

# **THE NEED TO IDENTIFY SYSTEM ARCHETYPES AND LEVERAGE POINTS FOR THE PROTECTION OF AQUIFERS IN THE WATER-ENERGY NEXUS**

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## **ABSTRACT**

As the world's population approaches the 9 billion mark (United Nations, 2011) and the demand for energy increases, increased pressure is being placed on freshwater supplies in the earth's 'water-energy' systems. This paper, based on research for the completion of my doctoral dissertation, studies a number of concerns regarding the contamination and depletion of freshwater aquifers as the energy sector continues to grow. To address these concerns, this paper proposes that environmental tax policy, and in particular, ecological tax incentives for aquifer protection – within a socio-ecological systems framework - can play an important role in protecting potable water sources by promoting long-term sustainable practices.

Daly (1996) discusses fifteen principles on sustainable development. Though nearly twenty years old, these principles are as relevant today as they were when they were written – if not more so, now. The principles are integrated into a 'regulatory framework for the protection of aquifers' in this study, in an attempt to link existing ideas regarding 'sustainable development' with new ideas formulated using a systems approach.

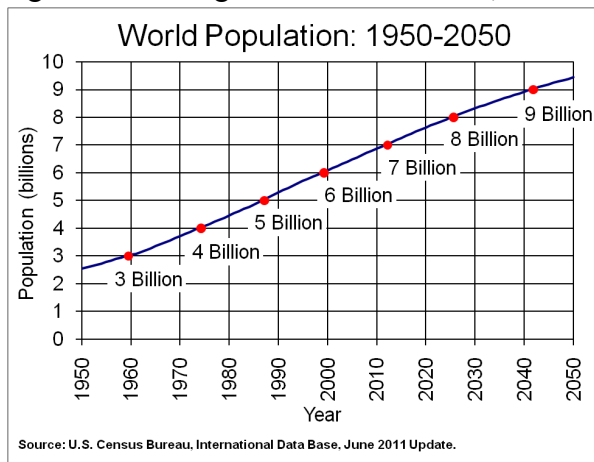
The interactions between energy production/usage and potable water supplies is depicted in the paper through a series of systems archetypes, wherein balancing loops are identified as points of leverage for the introduction of ecological tax incentives for aquifer protection. These points of leverage are then identified within the larger framework, where they will later be tested using primary data from various stakeholders (using a grounded theory methodology) in order to discover a theory and themes on the use of ecological tax incentives for water protection.

The study takes an interdisciplinary approach to deal with the multi-faceted dilemma facing the water-energy nexus, and the paper explores the situation using theories of complex open-systems, e.g. (Meadows, 2008; Senge, 1990; Sterman, 2000; von Bertalanffy, 1972), environmental regulations and tax policy, e.g. (Baumol & Oates, 1988; DiJohn, 2010; Fullerton, 2001; Gunningham & Grabosky, 2004; Määttä, 2006; Pigou, 2002; Tinbergen, 1952), and resilience, e.g. (Arrow et al., 1995; Berkes & Folke, 1998; Gunderson, Allen, & Holling, 2010; Holling, 1973; Walker & Salt, 2006). The paper then concludes with the suggestion that economic/environmental policies based on systems thinking will offer a more sustainable and resilient future for the earth's freshwater supplies.

## INTRODUCTION

The earth's population is expected to triple from 3 billion to 9 billion inhabitants between 1950 and 2050, as seen in

Figure 1. In the grand scheme of time, one hundred years is not long, and the fact that the population is predicted to triple during this period is alarming.<sup>1</sup>



As the population increases, so does the demand for energy, and the current level of consumption is expected to double by

### Figure 1. Global population growth

(<http://www.census.gov/population/international/data/idb/worldpopgraph.php>)

the year 2035 – with the largest growth taking place in non-OECD countries (U.S. Energy Information Administration, 2011a). Currently, there is a movement towards the production of unconventional natural gas (UNG) to supply this demand, i.e. (Olah, Goepfert, & Prakash, 2009). The extraction of this UNG is often conducted in close proximity to the earth's groundwater (aquifer) supplies (U.S. Energy Information Administration, 2011b) - which is a concerning issue at the heart of this study - as the earth's water supply is limited and becoming scarce in many regions, i.e. (Barlow, 2007; Brooymans, 2011).

*“Water scarcity has attracted attention globally and is considered the major environmental issue facing the 21<sup>st</sup> century.” (Brooks, Ffolliott, Gregerson, & DeBano, 2003, p. 8)*

Thus, there is a need to manage the quantity and quality of aquifers with policy instruments designed to protect the resilience of water, and this study proposes that this will best be achieved through a socio-ecological, complex systems framework. Figure 2 illustrates the framework developed in this study, recognizing that a gap currently exists

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<sup>1</sup> At the time this paper was written, the population approximated 7.091 billion people. (U.S. Department of Commerce)

between economic activities and ecology, and that a socio-ecological model designed for resilience and sustainability is required as we move forward.

