FROM MOSAIC TO SYSTEMATIC: APPLYING SYSTEMS THINKING TO WATER RESOURCE MANAGEMENT

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ABSTRACT

Effective Water Resource Management (WRM) is a complex undertaking that requires a variety of solutions; including economic ones. Both supply-side and demand-side management approaches have been implemented with the goal of meeting the demands of multiple stakeholders while being constrained by challenges such as infrastructure inefficiencies, water source access issues, and short-termism/political expedience. While successes have been made on both the supply and demand side, there is doubt that either approach is sufficient on its own to promote effective, sustainable water resource management over the long-term. In light of this, it is natural to propose an amalgamation of the two. However, combining the approaches without considering 1) which variant is most appropriate or, importantly, 2) potential interaction effects between the two means the hybrid will be merely mosaic in nature. While such mosaic approaches do reflect a much needed diversity in solutions, they may run the risk of being suboptimal or, worse, counterproductive. Instead, a systems-based approach toward effective management is necessary.

A complete systems approach includes an understanding of the goals and assumptions underwriting WRM. An important place to begin is with the concept of resilience. Water infrastructure managers want their systems to be resilient to stress and the recent crisis in Cape Town, South Africa, illustrates the perils of failing to meet such a goal. Furthermore, the economic strategies highlighted above are intended to make water systems more resilient. Given this role, it is critical to be clear about the definition of resilience, who the stakeholders in a resilient system are, and over what time scale resilience is measured. A systems-based approach to WRM should begin by minimizing conceptual uncertainty. In Part 1 of this paper, the authors canvas several resilience concepts and highlight some of the philosophical contentions that lie behind them. In Part 2, the authors review economic theory for both supply and demand-side approaches. In Part

3, the authors consider how these two strategies can be applied to WRM specifically; leveraging Ludwig von Bertalanffy's concept of isomorphology to clarify the connection between general economic theory and its application to the management of water resources. The authors conclude with a summary of the major outcomes of this initial analysis and open questions to be addressed in future research.

Keywords: water resource management, isomorphology, resilience, supply and demand-side economics.

INTRODUCTION

There appears to be an increased appreciation for the role of systems thinking in the domain of Water Resource Management (WRM). Scholars and decision makers allude to the importance of "big picture" thinking when looking at how to best manage water. This appeal is an understandable one. Effective WRM must take into account multiple stakeholders, constraints regarding both quality and quantity of available water, and the uncertainty associated with external stresses such as drought. Given all of this, including additional uncertainty regarding how climate change will manifest, it is difficult to see how effective WRM can be achieved *without* taking a systems approach; but what can a systems approach do more specifically?

A systems approach to WRM can describe and predict the dynamics associated with the aforementioned stakeholders. Using tools such as behavior-over-time graphs and causal loop diagrams, decision makers can model current dynamics, predict future ones, and consider hypothetical changes to a water system; looking for primary, secondary, and tertiary reverberations. These same tools can be used to model other system stresses such as infrastructure flaws. A systems approach can identify important relationships between components and identify key leverage points. While attractive, this list of benefits remains on the vague side.

In this paper, the authors work toward a more specific systems approach to WRM. Doing so requires, first, an examination of fundamental concepts to WRM such as resilience and sustainability. Related to these is a question of system scope; regarding both physical and temporal parameters. Developing a more specific systems approach also requires a lens; supply-side and demand-side economics in the case of this analysis. Throughout the paper, the authors demonstrate how systems thinking can be applied to promote effective WRM.

PART 1: PHILOSOPHICAL FOUNDATIONS

One of the chief goals or indications of effective WRM is to have a system that is resilient to a variety of stresses. Sustainment practices of water resource infrastructures tend to be reactive versus proactive. This is sometimes understandable given the lack of funds available to take additional steps to support advanced thinking. (Horbatuck, Burgess, & Beruvides, 2018). The middle game of this research program introduced in this paper is to identify appropriate, defensible metrics of water system resilience and then examine the correlation (if any) between these and the economic strategies highlighted in this paper. Such an aim is appropriate to current discussions in the literature about resilience and related concepts of sustainability. However, this same literature demonstrates ambiguity regarding these concepts. A system is only as good as its aim. With this in mind, it is instructive to examine some of the philosophical underpinnings of resilience.

