RESOURCE HISTORY MATTERS:

SES PATH DEPENDENCE IN THE ANTHROPOCENE

By

Elijah Tangenberg

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Honors Committee

Chair Name: Dr. Ronald J. Oakerson Signature: Ronald J Oakerson

Professor Name: Dr. Peter Meilaender Signature: Peter Meilaender

Professor Name: Dr. Eli Knapp Signature: Eli Knapp

Author Note:

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“Petals of the mountain rose
Fall now and then,
To the sound of the waterfall?”
- *Matsuo Basho*

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Abstract

Path dependence occurs when early events in an institution's or technology's history have irreversible implications for its future development and efficiency. The design of a machine or the interpretation of a law are both examples of adoption and development processes where early events determine future outcomes for the entity in the wider economic or political environment. In this paper, I extend analysis made in these fields to social-ecological systems (SESs), arguing that they also exhibit two types of path dependence. The first type is concerned with the long terms effects of appropriation and management on a resource system, termed "subsystem path dependence." The second type, termed "institutional path dependence," stems from the proliferation of institutional innovations throughout an SES's nested system of rules. Both environmental and institutional changes can have strong long-term effects on the governance of the entire SES and the functioning of its ecosystem.

In defining and distilling the components of SES path dependence, the analysis uses theoretical arguments from both ecology and political science. Resilience theory, the adaptive cycle, institutional analysis and development (IAD), and historical institutionalism (HI) are all used to understand the ecological and institutional components of an SES as well as the connections between them over long term processes of change. Within these theories, SES path dependence is shown as a multi-layered phenomenon where governance can become set in configurations resistant to alternative arrangements for resource appropriation and management. The development of groundwater governance in Southern California is used as an illustration of subsystem path dependence, examining both the nature of the resource system and the development of institutions.

I. Introduction

Changes in the natural environment have defined human history since its beginning, opening and closing off opportunities for development along the way. While many natural events were beyond human control, several of them were anthropocentric in nature and the result of institutional crafting. Some of these human initiatives led to stable resource-based societies, while many others led to disaster as the environment failed to sustain the population. It is this process of learning and adapting that led to what is called modern society, built on high levels of resource extraction for the creation of goods that we all consume. However, the destructive nature of extraction has not gone away and, in fact, has become worse as we intensify the use of natural resources and find new ways to appropriate them. Resource system collapse, the worst outcome of over-extraction, threatens numerous communities not just with economic harm but in terms of health and social outcomes as well. This is because the collapse of a resource system is disastrous not only for the livelihoods of those who depend on that system but also for other natural processes linked to that system that sustain the community. The possibly widespread impact of system failure leads policy analysts to prioritize the preservation and stabilization of resource systems through governance and management.

Many different aspects of ecological-anthropological connections matter for sustaining natural systems, from the development of traditional ecological knowledge to the integration of resource system behavior into the organizations that manage them (Cleveland et al., 1997; Menzies, 2006). One approach that has emerged to combat natural resource collapse is “adaptive governance and management,” where resource governance arrangements adapt to the current needs of the resource system (Decaro, Chaffin, Schlager, Garmestani, & Ruhl, 2017; Folke et al., 2002, 2004). These topics and methods are important to understanding the role that natural resources play in shaping the collective consciousness of the people who live and work in them and how these factors relate to changes in the resource system. However, these ideas do not examine the effect of change on pre-existing governance arrangements, or how these changes impact the development of the institutions that govern other resource systems. Based on these gaps in knowledge, analysts need to ask several questions. To what extent can new governance arrangements be fitted to existing institutional-resource system relationships to ensure their preservation? How does institutional change take place within these relationships? Perhaps the most pressing question is this: how can the processes of ecological and institutional change be used to sustain resource systems for years to come?

To answer these questions, the argument presented here examines how user-driven changes in a resource system can lead to institutional development through the history of ecological (or physical) changes in the resource system. In the process of examining resource change, I survey the institutional-ecological relationships within what are called social-ecological systems, or SESs, to provide a theoretical basis for connecting resource and institutional change as they both relate to resource system use. These changes occur both at the micro and macro levels of an institutional structure, as well as on the interplay between different types of institutional change within an SES. The resulting analysis and the conclusions that follow it are conjectural and not meant to provide either a complete theory or a set of empirical observations. Rather, the analysis draws upon well-established theories from political science and ecology to construct the theoretical basis for what is here called "social-ecological system path dependence," how changes in a resource system or institution close off future options for development.

A theory of SES path dependence needs to establish and refine what an SES is conceptually, who benefits from it, how they interact with each other, and their relationship to the ecosystem. To do this, the process of theory-building requires two different analytical clarifications: first, an understanding of how resource systems work and how beneficiaries interact with them, and second, how institutions are constructed from systems of rules. Laying out the definitions and distinctions used in this argument starts in Section II, which outlines the basic analytical framework of analysis, as well as the conceptual building blocks that will be used throughout the argument.

The in-depth examination of resource system components begins in Section III, where resource systems are analyzed and elaborated using the theoretical language of common-pool resources (CPRs). For this section I borrow from the defining aspects of CPRs and refine it to better suit the needs of an SES path dependence analysis, especially the concepts 'resource subtractability' and 'resource units'. How resource systems are conceived within the analysis is explained in Section IV, including the relationship of a resource system's physical aspects to its degradation. Concepts from resilience theory as well as the adaptive cycle model are used to examine how resource systems degrade and collapse, as well as how degradation and collapse relate to the subtractability of the resource.

Section V shifts the argument's focus from resource systems to institutional systems. Specifically, the section clarifies the structure of institutions and activities that occur at different institutional levels, including the application of adaptive governance practices to resource appropriation and management. The section primarily uses terminology from the Institutional Analysis and Development (IAD) framework, including analytical and structural methods for distinguishing institutions and their connection to polycentricity. These concepts clarify what is meant by institutions and how they relate to resource extraction.

Section VI combines the institutional language developed in Section V with the resource system framework set out in previous sections and applies it to a historical analysis of institutions. Section VII applies the conceptual apparatus developed over the preceding sections to an analysis of Southern California groundwater governance. The example demonstrates the threats that path dependence poses to resource system stability, as well as the opportunities for institutional path dependence to solidify adaptive governance systems. The argument concludes with Section VIII, summarizing what the argument has accomplished as well as future routes for analytical development.

II. Analytical Framework

A. Fundamental Terms

Social-ecological systems (SESs) are conjoined institutional and ecological subsystems (Gallopín, 2007). In an SES, institutions and ecological processes are in mutual interaction, each changing in response to what the other is doing. The SES's *ecosystem,* the ecological component of an SES, contains several distinct *resource systems* (Ostrom & Cox, 2010, p. 6). A resource system is any natural system that produces a stock of resource units for human use. Examples of resource systems include fisheries, forests, and groundwater, each of which the SES beneficiaries use for consumable goods and services. When a resource system fails, beneficiaries of the resource system can no longer derive the services they once obtained from it.