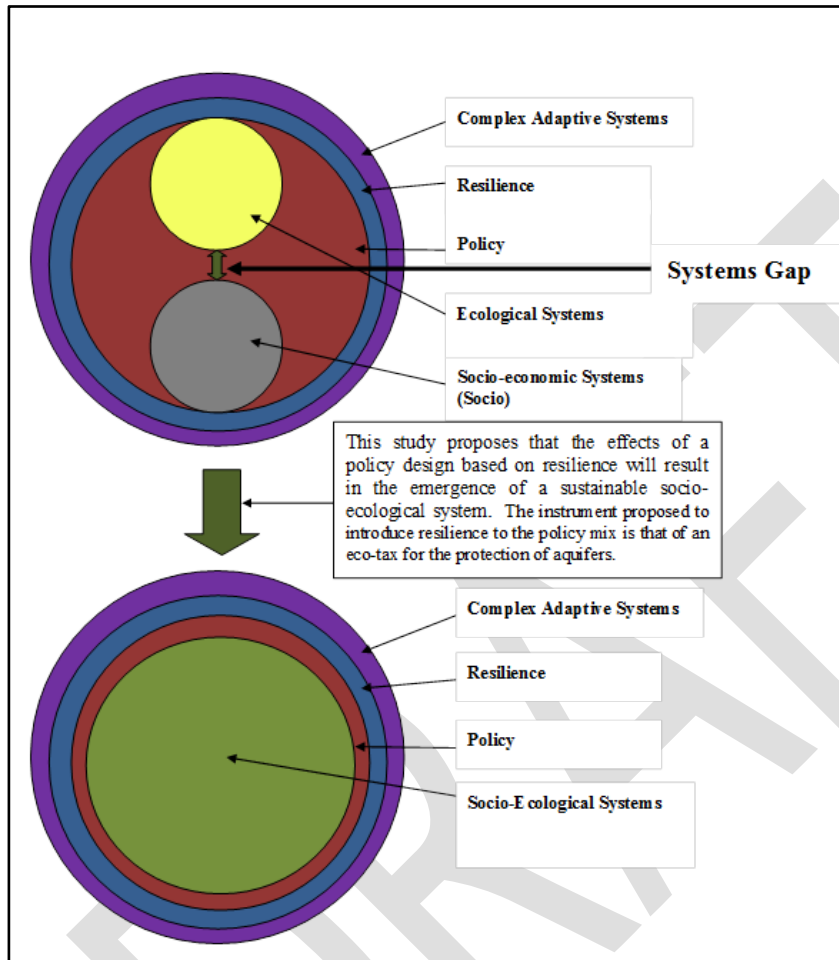


Figure 2. The Systems Gap

Daly (1996) addresses fifteen principles created in 1995 by the United States President's Council on Sustainable Development. Though nearly twenty years old, these principles (paraphrased and listed here) are as relevant today as they were when they were written – if not more so now.

Principle 1: Preserve the integrity of natural systems.

Principle 2: The economy, environment, and society should be integrated.

Principle 3: Market strategies are required for sustainable development.

Principle 4: Population growth and the earth's capacity must be considered.

## **The Protection of Aquifers, Working copy – Please do not reference**

Principle 5: Consumption patterns must change and the use of natural resources improved.

Principle 6: Poverty must be eliminated.

Principle 7: The costs and benefits of the environment should be shared by all.

Principle 8: Current choices must consider future generations.

Principle 9: Scientific uncertainty can potentially affect health and the environment.

Principle 10: All stakeholders must make fundamental changes.

Principle 11: Resource concerns affect security.

Principle 12: Free institutions are required for sustainable development.

Principle 13: Information should flow freely amongst all parties.

Principle 14: Science and technology are needed for advancements in sustainable development.

Principle 15: National sustainability must be considered from an international perspective.

These principles are integrated in the theory of the Systems Gap model, in an attempt to link existing ideas with new concepts based on resilience and complexity.

This paper offers an introduction to some of the key areas of the research, and begins the development of the systems archetypes analysis that will be used to identify leverage points for sustainability and resilience.

### **ADDRESSING THE WATER-ENERGY NEXUS AS A SYSTEM**

Concerns arise when the development of energy supplies encroaches upon potable water resources. The current supply of water<sup>2</sup> cannot be increased in volume due to the science of the hydrological cycle (Brooks, et al., 2003). Additionally, the time to reverse pollutants is either so slow (for groundwater) or expensive (for surface water) (Gupta, 2011), that there exists a need to develop policies to protect freshwater supplies as energy demands increase globally.

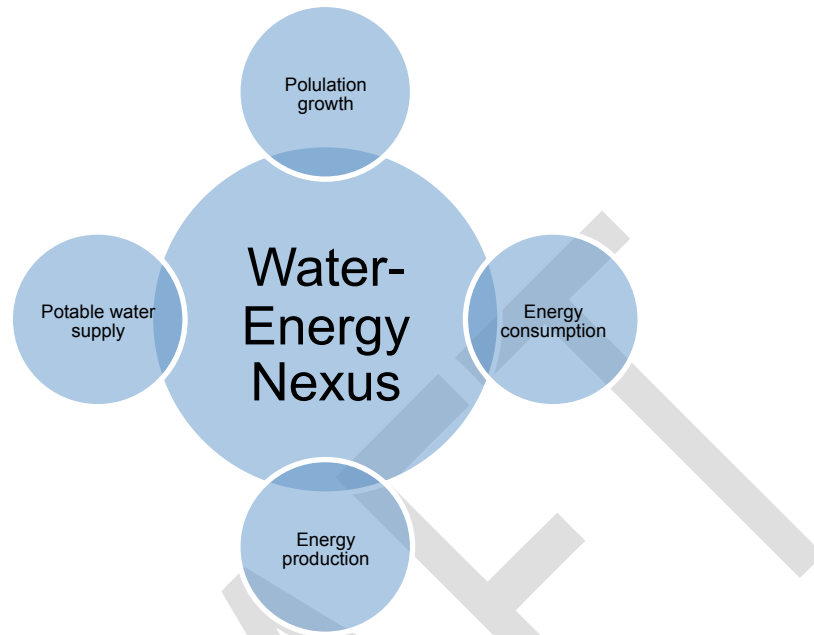
The water-energy 'nexus' can be structured around the following factors:

- Population growth
- Energy consumption
- Energy production
- Potable water supplies

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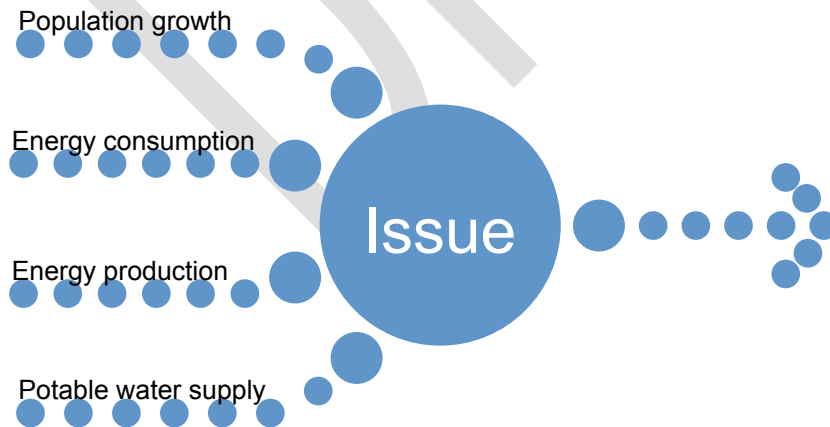
<sup>2</sup> The total amount of water on earth is approximately 332.5 million cubic miles; however, less than four percent of this water is fresh water, with the majority trapped in glaciers and ice. (USGS, 2013)

as illustrated in Figure 3.



**Figure 3. Components of the water-energy nexus**

And it is important that these factors be studied from an intertwining complex systems perspective (as indicated by the blending of the issues in Figure 4), rather than as isolated topics. The effects of the components on one another must be clearly understood.



**Figure 4. Recognizing the water-energy nexus as an intertwined, complex system**

In order to address these issues from a systems viewpoint, archetypes as described by Senge (1990) are presented in the following section.

### **SYSTEMS ARCHETYPES TO UNDERSTAND THE WATER-ENERGY NEXUS**

The components of the issue presented here cannot and should not be studied as static objects, but rather as interacting players in a system driven by a) human behavior – which we do not fully understand, and b) ecological interactions – many of which we do not yet fully understand. Senge (1990) points out that the most common method of dealing with situations is by reacting to events, and that a more useful process exists in the determination of long-term patterns of behavior, with the most powerful method for understanding and resolving issues being through the understanding of the systemic structure. (Coghlan & Brannick, 2001, p. 100) reference Senge's views on the system's approach as "hold[ing] the key to integrating intuition and reason, because intuition goes beyond linear thinking to recognize patterns, draw analogies and solve problems creatively."

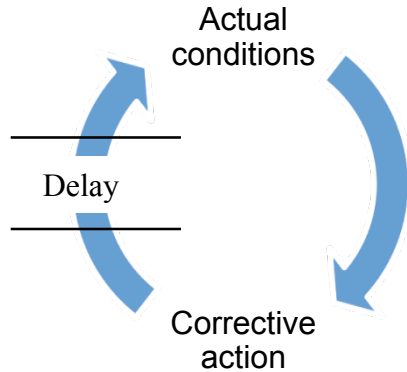
In this study, I incorporate eight systems archetypes that Senge discusses. These archetypes are presented here – beginning with 'balancing process with delay - and each model is discussed as it relates to the water-energy nexus. Issues of regulation and resiliency are also discussed throughout the models.

Further research will involve exploring the mental models (discussed later in this section) from various stakeholders, as they relate to the archetypes. Leverage points for change will also be developed throughout the study, working with the twelve points of intervention<sup>3</sup> identified by Meadows (2008).

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<sup>3</sup>The twelve leverage points are: constants and parameters, buffers, stock and flow structures, delays, balancing feedback loops, reinforcing feedback loops, information flows, rules, self-organization, goals, paradigms, and transcending paradigms.

### Balancing process with delay

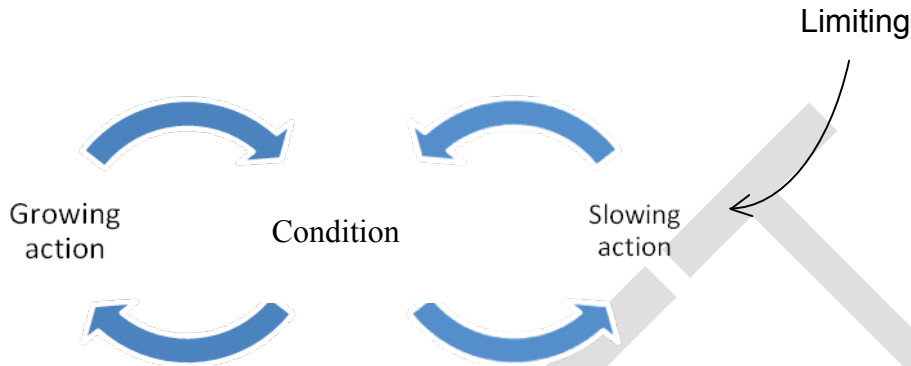


Understanding and working with the concept of delay is critical for the protection of aquifers during energy production, and is recognized by Meadows (2008) as a leverage point for intervention. The system archetype ‘balancing process with delay’ examines the idea that “[a] person, a group, or an organization, acting towards a goal adjusts their behavior in response to delayed feedback. If they are not conscious of the delay, they end up taking more corrective action than needed, or (sometimes) just giving up because they cannot see that any progress is being made.” (Senge, 1990, pp. 389-390).