1.1 Resilience, Adaptive Capacity, and Sustainability in the Literature

Generally, resilience is thought of as the ability of a system or entity to retain its identity (composition, functionality, etc.) over time despite the presence of stresses. Curiously, it also involves the capacity of the system/entity to evolve over time. So, a kind of dynamic identity emerges from this characterization. For instance, appealing to Berkes, Colding, and Folke (2003), Plummer and Armitage (2007, p. 65) offer the following definition of resilience:

> (1) the ability of a system to absorb or buffer disturbances and still maintain its core attributes; (2) the ability of a system to self-organize; and (3) the capacity for learning and adaptation in the context of change.

Milman and Short (2008, p. 759) quote Folke's (2006) definition of resilience as the capacity "to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks."

Based on these definitions, other terms used in connection with resilience might be confused for synonyms. For example, quoting the IPCC, Lemos, Manuel-Navarette, Willems, Caravantes, and Varady (2016, p. 52) define adaptive capacity (AC) as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond." Milman and Short (2008, p. 759) state that AC is the ability of the system to "adapt to stresses and changes and to transform into more desirable states." AC on this view is not resilience per se but rather a system's elasticity that it allows it to flex with stressors and adapt over time; sometimes rapidly (Bunch, Morrison, Parkes, & Venema, 2011).

The distinction between sustainability and resilience is less clear than the one between resilience and AC. For instance, Milman and Short (2008, p. 759) state: "Sustainability indictors [sic] are distinguished from other indicators by their need to measure the ability of a system to adapt to change and continue to function over a long time span." One interpretation here is that sustainability adds a time requirement to resilience definitions. But given that the latter require that a system maintain its identity under stress and demonstrate the ability to adapt to new conditions, time is already implied in the definitions above. Perhaps the difference is in the length of the time span in question. The authors return to this point in 1.2. In the meantime, other scholars appear to treat sustainability as a measure of resilience (Plummer & Armitage, 2007). Though it is possible that scholars simply need to write about these concepts more clearly, the more likely explanation is that there remains some conceptual ambiguity regarding resilience, AC, sustainability, and the like.

1.2 Conceptual Analysis

Though sometimes used interchangeably, the terms 'sustainability' and 'sustainable development' do not always connote the same idea. Sustainable development has, historically, had an anthropocentric orientation. The Brundtland Definition of sustainable development frames the obligation as meeting the needs of today without compromising the ability of future generations to do the same (U.N. World Commission on Environment and Development, 1987). This definition, which has been incorporated into several of the codes of ethics that govern engineers involved in WRM, declares human outcomes to be the sole concern. That is, success in the context of this definition is a function of meeting human needs both today and in the future.

Sustainability by contrast casts a wider net. Positive outcomes for non-human stakeholders and ecosystems are valued regardless of (or in contradiction of in some instances) those for human beings. Knowing where to define the boundaries of a system (e.g. anthropocentric vs. non-anthropocentric) is both key to analysis and reflective of deeper philosophical questions about what is valuable and why (Hamilton & Burgess, 2015). Moreover, this difference has systems level implications. If, given the above, definitions of sustainable development focus on human activity and outcomes, this will translate into whether a system is determined to be successful (including resilience). But, of course, the time horizon for human success can be measured in years. It is a different case if sustainability is the goal. If the focus is on ecosystem health, success can take decades to manifest and be measured. Furthermore, if the system is defined in broader terms, component sub-optimization (e.g. near term economic outcomes) may need to be sub-optimized to promote overall system optimization. While there is some appreciation for the importance of greater temporal horizon specificity in the literature, more works needs to be done. Doing so should also involve critical examination of value level assumptions about what is and is not valuable regarding human beings, non-human species, and the environment as a whole.