Some ecosystems, such as a geological area, may be large enough to contain multiple resource systems of the same type that function semi-independently from each other. Each resource system may have different beneficiaries, even though the beneficiaries collectively exist within the same ecological system. For this reason, there may be distinct rules and organizations within an SES that regulate a specific resource system or type of resource system within the SES (Cleveland et al., 1997, p. 9).[1] For greater analytical clarity, I distinguish rules from organizations based on the resource system they govern, then focus on the ecological and institutional interaction within the SES.

Resource systems are composed of *attributes*, the physical elements that interact to produce a resource unit, including the resource units themselves. What distinguishes resource units among other attributes is that they are 1) a divisible portion of the resource, 2) appropriable from the resource system, and 3) usable by beneficiaries in the form of a service or good (E. Ostrom, 1990, p. 30). In a fishery system, for example, the weeds in which the fish hide are resource attributes. While they are divisible and appropriable, they are not usable by beneficiaries. In contrast, the fish in the resource system are resource units; one fish is distinct from others, they can be taken from the fishery, and are usable by beneficiaries.

On the institutional side of the SES, there are two types of positions relevant to my argument: appropriators and managers. *Appropriators* are beneficiaries—individuals or organizations—that withdraw resource units from a resource system. The *managers* of a resource system are individuals or organizations that perform non-appropriative activities to maintain the functions of the resource system. Activities assigned to managers include the maintenance resource system attributes, such as the controlled burn of a forest, or the introduction of additional attributes into the resource system, such as building and operating a dam on a river. Managers are not necessarily appropriators or even beneficiaries of the SES they help to sustain. It may be the case that a manager supplying managerial services to a resource system does not derive benefits from that resource system at all.

The terms ‘appropriator’ and ‘manager’ denote “positions” assigned to individuals in the SES’s institutional framework (E. Ostrom, 2005, p. 40). The term *institution* here refers to the rules that are the basis of decisions and actions taken by people in interaction with each other and the resource system (North, 1991, p. 97; 1990, p. 5; E. Ostrom, 2005, p. 180). The institutional arrangements consist not only of rules that govern appropriator and manager behavior but also of rules that define what positions there are, who is given what authority, how decisions are reached, and the process for changing rules.

In the analysis that follows, appropriators and managers are the primary positional focus since their decisions directly affect the behavior of resource systems. While sometimes managers and appropriators are the only positions defined in an SES’s institutions, this is not always the case. The institutions may also define arbitrators, monitors, information distributors, or a multitude of other roles that are not taken by managers or appropriators (E. Ostrom, 1990, p. 41). Similarly, there may be people who participate in a larger production process who help transform resource units into consumable goods for beneficiaries (V. Ostrom, Tiebout, & Warren, 1961, p. 834).

However, both alternative positions and production processes external to appropriation and management are outside the scope of SES path dependence analysis. None of them possess the same direct connection to resource system functioning and are presumed not to have a large effect on resource system behavior.

Both appropriation and management activities can be distinguished from governance. *Governance* is the process by which rules are formulated to define the constraints within which appropriators and managers can make decisions and act (Oakerson, 2004, p. 29). The fundamental question of governance in an SES's institutional framework is what occurs where. In this case, the 'what' is management, appropriation, and governance, and the 'where' is the forum where these activities take place. To address this question I draw upon the Institutional Analysis and Development (IAD) framework associated with the work of Vincent and Elinor Ostrom (E. Ostrom, 1990, 2005; V. Ostrom, 1994). IAD analytically divides an institutional system into three levels each with three components, as shown in Figure 1. Each level serves a distinct role in shaping the limitations and opportunities available to SES beneficiaries (E. Ostrom, 2005, p. 58). The components are 1) the rules that form the basis of decision making at that level, 2) the decision making that occurs within those

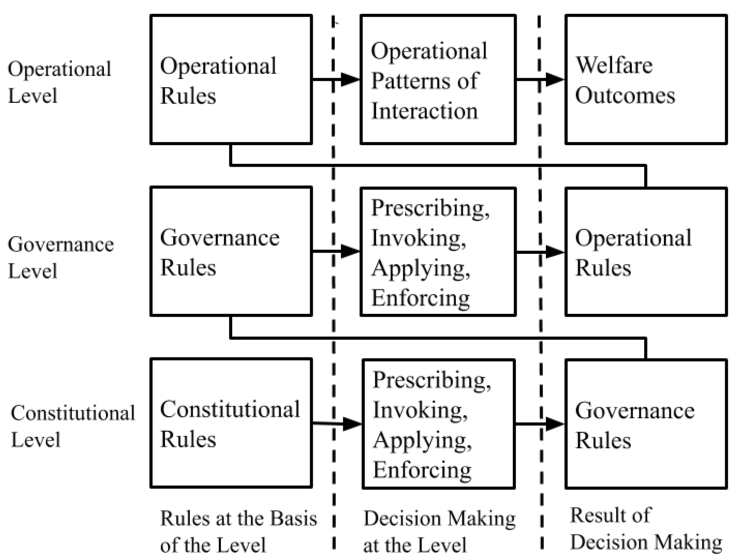

Figure 1: Diagram Showing Different Institutional Levels. Adapted from Oakerson and Walker (1997, Pg. 30).

rules, and 3) the outcome of the decision making. At the operational level, the outcome is the welfare of those who live within the system, while the outcomes of governance and constitutional levels are the rules that operate at other levels.

Day-to-day decisions and actions that directly affect attributes within an SES's resource system occur at the *operational level*, where managers and appropriators interact with resource attributes (2005, p. 60). Operational decisions occur within a set of operational rules, which specify what individuals may, must, and what must not do (E. Ostrom, 2005, p. 142). In the context of an SES, operational rules define how many resource units may be extracted over a period of time and the actions that may or must be undertaken by managers to facilitate a resource system's renewal and maintenance (E. Ostrom, 1990, p. 52). These rules can involve just a few or many different individuals and organizations in various institutional positions working together to reach a collective objective (Oakerson, 1994). The rules at the operational level form the framework in which social norms and individual strategies take shape among appropriators and managers and determine how they perform their tasks within the resource system (E. Ostrom, 2005, p. 156).

Operational rules emerge from the *governance level* of the institutional framework (Oakerson, 1994).[2] The governance level regulates actions taken by the operational level by prescribing rules, invoking rules (i.e., citing a rule and asking for its application), applying general rules to the specific case, and enforcing operational rules by using sanctions (Oakerson & Walker, 1997, p. 30; E. Ostrom, 2005, p. 60). The resource system reacts to changes made at the governance level through the resulting alterations in actions taken at the operational level of the institutional system. There may be multiple governance forums for making decisions about operational rules, depending on the institutional configuration (E. Ostrom, 1990, p. 54).