Arrow et al. (1995, p. 93) state, “Economic activities are sustainable only if the life-support ecosystems upon which they depend are resilient. Even though ecological resilience is difficult to measure and even though it varies from system to system and from one kind of disturbance to another, it may be possible to identify indicators and early-warning signals of environmental stress.” Thus, this study proposes that policy mechanisms encouraging the recognition of indicators and stressors are necessary in order to protect freshwater sources.

As delays in markets can lead to “persistent disequilibrium and instability” (Sterman, 2000, p. 171), the same might be said of the water-energy nexus, with a key difference being, however, that man-made markets have the potential to quickly return to stable states with additional feedback loops. The same is not necessarily so for aquifers which take hundreds if not thousands of years to recharge.

## Limits to growth



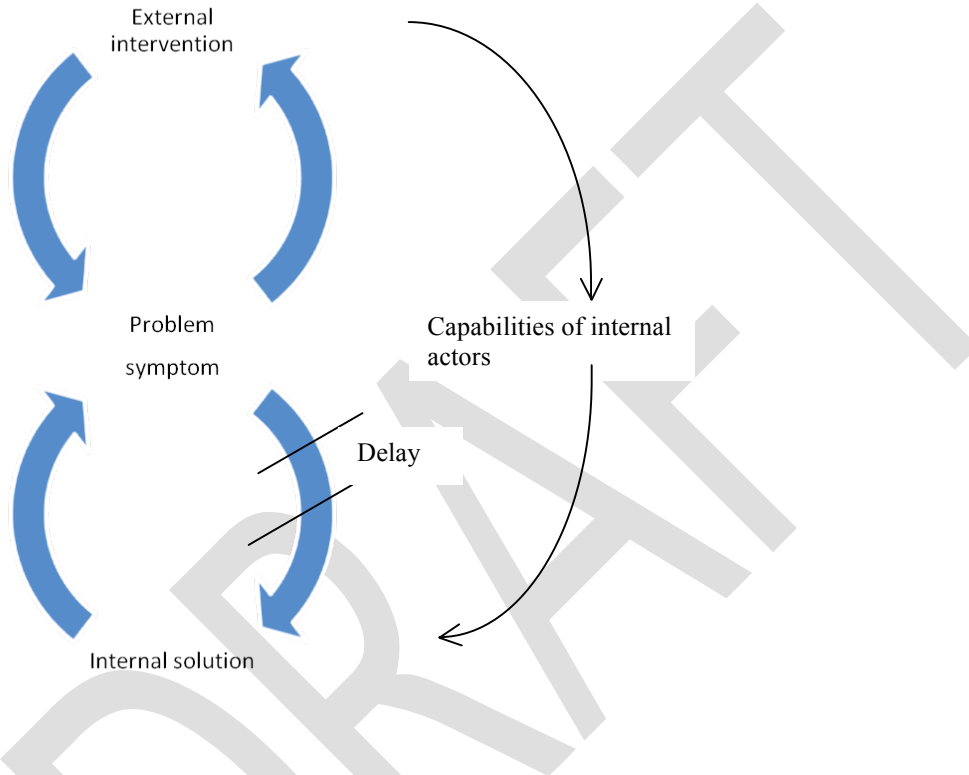
The 'limits to growth' archetype relates to the issues within the water-energy nexus as population growth and the increased demand for energy drive the growing action of energy production, which is increasing at a rapid rate globally in the form of unconventional natural gas extraction (U.S. Energy Information Administration, 2011b). The supply of potable water required for and potentially affected by extraction acts as the limiting factor. This balancing feedback could potentially slow industry growth, but the fact that the limiting factor in this archetype – water - is life-sustaining and limited is cause for concern.

In contrast to a typical 'limits to growth' situation which may result in the unfortunate demise of a business or initiative, a different type of risk exists if potable water is affected and resilience is lost. Holling (1973) explains that the constructs of *external changes*, *the unexpected*, and *relationships* must be understood for resilience to take place. Thus, the system must be highly sensitive to the limiting factor, and policy must be designed to encourage an understanding of these constructs.

The constructs of external change and the unexpected are explored in the study within the context of resilience in ecosystems (Berkes & Folke, 1998; Gunderson, et al., 2010; Holling, 1973; Walker & Salt, 2006), with much emphasis placed on theories of perturbations and regime shifts (Scheffer, 2009) whereby an ecosystem may abruptly shift from one stable state to another following gradual incremental changes of a particular (or several) variables. The third construct, relationships, is explored from a general systems theory perspective (von Bertalanffy, 1972).