Suppose, however, that one wishes to side-step this debate in favor of near term action and system improvement. That is, suppose one simply assumes that sustainable development ought to be the goal. There is some merit in the inclination. Even meeting the demands of sustainable development, the less ambitious of the two goals, will require significant changes to current practices. Such a move does not escape conceptual ambiguity. For instance, referring to the Brundtland definition, it is reasonable to ask what constitutes a need. Does a need cover the basics outlined by Maslow and others – food, water, shelter, and clothing? Or, is a more inclusive list appropriate; one that includes education, health care, and other such goods. Here again, the difference is more than an academic one. A more inclusive list is more defensible but also places additional pressure on resources including water (Burgess, 2014).

A similar concern arises when considering ‘future generations’. Does this definition merely refer to existing human beings (e.g. children and grandchildren) or does it include individuals who do not currently exist yet? If it is the latter, how far out should a decision maker go when considering how to use/budget a resource? 100 years? 300? In perpetuity? Not surprisingly, choice of time horizon (system parameter) has important for the here and now (Burgess 2014; Elder, Beruvides, & Burgess, 2018). See Table 1 for a summary of key characteristics.

Table 1: Sustainable Development vs. Sustainability

Concept	Stakeholders	Time Horizon
Sustainable Development	Typically anthropocentric in orientation, non-human species are of secondary consideration (at best) Defining needs and desires is an ongoing project	Horizon reckoned in terms of human lifespans Ongoing debate about how many generations ought to be considered
Sustainability	Allows for a more inclusive list of stakeholders including flora, fauna, and ecosystems as a whole	More expansive time horizon to accommodate slower changes in ecosystems as well as system health reckoned over multiple human generations

Finally, others have begun to look at the paradigm underwriting traditional conceptions of sustainable development. In practice, sustainable development is sometimes framed as reducing harm (overdrawing a water supply, minimizing the pollution of commons, etc.). McDonough and Braungart (2002) acknowledge the appeal of such an *eco-efficient* approach but contend that it is not enough. They, along with others, have argued that a more nutritive approach is needed. The emphasis should not merely be on minimizing harm but on restoring/replenishing the environment; leaving it better than when we found it (Braungart & McDonough, 2002). Taleb's (2014) concept of anti-fragility may have similar implications in this domain though this is a discussion best left for another time.

1.3 A Systems Approach

Returning to the question – what does a systems approach look like here? At a minimum, a systems analysis can validate the definitions of resilience offered above by identifying what properly constitutes a system. Though the term 'system' is used throughout resilience discussions, this does not mean it is consistent with systems thinking and engineering. Anderson and Johnson (1997) establish several requirements for something to be considered a system:

- It (system) is composed of parts that must all be present for it to carry out its purpose optimally
- A system's components must be arranged in a specific way for it to carry out its purpose
- Systems have specific purposes within larger systems
- Systems maintain their stability through fluctuations & adjustments
- Systems have feedback

These requirements are reflected in the definitions of resilience, adaptive capacity, and sustainability discussed above. They offer, then, a benchmark establishing that the subject of resilience analysis is in fact a system and therefore the appropriate focus for the application of systems tools.

Parameter choice, including stakeholder boundaries, geographic considerations, and time horizon, are all key considerations highlighted thus far. A systems approach to WRM can inform the choice of these parameters though this should not be a unidirectional process. Systems alone cannot necessarily dictate which time horizon *should* be adopted for example. Here thoughtful deliberation at a social-political, economic, and philosophic level is necessary and should inform modeling choices. The flow of influence, in other words, should be bilateral. Still, requirements associated with applying systems tools such as behavior-over-time graphs and causal loop diagrams can add clarity to WRM analysis.

A systems approach to WRM, to be fully effective, must include a clear idea of the goals and aims of the system. In the context of this paper, the aim of the system is defined as the direction or determined course in order to achieve a target or desired state. A goal or goal of the system is the desired state, results, or purpose of the system. The key difference between the two is that a goal is the target the system is trying to get to and the aim is the course on how to get there. The aim can be long-term and broad, whereas the goal is very finite, specific, and measurable. Therefore, by definition, a system is goal-seeking to achieve accomplishment. Per W. Edwards Deming (2002, p. 23), "Create constancy of purpose [or goal] toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs." An effective system provides the resources for accomplishment of a goal. Deming (1994) attributed a goal to an arbitrary value, particularly a numerical goal.