Decision-making at the governance level is also rule-based, shaped by governance rules prescribed, invoked, applied, and enforced at the *constitutional* level (E. Ostrom, 2005, p. 61). Constitutional rules underlie decision-making at all levels by specifying who uses rules within what limits (2005, p. 58). They are also the most difficult rules to change, since the rules for constitutional modification usually pose a high bar for alternation, such as near unanimity in agreement (2005, p. 58). This can be the benefit of the institutional system; by being inflexible to temporary political shifts, constitutional rules reduce uncertainty by creating a “stability in mutual expectations” (2005, p. 58). In other words, individuals interacting with each other and with the resource system can make decisions based on the assumption that constitutional rules will largely remain constant.

Together, operational, governance, and constitutional rules form the three levels for institutional decision making and action. People develop operational rules at the governance level through discussing changes in the resource system’s condition (Decaro et al., 2017; Koontz, Gupta, Mudliar, & Ranjan, 2015). Governance level rules are developed at the constitutional level as individuals use powers given to them within the limits of the constitutional rules. Through patterns of interaction and institutional modification, resource systems within the SES may develop a distinctive set of constitutional and governance rules, even across systems that produce identical resource units. Constitutional decision-making can shape long-term patterns of institutional development and resource history from structuring these activities.

In respect to a resource system, rules can also aim to place some resource attributes out of the reach of appropriation and management activity to the point that they become effectively invisible to appropriators and managers. Examples include sacred forests exempt from cutting (Sheridan, 2009), water sources in a managers risk portfolio (Wolff, 2008, p. 101), species protected under the Endangered Species Act, and the rights given to resource systems at the constitutional level (Weger et al., 2019, p. 8). In each of these cases, the constitutional or governance rules of an SES enable or disable the possible actions of individuals or organizations within the SES's ecosystem. Dams will or will not be built, forests will or will not be logged, therefore creating boundaries for innovative appropriators and managers. The implications of rules for resource system development points to a larger fact of institutions within SESs: whether a resource attribute may or may not be manipulated under the current rules guides operational level norms and strategies. If these rules cannot be changed at the governance level due to constitutional constraints, the resulting institutional development may be determined by these provisions (V. Ostrom et al., 1961, p. 837).

However, rules are not the only source of constraint facing decision makers. In fact, rules are relatively soft restrictions on appropriator and manager actions, since they can be and sometimes are ignored. In contrast to rules, physical attributes pose hard constraints that cannot be ignored without consequence. Decision makers at the governance and constitutional levels therefore take account of resource constraints in formulating rules (Cleveland et al., 1997, p. 21).

Within the resource system, this inquiry is primarily interested in the emergence of new *physical* constraints, through the actions or inactions of appropriators and managers, and the consequences of those physical constraints for institutional development within the SES. In such a system, development occurs over time as manager and appropriator operations alter how the resource systems function within the ecosystem (Berkes, Folke, & Colding, 1998, p. 21). Shifts in a resource system's behavior are precipitated by changes in the resource system's attributes. Since changes in system attributes can affect how the resource system and the ecosystem functions, these events change the opportunities available in institutional operation and governance (Anderies, Janssen, & Ostrom, 2004). Poorly functioning SESs are characterized by a loss in attributes across resource systems, leaving institutions unable to provide for beneficiaries outside of a few services. This situation can be the result of natural disasters that destroy the productive relationships between attributes or the result of institutional structures that promote ecosystem destruction.

Over time, institutional analysts have examined what factors come together to create long-enduring SESs. One of their findings is that there is a dynamic relationship between institutional practices and resource systems to the point where they interlock to create mutual dependence (Berkes et al., 1998, Chapter 1). Governance and constitutional level institutions in these systems offer flexibility to managers and appropriators to create and change the operational level rules (Armitage, 2008, p. 16). Developing knowledge about the ecosystem's resource systems, creating institutional levels to adapt to changing conditions, and fostering absorption capabilities of resource systems to internal and external shocks—all have been attributed to enduring SESs (Berkes et al., 1998, p. 21).

While the study of SESs has been progressing among IAD institutionalists, historical institutional (HI) analysis has developed its own theories of institutional change. Within HI, the goal of historical inquiry is to plot the course of politics across time and identify the conditions required for change (Steinmo, 2008, p. 164). Several different theories of institutional change have emerged out of HI, such as gradual changes in governance (Mahoney & Thelen, 2010), to 'critical junctures' where a crisis leads to an institutional innovation (Hogan, 2006; Schmidt, 2010). Both approaches mentioned here share a similar thesis: institutions change over time as people within those institutions find opportunities to alter or reorient those institutions (Pierson, 2004, p. 155). Patterns of institutional development may lead to the solidification of an institutional system that is not easily altered, either because of the political cost or the established relationships between people (Pierson, 2004, pp. 145, 147). In other words, the configuration has become *path dependent*. Path dependence has been traditionally defined as the long-term effects that decisions have on the future development and efficiency of institutions and technologies (Liebowitz & Margolis, 1995)—in short, how past decisions constrain future decisions.

The strain of HI analysis that is explored in-depth in this argument is called punctuated equilibrium theory. Punctuated equilibrium develops when multiple structural (*not* analytical) levels of decision making, such as those found in a federal system, and the behavior of decision makers at each structural level create an institutional system characterized by long periods of stability punctuated by political mobilization emerging from lower to higher levels (Baumgartner & Jones, 1993; True, Jones, & Baumgartner, 1999, p. 156). In this theory, the structural levels are broadly defined as governance *subsystems* connected to a *macropolitical* system, with issues in a subsystem emerging to creating large-scale changes in the institutional landscape (Baumgartner & Jones, 1993;

Redford, 1969). Like most institutional HI theories, the focus in punctuated equilibrium is on the method by which institutional innovation is propagated from the subsystem outward. While this means that the focus is mostly on legislatures and committees (Baumgartner & Jones, 1993; Jones, Sulkin, & Larsen, 2003; True et al., 1999; Zittoun & Peters, 2016, Chapter 6), the methods are also presumed to apply to court systems through the use of precedent (Hathaway, 2003). Punctuated equilibrium theory has also been applied to natural resource management and locked-in resource management practices (see Wood, 2006).

With a theory of institutional path dependence in front of them, institutional analysts studying SESs come across a conundrum in understanding changes in institutional-ecological relationships. On the one hand, they are presented with a theory of institutional-ecological relationships where stakeholders develop institutions based on the characteristics of resource units and the resource system. On the other hand, they are presented with a theory of institutional development where individuals and organizations change their institutions in reaction to other institutions changing around them. Neither theory seems to capture changes in SESs with diverse stakeholders or interlocked resource systems. For example, classic cases of successful institutional development, such as decentralized groundwater governance in Southern California (Blomquist, 1992; Green, 2007; E. Ostrom, 1990), cannot be easily categorized either as cases of developing relationships operational rules and resource systems or of a process of institutional proliferation. Neither alone can explain the system's continued flexibility toward changing strategies for management, or its remarkable durability in the face of calls to consolidate it (Erie & Joassart-Marcelli, 2005; Green, 2007). A theory of SES path dependence must be able to explain how these phenomena can coexist.