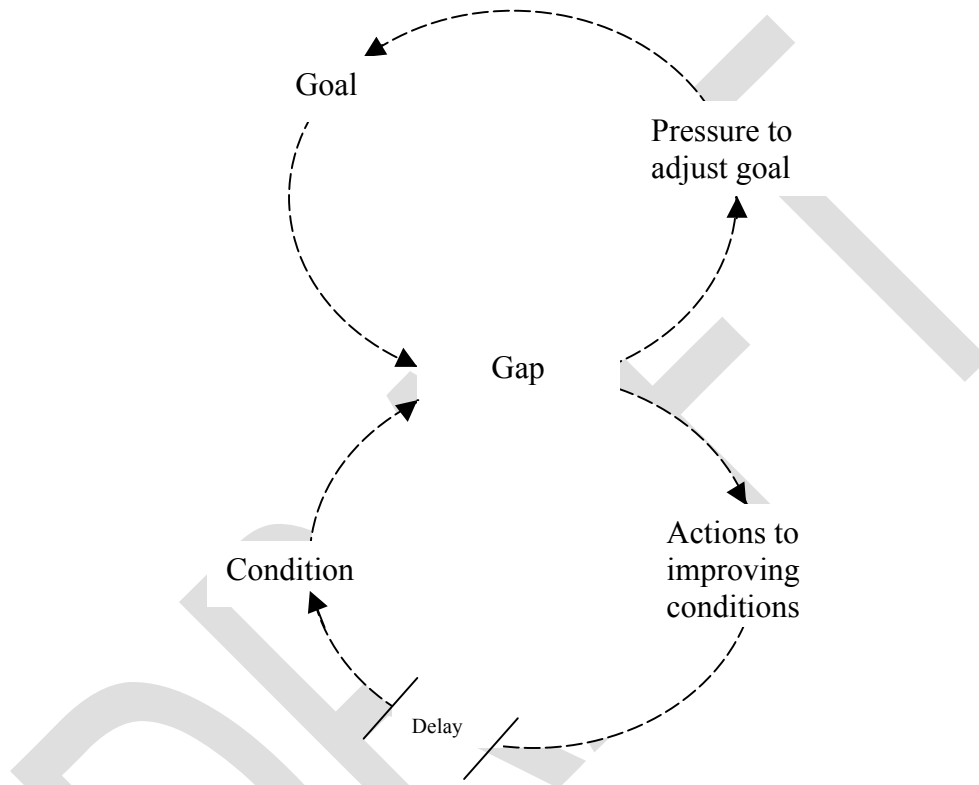


**Shifting the burden (to the intervenor)**



Jumping straight from the archetype of ‘shifting the burden’ to ‘shifting the burden to the intervenor’ in my study, I discuss that the symptomatic solution in the former is, to an extent, the external intervention of government regulations in the latter. Regulations are criticized for their inability to promote innovation (Hansford & Woodward, 2008), and as such, they have the potential to delay the fundamental (internal) solutions to aquifer protection. While regulations do play a role in certain circumstances, a comprehensive policy mix must be carefully designed in order to determine the most effective instruments (Gunningham, 2009; Tinbergen, 1952), some of which will allow for innovative developments by internal actors.

### Eroding goals

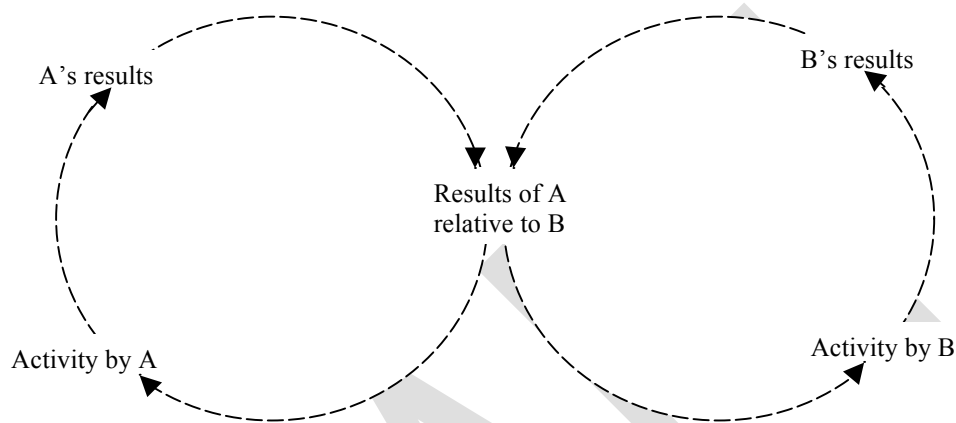


The archetype of ‘eroding goals’ is similar to the systems gap model presented earlier in Figure 2. This archetype emphasizes the push for short-term solutions at the expense of long-term goals. (Senge, 1990, p. 395) cites the example of “[s]liding targets for controlling dangerous pollutants”. The short-term development of energy can potentially have long-term effects as unconventional natural gas is in close proximity to the geological structure of aquifers and the surrounding ecosystem (Vance & Ganjegunte, 2010), which can take a long time to show effects.

This study takes the stance that any adverse affects to aquifers, whether from contamination of the water or from excessive withdrawals, are *irreversible*. “[P]olluted groundwater...may be so slow to recover that one might think of the pollution of aquifers as almost irreversible. For this reason, great care is needed to protect groundwater, particularly deep aquifers.” (Gupta, 2011, p. 160). Pindyck (2007, p. 60) states that “The

role of uncertainty in policy design is especially important for environmental problems that involve long time horizons.”<sup>4</sup> Thus, policy must be designed to encourage ecological protection – which one hopes will subsequently narrow the gap between economics and ecology.

