of such hypotheses, the use of computer simulation is strongly encouraged (Lane and Smart, 1996 - quotation from John Sterman). Dowling et al. (1995) reported in detail the difficulties that they experienced in attempting to represent two archetypes as stock and flow diagrams in order to simulate their behavior. Their experience adds weight to the idea that many archetypes are too poorly posed to be recreated as formal models (Lane and Smart, 1996). Archetypes need to be seen as products of formal dynamic models; not the origin. The practice of archetypes without a more sophisticated supporting model can cause ambiguity and inconclusiveness.

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