To begin this task, in the next subsection I make a deeper examination of resource systems and how they change in response to physical constraints and governance rules. From there, I go on to expand the three institutional levels of the IAD framework and its relationship to institutional path dependence as posited by HI. I then merge the resource system analysis with the theory of institutional change to create a comprehensive picture of the institutional forces within an SES and thus bring analysts closer to a theory of SES path dependence.

B. Previous Approaches to Resource System Change

1. Resilience Theory

Among existing institutional analysis concepts, ecosystem resilience comes closest to describing long-term SES behavior patterns. *Resilience* in human ecology refers to the extent to which an ecosystem can absorb human impacts before the system shifts into an alternative state (Holling, 1973, p. 14). In resilience theory, ecosystems can have multiple distinct equilibrium states. Equilibrium occurs when system attributes maintain a constant relationship with each other within their resource systems while providing a respective resource unit or service (Holling, 1996). SESs with high ecological

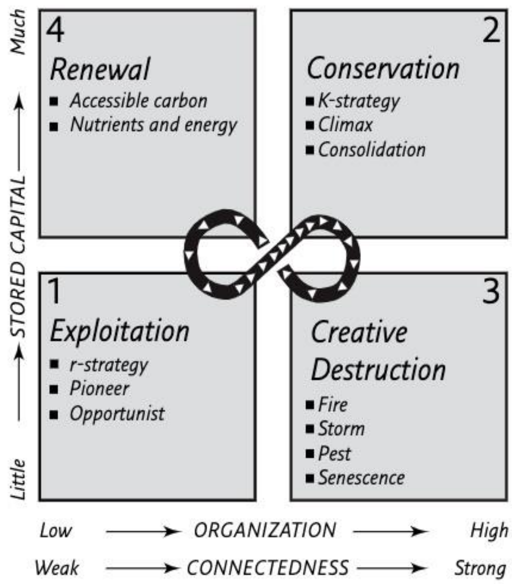

Figure 2: The Adaptive Cycle. Adapted from Holling (1986)

resilience will, in the event of a disturbance, maintain their attributes and processes that control system behavior. Systems with low resilience, in contrast, will experience a change in attributes and processes as a result of the event (Folke et al., 2004, p. 567). Resilience increases with a greater diversity of key structuring attributes that drive resource system processes (Holling, 1973; Walker, 1992). SES beneficiaries can create institutions that affect their ecosystem's behavior by managing attributes, either altering or eliminating them (Folke et al., 2002). These operations in effect manage an ecosystem's resilience.

When manager and appropriator operations are successful, their actions keep the ecosystem and other resource systems from moving into a different or sub-optimal stable state (Berkes, 2009, p. 1693). Resilience theory has developed tools to explain long-term SES behavior based on management actions, most importantly the adaptive cycle model. An adaptive cycle is an infinite loop of resource system phases of exploitation, conservation, destruction and renewal (Holling, 1986, p. 95). In Holling's adaptive cycle model, "how long an inappropriate policy is successful depends on how slowly the ecosystem evolves to the point when the increasing fragility is perceived as a surprise and potential crisis." (Holling, Allen, & Gunderson, 2009, p. 102). Different points in the cycle correspond to varying degrees of resilience. The resilience of a resource system is expected to decrease from exploitation to conservation and increase from creative destruction to renewal (Gunderson & Holling, 2001, pp. 6–8). The relationship can be seen in Figure 2, where the system becomes more interconnected as cycle moves from exploitation to conservation, and then becomes looser as it moves from destruction to renewal.

Separate adaptive cycle models can be interlinked to demonstrate system processes occurring at different temporal and spatial scales, with faster adaptive cycles occurring at smaller scales and slower cycles taking place at larger scales. The total interlinked system is called a “panarchy” and can explain patterns of resource renewal and collapse by referring to processes occurring at different scales (Gunderson & Holling, 2001). Resource managers and appropriators develop knowledge about the overall system through interacting with it, and decision makers at multiple levels create institutions and management strategies according to the placement of the process in the panarchic scale (Berkes et al., 1998, p. 19). An adaptive cycle therefore demonstrates that a well-functioning SES reflects the mutual adaptation of institutions and the resource systems to balance the preservation of functions with requirements for stability. The model of an adaptive cycle can then demonstrate the mechanisms for ecological and institutional adaptation at multiple levels of time and space.

In comparison to IAD, a panarchy can present an SES model where the historical events in a resource system’s history are connected to its current performance. However, the panarchy model itself cannot be straightforwardly integrated into the current understanding of institutions. The concept is inhibited by its vagueness, and while this makes it useful for its application to multiple circumstances, there is no agreed-upon analytical method for examining how a panarchy works. An analyst looking at an SES may be able to identify how certain institutional events fit into an adaptive cycle. However, it is very difficult to find the corresponding panarchic level it fits into, or its placement in overall resource history. Specificity is important to consider since analysts can then describe the integration of manager and appropriator operations into resource system processes.

2. IAD and Resource Dynamics

A similar critique applies to IAD, which has developed a broad and robust institutional language that can be as easily applied to a metropolitan area as to rural developing communities (Oakerson, 1992; Cox, n.d.; McGinnis, 1999; E. Ostrom, 1990, 2005). The breadth of the framework is made more impressive by its significant depth, deriving empirically testable principles for institutional design (E. Ostrom, 1990, p. 90) as well as testing within the field of game theory and across multiple cultural traditions (E. Ostrom, 2005, Chapter 8; E. Ostrom, Gardner, & Walker, 1994). The IAD framework, as seen in Figure 3, offers a method to examine institutional interactions and outcomes qualitatively and quantitatively, with the primary focus being on the action situation (Oakerson, 1992; E. Ostrom, 2005, p. 33). A sister SES framework has also been developed with the

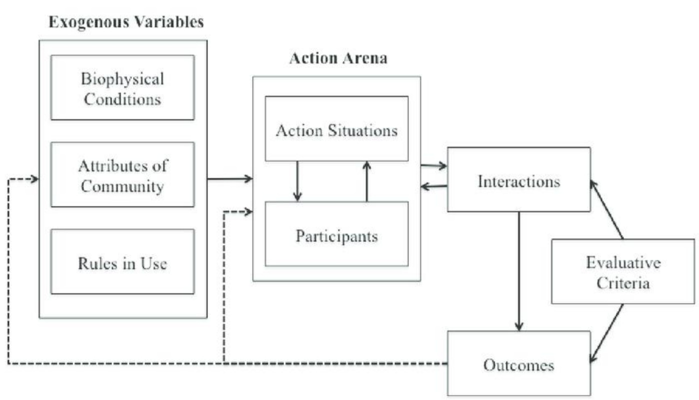

Figure 3: The IAD Framework. Adapted from Ostrom (2005)

assistance of ecologists, who are able to take into account more specific aspects of the resource system and the institutional structure (Hinkel, Cox, Schlüter, & Binder, 2015; McGinnis, 2010; E. Ostrom, 2007).