A system's aim requires management to define and, in some cases, change the requirements or boundaries. According to Deming (1994), without aim, there is no system; rendering the moot the identification of necessary components (and interrelationships between these) and processes within the system. The ability to change the system requirements allows us to constantly improve on the processes of the system (continuous improvement) (Deming, 1994). The introduction of proper governance and funding to support overall system management would help improve the system by allowing for improvements in operations management and help optimize the system for sustainability (Horbatuck et al, 2018). Here again there is an opportunity for bilateral interaction between the conceptual analyses initiated in 1.2 and systems engineering. Constraints on modelers and their software can help inform operational definitions of resilience, sustainable development while philosophical analysis can push systems theory in new directions with the hope that this will lead to improvements in systems tools as well.

PART 2: ECONOMIC FOUNDATIONS

2.1 Demand-Side Economics

Classic laissez faire economics holds that equilibrium between production of goods and services (supply) and demand for these same goods/services occurs naturally. Examples such as the Great Depression and its aftermath appear to challenge this classical notion. For some, the Depression indicated that a hands-off approach was insufficient; the economy needed some level of steering or intervention to function properly. Demand-side economics, frequently associated with economist John Maynard Keynes, represents one such approach to intervention. With unemployment at record heights, Keynes and others speculated that increasing demand for goods and services would help remedy this problem (Ekelund Jr., Ressler, & Tollison, 2006). This same increase in demand would also pump the bellows of the economy. This framed economic growth primarily as a function of increased consumption (vs. increased production). It is important to note, however, that this increase is not merely a function of individual consumers. In characterizing demand-side economics, Klein (1983, p. 26) states “Demand-oriented theory emphasizes the role of demand in this layout. It analyzes the demand for goods by households, the demand for labor by enterprises, and the demand for capital goods by enterprises, assuming implicitly that adequate supplies of capital goods will be forthcoming from the business sector.”

In the face of imbalances in the macroeconomy then, Keynesians “…favor the use of discretionary fiscal policy – the use of government expenditures and taxation or, to a lesser degree, discretionary monetary policy – to force the aggregate demand rightward…” (Ekelund Jr. et al, 2006, p. 591).

By decreasing unemployment, increasing government spending, and other interventions, the intent is to increase the amount of money that consumers have, especially at the lower and middle class, which in turn leads to more spending in the economy (Ekelund Jr. et al, 2006; Klein, 1983). Demand-side approaches can be appealing in terms of both the amount of control over outcomes that interventionists (e.g. government) have and the relatively quick production of desired effect; especially compared to interventions that are slower to take effect (Ekelund Jr. et al, 2006). However, concerns linger about how long the effects of demand-side interventions tend to last and downsides associated with increased government bureaucracy. Supply-side approaches purport to remedy these deficiencies.

2.2 Supply-Side Economics

Supply-side approaches are framed as a foil for demand-side approaches. The former is seen as a corrective to an unduly heavy emphasis on wage growth and other demand-side interventions viz. economic growth. Barro (1997, p. 502) defines supply-side economics as “the study of the causes and effects of changes in supply and productivity of factors to production. This approach emphasizes the negative effect of income taxes on the incentive to work.” Ekelund Jr. et al (2006, p. 597) reinforce the demand-side foil role by observing that “Macroeconomic policy since the mid 1970’s has been shaped by the recognition that excessive and prolonged use of demand management might have adverse effects on the economy.”

In the domain of taxes, supply-side approaches traditionally hold that a decrease in tax rates will lead to a net increase in tax revenues. Though paradoxical at first blush, this claim is informed by the relationship between tax revenue and tax rates illustrated in the Laffer Curve (Exhibit 1). Supply-siders are not anti-tax. Rather, the argument is that revenues diminish beyond a certain tax rate; undercutting the point of taxes to begin with.