### Escalation



The systems archetype of escalation addresses the situation that arises when competition is present. Rather than working from within a win-win framework, competition can drive players to act defensively in order to remain in the game, and this can result in different outcomes than originally planned.

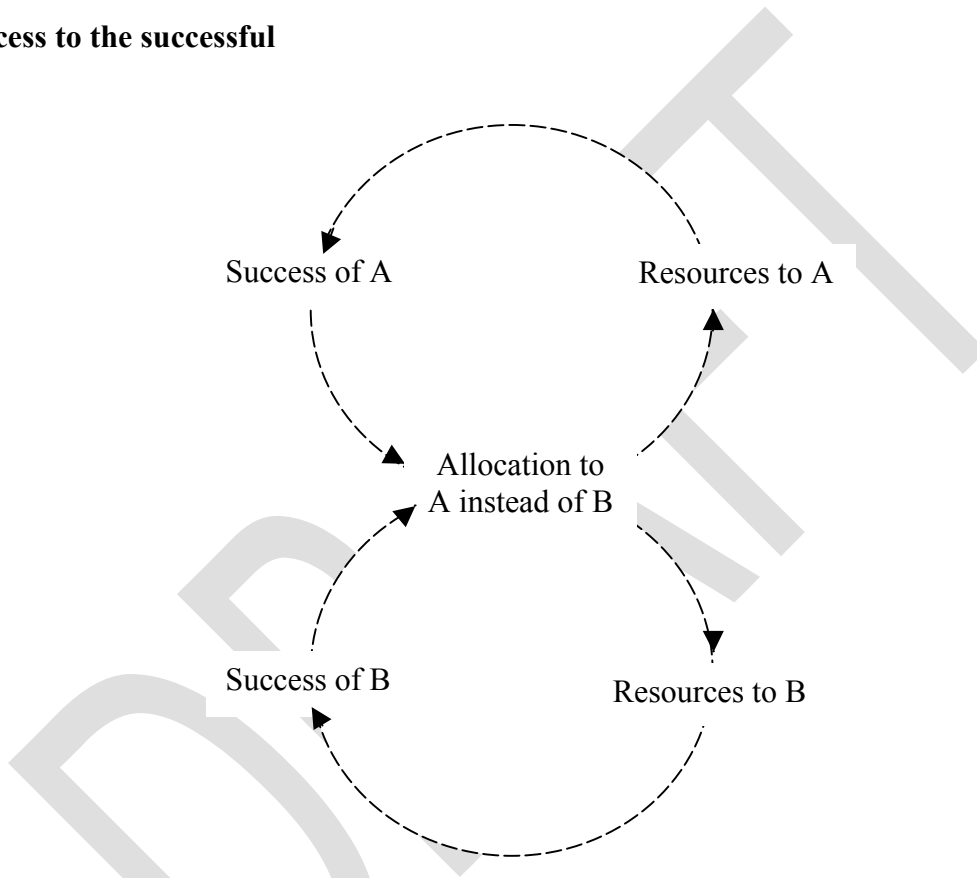
A variety of players, both senior and junior, exist in the unconventional natural gas industry (Government of Alberta, Spring 2012), and as such competition is a large factor. Efforts are in place to coordinate practice standards (PSAC, 2013), but the archetype of escalation must be monitored carefully to avoid harmful effects to aquifers.

When developing policy, competition is an important factor that must be addressed, both from the standpoint of escalating activities, and also in fairness in policy setting.

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<sup>4</sup> While Pindyck (2007) discusses uncertainty in environmental policy setting using climate change as a primary example, he stresses the need for research in other areas of environmental danger, including water depletion and degradation.