In cases of resource system change, I argue that action situations are better thought of as spaces in flux, where resource attributes change, and people respond to those changes. When an IAD analyst approaches an SES, they most often describe it in terms of *forums* at the governance and constitutional levels*, action arenas* at the operational level. Forums are where the action situation takes place and specify what rules apply to those within the forum, thereby affecting the outcome of the level. At the operational level, the resource system forms the action arena and is occupied by different people (called participants) in positions defined by the operational rules, in this case appropriators and managers (E. Ostrom, 2005). Unlike in a forum, the action arena does not presume that appropriators and managers are directly interacting with each other through communication or agreements. Instead, they are merely following the operational rules, interacting with each other indirectly through resource attributes.

Resource units and attributes are outside the analyst's field of vision, for the most part assumed to exist outside of the arena until appropriated, introduced, or managed by people within the forum. However, this model is too limited, as is seen in adaptive management practices, where managers and appropriators react to changes in resource system behavior (Folke et al., 2004, p. 574; Walters, 1986). An example of resource units being integrated into rule choice is seen in Section VII, where the decreasing stock of water resource units leads groundwater pumpers to basin adjudication (E. Ostrom, 1990, p. 152). In some contexts, the reaction of an attribute to an operational rule or their absence from an arena may be as important as those actions taken by people for long-term institutional development. Taking this approach may allow analysts to think of institutions as being more dynamic than static, adapting to changes in resource systems.

The tendency in institutional analysis to keep ecology and institutions distinct from each other gets to a broader point about how SES governance is examined. Maintaining the analytical separation between ecological and institutional forces may mean that analysts are left with a gap of understanding between changes in the resource system and institutional development. To create a cohesive vision of an SES, changes in resource attributes need to be thought of as playing an ongoing role in management and governance. Since the diversity and characteristics of resource attributes determine the range of institutional configurations that can be created by managers and appropriators, any analysis of SES change needs to articulate attribute loss in the context of institutional development. Therefore, it will take a deeper elaboration of the adaptive cycle model and principles of institutional analysis to examine the effect that historical factors have on current resource system use.

C. Looking Toward Path Dependence

Path dependence may offer a framework to understand the connection between resource systems and institutional processes. *Path dependence* is defined as any process where initial decisions about a good or system have long term effects on the development of the good or system (Jones, 1994, p. 52; Pierson, 2000a, p. 252). In this definition, path dependence can apply to several different processes, each with different causes. The first of these is *positive feedback*, i.e., the good or institution gets easier to use and cheaper to access as it is popularized (Arthur, 1994, p. 2).[3] The idea that path dependence could emerge through positive feedback grew out economic theory and was the first focus for research on path dependence (Arthur, 1989, 1994; David, 1985). The most common subject for path dependence analysis is technology adoption, such as in the now-famous studies on QWERTY keyboards (see David, 1985).

From a perspective of increasing returns, a use of an institution is analogous to adoption of an economic good. In political science, increasing returns based on patterns of use are assumed to occur as they ease decision-making processes and become increasingly efficient the more they are adopted (Hathaway, 2003) or as political bodies are coordinated (Pierson, 2000a). These institutional shifts not only lead to what is considered a more efficient outcome but also have implications on how easy they are to change. The more an institution is used and relied upon, the costs to switching to an alternative also rise, meaning that the status quo may continue to be pursued even after it results in negative outcomes (Pierson, 2004, p. 147). Thus, path dependence is not just an examination of an outcome based on decisions made within an institutional structure. It is an outcome that has unique properties in terms of the institutional costs to reach it as well as the costs to change it.

I argue that path dependence should factor into the analysis of an SES. Since the evolutionary paths of institutional development are important for understanding an institutional system's current constraints, examining past resource system decisions are important for understanding current system outcomes (Pierson, 2000a, p. 251). Though grounded in economic theory, path dependence is still a notoriously "blurry" concept in the social sciences (Vergne & Durand, 2010, p. 737). While it is recognized by researchers as being vital to understanding institutional development, some areas have not established a firm empirical basis for it. It thus remains outside the scope of my argument to formulate an empirical methodology for determining path dependent behavior in the context of SES systems. Instead, the argument's aim is to explore avenues for the development of an SES-focused path dependence analysis using widely reviewed case studies in the academic literature.[4] The concepts introduced here are applied to SES path dependence in Section VII of this paper.

III. Adapting CPR Theory

IAD offers an important conceptual tool for analyzing a widely observed type of resource system: the common pool resource (CPR) (E. Ostrom, 1990). CPRs are resource systems shared by several appropriators where a resource unit drawn from the system cannot be appropriated by someone else. As appropriators compete with each other over scarce resource units, they run the risk of resource system depletion and collapse (Hardin, 1968). The possibly irreversible damage of appropriator and manger action creates the basis for institutional outcomes seen in SES path dependence analysis.

CPR theory is expansive, and it falls outside of the scope of my argument to examine all its facets. It is essential, however, for understanding of how resource systems relate to institutional systems within an SES. In typical SES analysis, and in path dependence analysis as presented here, the resource system being analyzed is presumed to be a CPR (Berkes et al., 1998; Berkes, 2009; E. Ostrom & Cox, 2010). While this may not always be the case (due to the different kinds of resource systems that may exist in an ecosystem), the subjection of CPRs to irreversible change make them a good place to begin the formation of an SES path dependence analysis. Their vulnerability creates the possibility for a clear break with the past, and with it the incentive for appropriators and managers to prevent it.

A. Excludability and Subtractability: Traditional Perspectives

Two descriptive categories are essential for assessing CPRs: excludability and subtractability (E. Ostrom, 1990, p. 31–32). By definition, a CPR exists when a resource system exhibits low excludability and high subtractability.

Excludability refers to the degree to which appropriators can be prevented or inhibited from accessing the resource system (1990, p. 32). Resource systems with high excludability have physical features that limit the number of appropriators, such as a fenced-in grazing land or a small pond that can be easily enclosed or monitored. Resource systems with low excludability lack such features, such as unfenced pasture or a large lake with many access points.