The background idea is that the more money consumers have in their pockets, the more likely they are to spend a portion of this money thus pumping the bellows of the national economy.

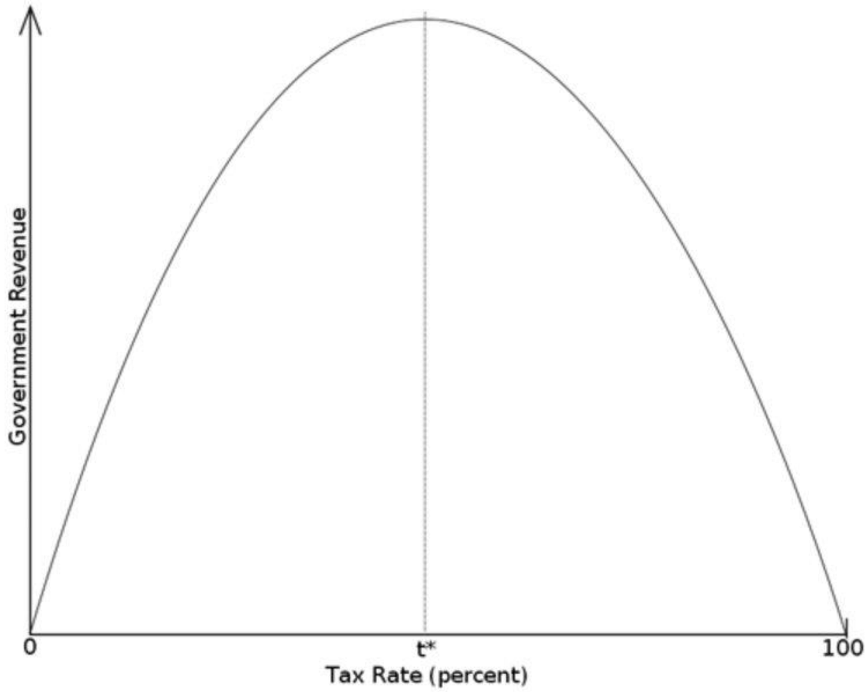

Exhibit 1: Laffer Curve

In addition to their skepticism about taxes, supply-side proponents also harbor concerns about the stifling role regulations can have on economic growth. Bureaucracy and unnecessary regulations, the argument goes, lead to economic calcification (Ekelund Jr. et al, 2006). The overarching idea with supply-side approaches is to make changes in the tax and regulatory structure to incentivize greater production which, in turn, will benefit citizens via an increase in supply (driving down prices) and increasing employment opportunities. Pejorative labels notwithstanding (i.e. trickle-down economics), the successes of such an approach can be difficult to quantify. They can, at a minimum, take time to manifest (Ekelund Jr. et al, 2006).

PART 3: ECONOMICS IN WRM

Though a simplified view, Figure 2 highlights the major forces acting in a water resource system. Each of these forces can and do exert stress on water resource systems. Effective WRM strategies take each of these into account as well as the interactions between them. These same forces can also act as leverage points in a system – manipulated in such a way to improve system performance and deliverables. This section of the paper focuses on economic interventions in WRM; extending the framework introduced in Part 2.