**Success to the successful**

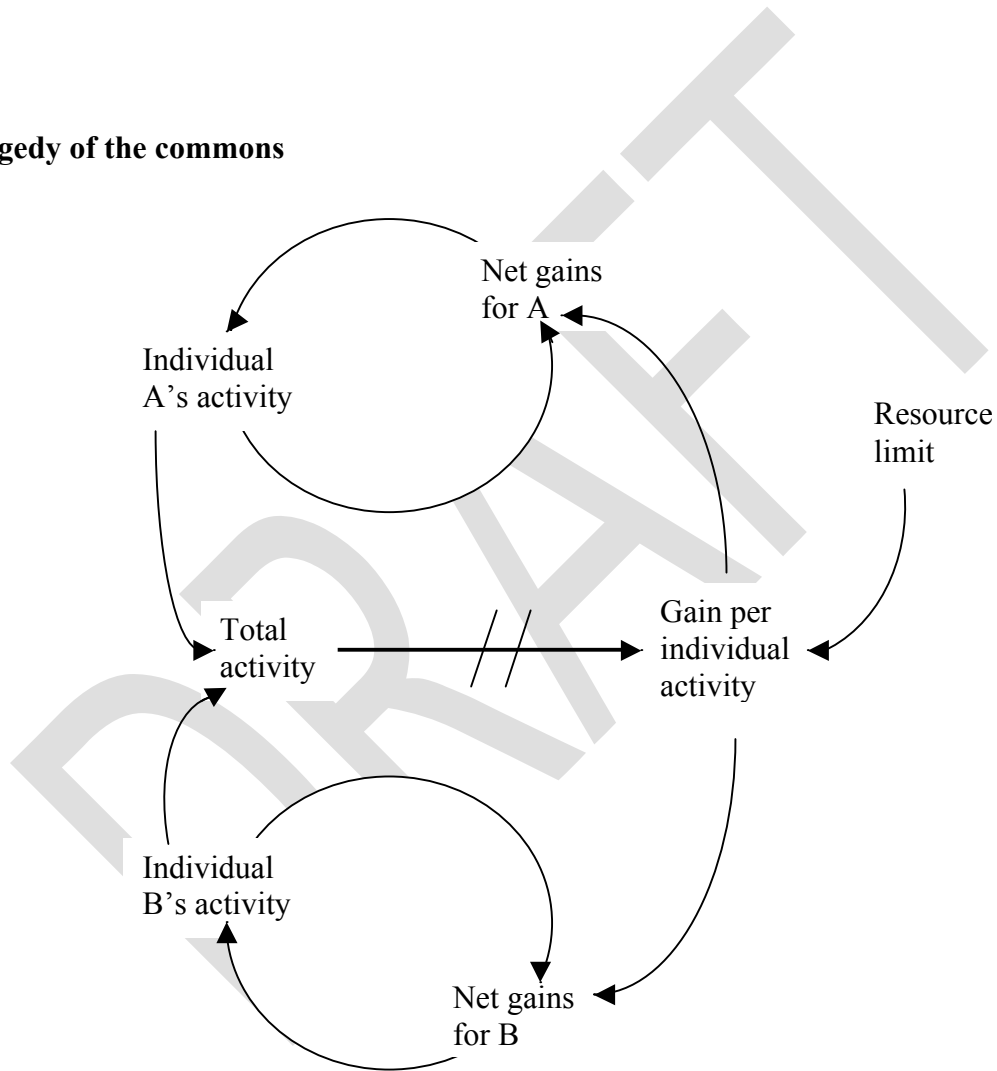


The success to the successful archetype also examines the effects of competition, but more so from the perspective of competition for a limited resource. A thorough understanding of the allocations of water made to various users within the watershed is required in order to address this archetype successfully. As the scarcity of water increases, competition amongst its many users (e.g. industry, agriculture, municipalities), will only continue to grow.

Senge (1990, p. 396) suggests that “In some cases, break or weaken the coupling between the [choices]”, which is echoed by the OECD’s (2001b) recommendation that economic growth should be decoupled from environmental pressures. Thus, in the water-energy

nexus, policy can play a role in the speed and effectiveness with which this de-coupling takes place.

### Tragedy of the commons

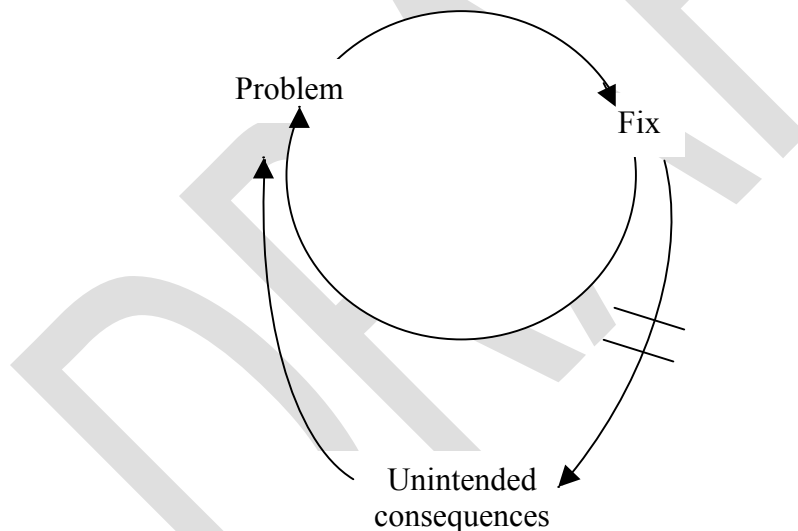


Hardin (1968) addressed the mismanagement of shared common pool resources in his famous essay "The Tragedy of the Commons". The systems archetype of the same name identifies the ways in which a scarce resource can be depleted when individuals act in their own best self-interest. The effects on water supplies must be considered as energy

production and consumption increases, just as water should be a part of any equation which involves its use.

In order to prevent tragedies or ‘regime shifts’ (Scheffer, 2009) from occurring, specific details of operations must be closely monitored, and policies carefully designed for positive outcomes. The OECD (2001a) propose that a move towards the use of market incentives will ‘create direct price signals to producers and consumers’, thus encouraging positive behavior, as externalities are borne by producers or users. Fullerton, Leicester, & Smith (2006) suggest that where broad-based behavior changes are necessary, taxes may be the most cost effective tool. Määttä (2006, p. 16) asserts that when using an environmental tax for resource utilization, “the term ‘environmental tax’ is an umbrella concept for two kinds of tax, pollution tax and resource tax.” While taxes designed for resilience is a new concept in the field of water protection, the link between resilience and taxes is explored in political realms (DiJohn, 2010), and likewise, the idea that ecological taxes and incentives be used for water protection is presented here.