Subtractability has been traditionally defined as a sort of stock reduction. Stocks are composed of resource units produced by the resource system (E. Ostrom, 1990, p. 3). A resource unit is a consumable good, such as fish, timber, or a flow of water. Resource systems with high subtractability have stocks that are depleted by unit appropriation. For example, lakes and savannahs have stocks of water and grass, respectively, which are reduced through appropriator activity. On the other hand, low subtractability resource systems can have multiple users jointly using a unit in a resource system's stock. For example, sunlight and radio airwaves are resource systems where a unit from the stock can be used by two different users at the same time while not diminishing from each other's enjoyment. Resource systems are considered more or less renewable in terms of the replenishment rate of the stock as compared to the flow rate of units from the resource system to appropriators.

B. Focusing on Subtractability

Resource systems that have low excludability must be shared by multiple appropriators, which can be difficult for maintaining high-subtractability resource systems (E. Ostrom, 1990, p. 30). In the traditional definition subtractability focuses on the relationship of a resource unit stock to appropriators (E. Ostrom, 1990, p. 31). Resource units in this conception tend to resemble products coming off an assembly line, where the product is a residual of the production process and not integral to the production process itself. However, viewing resource units as entirely separate from the resource system fails to grasp the central issue of commons analysis: the appropriation of resource units to the point of system failure.

To analyze CPRs and understand system failure, the appropriation of a unit needs to be considered in reference to two different phenomena: one is the resource unit as an appropriable good, the other as an element of a resource system's production process. Recognizing the relationship between resource units and resource systems prompts me to modify the concept of subtractability to distinguish between a subtractive effect among appropriators and a subtractive effect, not only on the resource unit stock, but also on the ability of the resource system to reproduce resource units. The dynamics that define the unit-appropriator relationship, referred to here as "instance use," and the unit-resource system relationship, here called "depletion use," are distinct but interconnected.

Instance use refers to the degree to which the resource unit is appropriable at a single point in time by a single appropriator. Subtractability in this sense is observed by looking at the consequences of a unit's subtraction for other appropriators. What an appropriator takes cannot be taken by another. Resource systems with high instance-use subtractability have *a rate of appropriation dependent on the number of appropriators*. For example, eating an apple supplied by an apple tree inherently deprives another from eating the same apple, displaying high subtractability in respect to instance use. In contrast, resources with units that have low (or even zero) instance-use subtractability have *a rate of appropriation independent of the number of appropriators*. One person watching television, for example, does not keep the airwaves from another person watching the same program, demonstrating zero subtractability in respect to instance use.

The second component of subtractability is the relationship of the resource unit's appropriation or extraction to the resource system, here called *depletion use*. Depletion use is defined as the marginal impact on the resource stock *plus* the impact on the resource system to reproduce after appropriation. Low depletion-use subtractability is characterized *by the rate of depletion that is less dependent on appropriation* given the remaining supply and the rate of renewal. Applied to the TV example, the use of airwaves now by the TV watcher will not reduce the station's ability to produce more tomorrow, indicating low depletion-use subtractability. When applied to the apple tree, however, picking an apple does not limit the tree's ability to produce apples in the future, although it reduces the remaining stock of apples on the tree for the short term. In other words, the rate of apple depletion is balanced by the resource's renewal. A high depletion-use subtractability system would be typified by *a rate of depletion (and replenishment) much more dependent on appropriation*. For example, an oil well has a rate of depletion entirely dependent on appropriation (with zero replenishment).

The stock and reproduction features of a resource system that together determine a depletion rate can be isolated from each other. This can result in new depletion-rate characteristics for the resource system. A resource system that displays low depletion-use at one point in time can become a high depletion-use resource due to natural or anthropocentric processes. An example, one that is further elaborated below, is the prevention of water inflow in a groundwater basin as the land above it is paved over. As water is kept from infiltrating the basin, the rate of replenishment declines and results in the depletion rate from appropriation exceeding renewal. In other words, while the rate of depletion can at one point be independent of the rate of appropriation, it can become dependent on appropriation after resource system attributes are altered.

	High Depletion	Low Depletion
High Instance Use	Non-renewable (Oil)	Renewable Resource (Oxygen in the atmosphere)
Low Instance Use	Group Resource (Light from a Battery)	Universal Resource (Sunlight)

Figure 4: Resource Subtractability In Terms of Instance Use and Depletion Use. Source: Author.

Figure 4 displays the possible combinations of instance and depletion use. Resources with high depletion use and high instance use are considered non-renewable resource systems. Renewable resources in contrast have high instance use and low depletion use. Universal resources have low depletion use and low instance use, while group resources have high depletion use but low instance use.

Based on the above argument, traditional subtractability can be considered a matter of degree (Oakerson, 1992, p. 44). In resource depletion terms, some resource unit extractions are more subtractive than others. The appropriators of potentially high depletion resource systems deplete their resource stocks faster than the appropriators of low depletion resource systems, even though both resources may have similar instance-use profiles. For example, an apple orchard and a fishery, both CPRs, are identical in respect to instance use. At a point in time, they may also both be renewable resources. However, they can potentially become different from each other in respect to depletion use. The appropriation of fish can affect the depletion rate as the stock fails to reproduce, changing it to a non-renewable resource. In contrast, appropriating apples from an orchard is unlikely to affect the reproduction of apples. The ability of a resource system to shift from renewable to non-renewable status points to the effect that current appropriation has on future appropriation. Depletion and instance use therefore frame resource systems as subtractive not only among the current appropriators but future appropriators as well.

IV. Remodeling Resource Systems

To better distinguish instance use and depletion use, a conceptual framework for analyzing resource systems needs to be established. Without such grounding, it would be difficult to conceptualize the disintegration of resource systems from resource stock appropriation, or the interconnected nature of resource systems within ecosystems. Such a characterization is constructed here using the research of Holling (2001; 1973) and other related work on ecological resilience.

A. Resource Attributes

Resource system attributes are the elements that interact to form the resource system (Folke, Holling, & Perrings, 1996).[5] The number of attributes contributes to the wealth of the resource system, which can be drawn upon to maintain resource system functions and keep the system resilient (Holling, 2001, p. 394). Resource system attributes can fall within two different categories. *Endemic attributes* are attributes native to the system that produce the resource units.[6] *Introduced attributes* are foreign to the resource system but interact with other attributes to affect resource unit production. What is and is not considered an endemic or introduced attribute is a subject of much debate in fields such as ecosystem rehabilitation (Allison, 2017, Chapter 5). For the purpose of this discussion, attributes are considered to be introduced if they entered a resource system after the exploitation phase and before the collapse phase of the adaptive cycle. Introduced attributes can include physical structures constructed by resource system managers, as well as attributes endemic to other resource systems that have been introduced into the resource system. Toxic chemical elements found in Southern California water tables discussed in Section VII, which subsequently alter groundwater quality, exemplify an introduced element (Green, 2007).