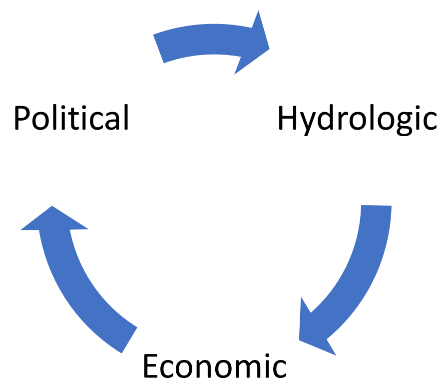

Exhibit 2: Forces Acting in Water Resource Systems

3.1 Demand and Supply-Side Approaches in WRM

Demand-Side

When considering how to best oversee a finite resource, or a "commons" in the case of water, a natural place to begin is with managing the demand for said resource. Some approaches rely primarily on technology to manage demand. Low-flow toilets and showerheads, for example, are intended to decrease pressure on the water supply with little active decision making expected on behalf of consumers beyond, in the case of voluntary programs, the initial purchase and installation of the equipment. Other demand-side strategies rely more explicitly on behavior modification such as mindful consumption of water (campaigns encouraging consumers to turn off water while brushing teeth, shaving, and so forth). It is worth noting that nudging, one of the approaches developed in light of the discoveries of behavioral economics, has a great deal of potential vis-à-vis behavioral modification. Nudging is a form of soft or libertarian paternalism that encourages, but does not require, subjects to make choices in their own interest (Thaler & Sunstein, 2008). A nuanced design of the choice architecture underlying consumer decision making about water could lead to higher degrees of system resilience.

There are other instances, however, where allowing consumer choice may be both inappropriate or ineffective; necessitating the application of political and/or economic forces instead. Lawn watering regulations exemplify this as well as, in more extreme case, close water metering. Some of these more forceful interventions were utilized in Cape Town to avoid "Zero Water Day" (Mahr, 2018). Perhaps one of the most underutilized strategies on the demand-side is the implementation of full-cost recovery pricing of water (Rouse, 2013). This last approach certainly requires behavior modification on the part of political leaders as well as their constituencies.

Supply-Side

Several strategies in the domain of WRM can be characterized as supply-side approaches. The most obvious of these is the move to increase the absolute supply of water by tapping into new sources. This includes drilling into new aquifers, increasing pump rates from existing ones, and/or piping in water from new sources (often further away). Regional supply variability notwithstanding, such approaches are questionable both in terms of sustainable development and sustainability given anticipated growth in population, agricultural development, and industrial production. More nuanced supply-side approaches also include rain water capture and improved water recycling. The latter can be further broken down into closing the loop between potable and grey water applications as well as so-called toilet-to-tap water filtration strategies. Addressing leaky pipes and other infrastructure inefficiencies that draw down the quantity of water available can also be considered a supply-side strategy (Rouse, 2013). While the strategies highlighted here all focus on sources of water, it is important not to overlook the impact of interventions intended to improve water quality; thereby increasing supply (Milman & Short, 2008).

A Multi-Faceted Approach

Prima facie, demand-side and supply-side approaches, as characterized above, have important contributions to make to effective WRM and to resilient systems more specifically. There is reason to doubt, however, that either is sufficient on its own (Uddameri, 2017; Al-Hmoud, 2018). Supply-side approaches alone do little to nothing to modify the behavior of consumers who are, arguably, the chief stress on water supplies. Demand-side alone appear to be incapable of absorbing or managing the pressure exerted by growth in population, agriculture, and industry (i.e. demand-side approaches alone do not lead to system resilience). Combining approaches, then, has serious appeal. However, merely combining approaches without much thought about to interaction effects threatens to make a hybrid approach mosaic at best. A more effective route is to assess how supply and demand-side approaches can be applied systematically.

3.2.1 A Systems Approach

A systems-based approach to integrating demand and supply-side economics in WRM ought to begin with establishing whether there is a connection between general economic theory and WRM. That is, while the various strategies in 3.1 have been characterized as either supply or demand side approaches, it is important to ask whether they share key similarities with demand-side and supply-side approaches in other domains (e.g. the national economy). Bertalanffy's concept of isomorphology can be helpful in determining whether such a connection exists. An isomorphology exists between two systems that demonstrate structural or, potentially, functional similarities. Two systems can be isomorphological even if the contexts they operate within or their components are very different. Bertalanffy observes that bacteria colonies and scientific publications both demonstrate exponential replication rates. They are, in this regard, isomorphological (Bertalanffy, 1968, p. 33). He goes on to enumerate several levels of similarity: 1) analogy 2) homology and 3) explanation; only the last two are sufficiently substantive for isomorphology. He dismisses analogical similarities as superficial; characterizing them as distracting if not more problematic (Bertalanffy, 1968). Homology and explanation on the other hand, can help illustrate important similarities between two systems leading to both better understanding and prediction. In short, analogy is not isomorphology.