### Fixes that fail



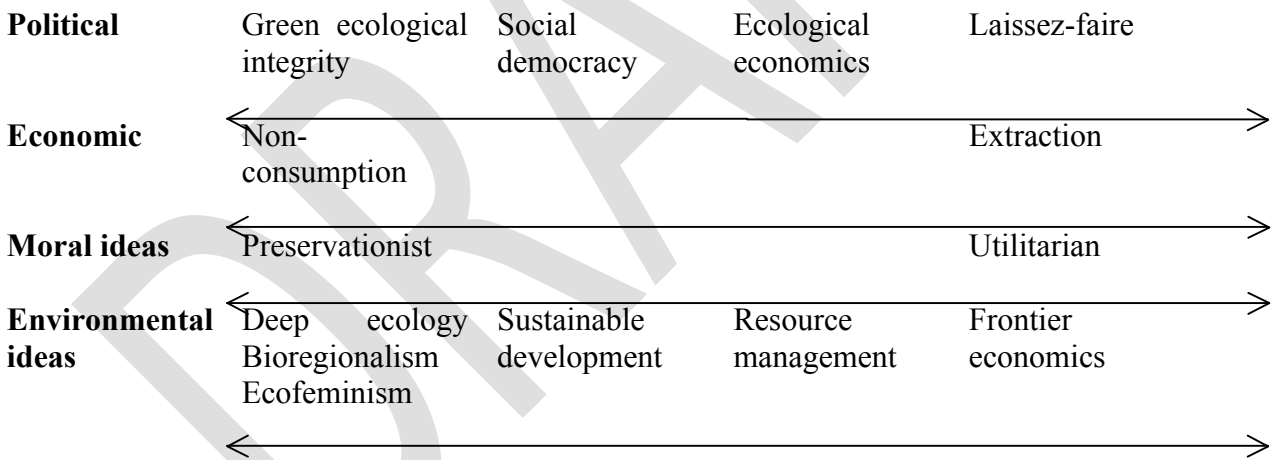
Fixes that fail are apparent in subsidies which create problems as great as or greater than the problems they were intended to fix (Baumol & Oates, 1988; Myers & Kent, 2001). As subsidies are a form of market instrument used in policy decision-making, the mix used to protect aquifers must be cognizant of both the negative and the positive effects that can result from any policy choice. The long-term spatial view must be considered in addition to short-term outcomes if resilience is to be achieved

**Mental models**

*“But perception is not whimsical, but fatal. If I see a trait, my children will see it after me, and in course of time all mankind, - although it may chance that no one has seen it before me. For my perception of it is as much a fact as the sun.” (Ralph Waldo Emerson, 1803-1882)*

As the population inches its way to 9 billion people, the number of mental models of the world also moves towards 9 billion. Perhaps the most fascinating component of any systems’ analysis is the wide diversity of human perceptions of the realities which surround them.

An important component in this research is to gain insight into the mental models of stakeholders in the water-energy nexus. Hessing, Howlett, & Summerville (2005) present a spectrum of environmental ideas which are factored into this study in the discussion of ecological tax incentives for aquifer protection.



**Figure 5. The spectrum of environmental ideas (Hessing, et al., 2005)**

Daly (1996, p. 6) says “the main issue in the sustainable development controversy truly does revolve around what economist Joseph Schumpeter called “preanalytic vision.” He discusses “empty-world” economics and “full-world” economics, referring to people’s preanalytic visions. These visions range from positions whereby the “empty-world” view believes that “humans could get away with ignoring the value of environmental assets and their impacts on them because these assets would be relatively abundant” (Costanza

et al., 2000, p. 151); to the “full-world” stance whereby environmental resources are finite and under constraints by the economy. Costanza, et al., (2000) discuss these viewpoints in the context of “technical optimism” and “technical skepticism”, and the authors describe the effect on the world that would result from policy based on these opposing ends of the spectrum if a) the optimist viewpoint was in fact reality, and if b) the skeptic viewpoint was in fact reality.

Thus, the various viewpoints along the spectrum must be carefully weighed in order that policy instruments are designed recognizing the various mental models, all the while protecting the earth’s freshwater supply. A further challenge to policy design, this is also one which must be met.

## **CONCLUSION**

Olmstead (2010, p. 188) states that “[o]ne of the biggest challenges to welfare improvement from water marketing is dealing adequately with externalities and public goods.” I would suggest that these are also some of the greatest challenges to the ‘welfare of water’. Pigou (1952) was a founding voice for the recognition of negative externalities in pricing, suggesting that these side-effects of business activities be charged a tax and that full-costing take place. Daly (1996, p. 90) discusses “ecological tax reform” using a Pigouvian tax in order to internalize the costs of “depletion and pollution”. Whether a tax to penalize, or an incentive for innovation is required, or both; and to what extent, and in what design, these questions must be asked and dialogues conducted in attempts to prevent the many common systems’ errors from taking place.

Fullerton et al. (2006) recognize that “environmental taxes are far from being a panacea for all environmental problems” and that in order to address certain environmental situations, regulations will still be required. Where broad-based behavior changes are necessary, however, they state that the cost of implementing regulations could be prohibitive, and thus, in these cases, taxes may be the most appropriate tool.

The fact that potable water quantity and quality is at risk as the global population continues to grow, demanding more and more energy, is an issue requiring immediate attention. Policies are needed that can address both the temporal and spatial characteristics of water usage from a systems perspective, encompassing ecological issues with the same importance as economic outcomes.

Working with systems archetypes based on mental models and leverage points for intervention, an opportunity exists to rethink the ways in which environmental policy is designed. The complex relations of the components in the water-energy nexus demand that we factor resilience and sustainability into our decision-making with a focus on both



long-term and short-term outcomes if we are to effectively manage the earth's freshwater supplies.

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