Attributes can possess *durability*, i.e., an ability to be passed through multiple resource iterations of a resource system's development and collapse. A highly durable attribute remains during resource system collapse (Gunderson & Holling, 2001, p. 8). There can be several factors that determine the durability of an attribute, such as the independence of the attribute from other resource system processes, having longer time scales for degradation, or having a massive quantity. A fragile attribute, in contrast, is highly dependent on internal resource system processes to be replenished, has a short time scale for degradation, or exists in a relatively small quantity. Depending on how durable attributes structure the resource system, the collapse of a single attribute may lead to the collapse of the entire system.

B. Functional Groups

Resource attributes form functional groups that perform similar functions within the resource system (Cleland, 2011). Diverse sets of attributes performing similar functions ensure that the resource system can respond to changes and provide appropriable units despite fluctuations in ecosystem or resource system conditions (Elmqvist et al., 2003, p. 490).

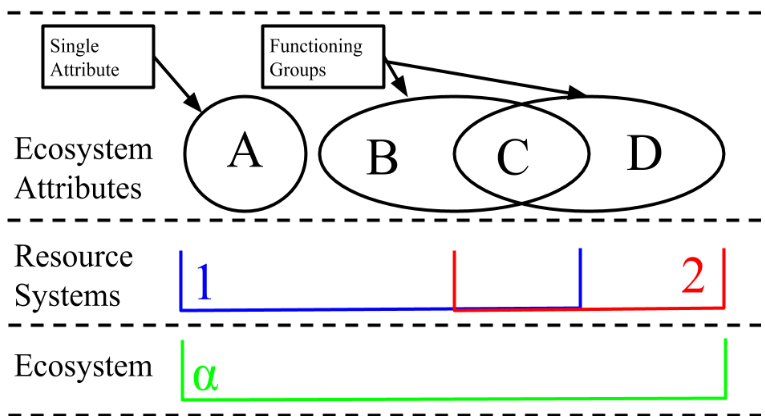

Figure 5: Example of the Relationship Between Attributes, Functional Groups, Resource Systems and the Ecosystem. Source: Author.

Even as these destructive events may reduce or eliminate certain attributes, the system can compensate by drawing on rich sets of redundant attribute configurations. In short, diversity begets redundancy, so that, as attributes degrade or reconfigure, resource system output remains consistent (Peterson et al., 1998, p. 14).[7]

C. Resource Systems and Ecosystems

Attributes can be shared among several resource systems within an ecosystem since each can be a part of different functioning groups that produce a resource unit. The shared attributes, in turn, are configured into distinct processes in the different functioning groups that compose resource systems. The overlap in key structuring attributes and mutual reinforcement are what give a resource system *resilience* (Peterson et al., 1998, p. 13). In ecology, these shared structuring attributes are referred to as ecosystem drivers (Walker, 1992, p. 20). Ecosystem drivers give physical structure to the resource system, i.e., drivers have strong interactions with other attributes that allow the ecosystem to function (1992, p. 20). In turn, these attributes promote key resource system processes that provide ecosystem services across time and spatial scales (C. S. Holling, 1992). A diverse number of driver attributes provide greater stability to their resource system and create a mutually reinforcing mechanism to keep the system in its current state (Elmqvist et al., 2003, p. 488). Based on the number of driver attributes in the same functional group, resource systems can flip into alternative, less productive, stable states as resource attributes are lost and resilience decreases (Folke et al., 2004, p. 573). Alternatively, since resource system processes are based on specific attributes, variations in those attributes can determine outputs or the development of the system.

D. Attributes and Subtractability

Resource system governance in this framework facilitates two operations with respect to the resource system: the collective actions of appropriators (e.g., coordination of appropriation and collective observance of appropriation limits) and the maintenance of structuring attributes by managers. Both actions occur in the context of the excludability conditions and instance-use subtractability conditions of the resource system, such as in a CPR. Within these conditions, the goal of renewable resource governance is to use institutional mechanisms to prevent the shift of a resource system from low depletion use to high depletion use. Management and appropriation activities should therefore seek to maintain the resource system, adapting institutional arrangements to account for changes in the system or the needs of stakeholders (V. Ostrom & E. Ostrom, 1977). From this perspective, resource system managers are focused on maintaining the durability of attributes and ecosystem drivers. The institutions formed are therefore not just for organizing appropriators, but for holistically maintaining the resource system as well.

E. Applying the Adaptive Cycle Model to Subtractability

An adaptive cycle can be used to represent resource system decline due to resource unit loss. As the number of attributes in a functional group decreases, the system's stability declines as well (Folke et al., 1996, p. 1019). Applied to the adaptive cycle model presented in Figure 2, systems in the r phase of development have built-in redundancy due to a proliferation of diverse functional groupings of attributes that produce similar self-maintaining processes. Redundancy is lost over time as the system moves from the r to k phase. Shorter timescale attributes are pushed out by attributes with greater longevity as well as by over-appropriation (Holling, 1986, p. 96). As the system becomes more reliant on attributes that have longer lifespans and are slow to replenish, the system gradually loses the attribute diversity that supports resource system processes. The resource system's stability is subsequently more susceptible to disturbances, increasing the likelihood of resource system degradation or collapse (Holling, 1986, p. 96). Therefore, resource managers need to maintain significant redundancy in a functioning group to sustain the production of resource units (Folke, Holling, & Perrings, 1996).

1. Attribute Loss from External System Collapse

Attribute loss to the point of collapse is associated with two different situations. The first is the disruption of large-scale adaptive cycles that support smaller cycles (C. S. Holling, 2001, p. 398). Since large time and spatial scale processes create a foundation for the faster and smaller systems, disruptions in the slower cycle are likely to modify resource system attributes at lower levels (2001, p. 398). Attribute loss at lower levels reduces resilience within the system. In terms of resource unit production, such changes can destroy the connections between a resource system's attributes that produce resource units. Smaller cycles can, as a result, become completely reorganized due to the destruction of a slower adaptive cycle (Scheffer, Carpenter, Foley, Folke, & Walker, 2001).[8] The loss of attributes in these cases is considered external to the resource system and possibly the ecosystem.[9]

2. Gradual Attribute Loss

The second way that system change can occur is through a gradual loss of attributes that leads to decreasing diversity in functioning groups (Folke et al., 2004, p. 570). In these cases, the outcomes of appropriator and management decisions allow the resource system to become increasingly vulnerable to changes in the higher cycles in the panarchy, and, in other words, lose resilience (C. S. Holling, 2001, p. 399). Unlike the stochastic change in a higher panarchic level leading to a loss in attribute diversity, the loss of resilience in a system is due to the collapse of a single cycle. In these cases, it can be possible that the large scale cycle will remain unaffected until a number of lower cycles fail and begin a shift in the larger spatial scale (Holling, 2001, p. 398; Rietkerk, Dekker, Ruiter, & Koppel, 2004, p. 1928).