So, is there an isomorphological similarity between general economic theory and WRM? The answer is mixed and leads to a proposed refinement of Bertalanffy's concept. At an obvious level, there is an important disconnect between the application of supply or demand-side theory at the level of the national economy and WRM. Whereas supply and/or demand-side approaches are applied with the goal of increasing economic growth (via either production or consumption), the goal in WRM is, in a crucial sense, completely the opposite. Effective WRM and related notions of resilience and sustainability are about managing growth; too much growth is a bad thing. Economic prosperity (e.g. income growth) does not face the same finitude that water resources do.

At this level, it would appear there is not an isomorphological similarity (homology or explanation) and that, subsequently, the application of at least demand-side approaches in WRM is either 1) ill-advised or 2) not really an application of economic theory (i.e. the approaches in 3.1 have been mislabeled). Stopping the analysis here, however, would be premature.

3.2.2 Developing Systems Theory

There is arguably a homological similarity between economic theory and WRM with respect to where the onus is placed regarding generating desired outcomes. For instance, in both domains, demand-side approaches include near term interventions targeted at a key component in the system: consumers. The appeal in both domains is the level of control decision makers have in effecting desire outcomes even if the dynamics move in wholly opposite directions (increase demand in the economy vs. decrease/mitigate demand in WRM). It would appear that this isomorphology is reinforced on the supply-side as well. In both the national economy and WRM, the goal is to increase production (supply). Here the dynamics move in the same direction.

The parallel between economics and WRM is further strengthened when considering the regulation of growth. In the United States, the Federal Reserve system, created in 1913 (Ferguson, 2008), is intended to stave off both excessive economic expansion and contraction. It has been variously credited and criticized for its role in preventing financial calamity and exacerbating it (Ferguson, 2008). The Fed manages growth through a variety of interventions including buying government bonds as a sign of confidence in its (government) strength and offering favorable lending rates to financial institutions to maintain healthy lending rates to businesses and individuals (Ferguson, 2008; Barro, 1997). Water resource managers share an onus similar to the Fed. On one hand, they must maintain a constant supply of water for municipal, agricultural, and industrial uses. Meeting these demands requires that the supply of water be preserved. However, an excessive emphasis on preservation will result in the depression, and ultimately loss of, agricultural and industrial income. This will be followed by shrinking municipalities. Water is, of course, essential to life. It is also essential to economics.

Looking for meaningful parallels between economic systems and water systems is not a novel project here. Bates (2015; 2017), for instance, compares groundwater consumption to deficit spending. Heavy reliance on this source of water coupled with unsustainable levels of consumption will have disastrous consequences if left unchecked. Bates (2017) proposes that a more sustainable level of consumption can be achieved if managers first recognize the isomorphic similarity that exists between groundwater and monetary systems. Successful policies in the latter, he argues, can be applied to the former (Bates, 2017).

Dynamic Essentialism
The claim that there is an isomorphic connection between economic theory and WRM rises and falls on a modification of Bertalanffy's concept. The authors argue that in order for isomorphology to be a useful concept in systems analysis, similarities must exist at the level of the essential characteristics of each system. This is implied in Bertalanffy's rejection of analogy as the basis of isomorphology but needs to be made more explicit. Essential characteristics are those that, when removed, change the fundamental identity of the system in question. Remove an essential characteristic and you are no longer talking about the same system (if it is a system at all, see Anderson and Johnson's definition of a system).

The dynamic dimension of essentialism arises from the observation that what is considered essential will shift with the purpose underwriting the initial comparison. So, for instance, it is useful to know that scientific publications and bacterial colonies both grow exponentially if the purpose of the comparison is to predict growth behavior and related phenomena (e.g. saturation points). However, this shared characteristic is less important, if at all, when assessing, say, how big data should be utilized in scientific research. What is really needed, then, is a more dynamic theoretic framework. In their paper analyzing the behavior of cotton commodities, Cantu and Beruvides (2013) observe that cotton has historically and economically been grouped with grain commodities (e.g. corn). They state: "As a result…the financial tools and assumptions for cotton tend to be similar to corn" (Cantu & Beruvides, 2013). What is interesting, however, is that cotton has key similarities to lumber. Both, for instance, are now consumed more internationally than domestically (relative to the U.S. economy). Both are considered price-takers (cotton and lumber futures have little causal impact on the market). And, while cotton is harvested seasonally, its capacity to be stored for long periods of time (vs. grain) is another shared characteristic with lumber (Cantu & Beruvides, 2013). With regard to measuring and predicting economic performance, then, Cantu and Beruvides (2013) argue that it is more appropriate to use the financial tools and assumptions associated with lumber (not grains). The comparison is not static here. From a production perspective, cotton is probably best compared to other fibers such as wool (Cantu & Beruvides, 2013). What emerges, then, is a multi-faceted isomorphology. In light of these insights, the authors propose *dynamic essentialism* when applying isomorphology. Dynamic Essentialism states that for an isomorphology to exist, two systems must share characteristics at the essential level and what is considered essential is a function of the purpose of the comparison.

Such an approach would offer a meaningful way to compare systems. It features both a focus on the core, identity conferring aspects of a system while remaining flexible enough to view systems through multiple lenses. If successful, this modification has the potential to enhance the application of isomorphology to qualitatively oriented problems (i.e. through the identification of contextually sensitive essential characteristics). Such an enhancement is desirable given the current lack of qualitative applications of isomorphology highlighted by Beruvides and Cantu (2013). That being said, this idea needs further work to avoid the very real worry that it will simply collapse into an arbitrary (and excessively convenient) form of epistemic relativism.

CONCLUSION

While calls for a systematic approach to WRM are not uncommon, there remains some ambiguity about what this entails. In Part 1 of the paper, the authors sought to add specificity by highlighting insights from systems thinking. For instance, understanding what constitutes a system (e.g. a collection of components that are ordered in a specific way, must all be present for the system to achieve optimality, etc.) is both basic and critical to formulating systems level interventions in WRM. The authors have also argued that the effective application of systems thinking and related tools requires clear identification of who and/or what is a stakeholder in the system. A systematic approach also necessitates greater clarity on the system's time horizon. Absent such clarity, concepts such as resilience, an important aim of WRM, will continue to suffer a noteworthy degree of relativity (which is not the same as situational sensitivity) and thus a problematic anchor for measuring WRM outcomes.

After providing a broad characterization of demand and supply side approaches in economics, the authors questioned whether several popular WRM strategies share meaningful structural connections with either demand or supply side approaches in Part 3 of the paper. Applying Bertalanffy's concept of isomorphology, modified with the notion of Dynamic Essentialism, the authors determined that there is a substantive similarity (homology) between demand/supply side economic theory and WRM practices. Establishing this connection is prerequisite to a systems approach to WRM that incorporates both supply and demand side approaches and captures potential interaction effects between these as well. Given the apparent parallel between Federal Reserve (and other centralized banking institutions) policies and effective WRM, it is worth asking whether lessons learned in the former can be applied to the latter.

This analysis only begins to outline a systems approach to WRM. It has, hopefully, provided some additional structure and details to calls for big picture thinking when it comes to managing water. There are certainly implications for the management of other commons like air, land, animal populations, etc. The need for concurrent development of a systems approach to WRM, at both a theoretic and empirical level, is evident in the previous pages. The surface of conceptual analysis has only been scratched with respect to core concepts in WRM like resilience. At the empirical level, and on the assumption that an isomorphology does exist between economic theory and WRM, work needs to be done identifying the efficacy of both supply and demand-side interventions. More specifically, a survey and defense of appropriate metrics of resilience needs be made. Choice of metrics, in turn, should be informed by parameters established through thoughtful philosophical analysis; the metrics of sustainable development will not be identical with those of sustainability.

Finally, systems theory can and should play a role in making sure that multi-faceted approaches to WRM do not collapse into merely mosaic approaches. Thoughtful coordination of the various components will lead to better outcomes. Again, the interaction between application and theory is unavoidably bilateral. This is not a bad thing.

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