Both attribute loss scenarios have common characteristics, the first being that system processes are developed out of hysteresis. In processes characterized by hysteresis, it is not possible to go back to the ecosystem's initial state by simply reversing the actions taken by actors to achieve the current state (Mäler, 2000). Hysteresis can solidify changes in the relationship between resource units and the resource system. For example, in the case of externally-based system collapse, management or appropriation activity collapses the underlying adaptive cycle so that the system undergoes a rapid, catastrophic and irreversible change (Scheffer et al., 2001). Similarly, in the internal collapse model a system change can occur as an effect of over-appropriating a resource unit to the point where the resource system can no longer recover (Folke et al., 2004, p. 568).

3. Role of Governance in Resource Unit Production

Within an institutional framework, governance rules have an indirect influence on the condition of the resource system and the welfare of beneficiaries. As seen in Section II, governance rules form the basic rules for decisions made at the governance level. The governance level prescribes, invokes, applies and enforces operational rules within the limits of the governance rules. Those operational rules structure appropriator and manager behavior by enabling and constraining the actions taken within the resource system. Since operational rules are the outcome of the governance level, governance rules indirectly influence the creation, alteration and use of operational rules. In other words, what can and cannot be done under the governance rules indirectly affect what is possible for appropriators and managers to do within the resource system, as well as the ability of the operational rules to adapt to changing resource system conditions.

The analysis assumes that the organizers of governance forums in an SES create institutions for each resource system within the ecosystem (Cleveland et al., 1997, p. 8). The system of nested institutional subsystems that govern resource systems creates the lower structural level of the SES's institutional framework, while some governance and constitutional rules pertain to the entire ecosystem at the macropolitical level (Cleveland et al., 1997, p. 9). Since different resources have different needs for appropriation and management, resource systems are governed to some extent independently of each other by unique systems of operational rules and possibly governance rules. The role of the governance level is to allow beneficiaries to choose how to alter institutional systems for their resource systems in relationship to system performance.

Governance rules can affect the formation of operational rules in several ways, three of which are explored here. First, governance rules can enable or restrain the ability of appropriators and managers to obtain changes to operational rules. Since governance rules restrain who can prescribe operational rules within the institutional system, they either act as a barrier or a gateway for appropriators and managers seeking operational change. For example, a governance rule may allow anyone who is an appropriator within the resource system to propose a new rule for managing the resource system. Within the analytical distinctions among levels of rules, the governance rules may allow for appropriators to create operational rules. Appropriators are the decision-makers at the governance level. Therefore, to some extent the resource system is self-governing. An institutional system like this would allow people acting at the operational level the ability to change the rules they operate under. An example of a governance level rule that constrains the appropriator's ability to alter operational rules would be one that asks them to appoint an independent third party to assess the resource system before operational rules can be changed. While appropriators have the ability to appoint an individual to act on their behalf, they do not then have a direct ability to change operational rules.

Second, governance rules (determined at the constitutional level) can constrain the substance of operational rules otherwise determined at the governance level, thus constitutionally precluding some resource attributes from being manipulated by managers or appropriators. A part of the governance level's ability to manage a resource system through operational rules lies in the interrelationship of resource attributes within their functional groups. Since renewable resource systems can have multiple different attributes in the same functional group, they can have similar appropriative properties as well and can to some extent be appropriated interchangeably (Holling et al., 2009, p. 57). The possibility for interchangeability can be a benefit in the context of the adaptive cycle model of resource system change. Recall that the redundancy of attributes in a resource system allows it to function even as a single resource attribute is diminished (Walker, 1992, p. 20). Dynamics in the ecosystem or other systems external to the SES can therefore be used to replenish resource attributes by managers based on the attribute's requirements for existence within the resource system.[10] Governance rules that constrain operational rules from including a wide range of resource attributes may affect the progression of the adaptive cycle by foregoing opportunities to replenish lost resource attributes. Alternatively, the ability of governance rules to constrain certain resource attributes from being appropriated may work for the system's benefit by preventing attribute loss.

A third related role for governance rules in maintaining a resource system is by allowing for institutional change to correspond to changing resource system dynamics. Governance rules may allow for information about the resource system to be integrated into operational rules at the governance level. For example, in some cases governance level forums provide opportunities for appropriators and managers to examine what attributes are present in the resource system after appropriation and management activity

(E. Ostrom, 2005, p. 206). In this context, a system's progress toward collapse can be assessed within the governance forum to see if the resource has already crossed a threshold taking it closer to a negative outcome (Folke et al., 2002, p. 440). Resource attribute quantity and diversity can therefore inform governance level decision-making in altering operational rules to best serve resource system resilience.

Examples of attribute-governance relationships can be expanded upon to include more advanced integrations, such as modeling or the introduction of new technology that changes resource system dynamics (Inland Empire Utilities Agency, 2019). However, over the course of my argument I will primarily focus on the three mentioned here. As actions under operational rules are undertaken across different resource systems, institutions can prevent damage to any one resource system and keep the overall ecosystem stable (Cleveland et al., 1997, p. 9). How to examine these institutional structures in the context of resource systems is the focus of Section V on SES institutions.

V. SES Institutions

Now that the concepts of CPR's and resource systems are sufficiently framed, the institutional theory of SESs needs to be similarly elucidated. The discussion first considers how institutions can be analytically and structurally differentiated. SES path dependence uses both methods of differentiations when examining the effects of institutional change. Concepts such as adaptive governance and polycentricity in IAD are then applied in the context of the structural distinctions as well as the response of governance to changes in the resource system.

A. Analytical and Structural Distinctions for Institutions

Institutions can be differentiated in several different ways, with the different approaches serving different purposes for analysis. A method has already been introduced from IAD for differentiating institutions by analytical levels—operational, governance, and constitutional—in Section II. The levels distinguish the kinds of decision making that occur with respect to what sorts of rules. The multiple levels are therefore useful for determining the origin of rules and who has what power over changing them. Analytical levels are different from structural levels, which refer to how the institutional system is put together as nested sets of relationships.[11] These are distinctions like 'local', 'state', and 'national', each of which has different characteristics in terms of who has jurisdiction over whom and what issues are processed by each level. IAD does not discuss structural distinctions in any depth. However, in institutional path dependence analysis, both structural and analytical distinctions among institutions are important in tracing the effects of institutional change at one or more analytical level on nested structural levels.

Before exploring structural distinctions in greater depth, the recurrent focus on analytical distinctions needs to be clarified in the context of SES path dependence analysis. As mentioned in the introduction, the focus here is on constitutional level rules and outcomes. Constitutional rules prescribe who can be considered as subject to the governance level and the procedures for creating governance level institutions (E. Ostrom, 2005, p. 58). The inflexibility of constitutional rules creates institutional restraint on governance level rules, or a "stability of mutual expectations" (E. Ostrom, 2005, p. 58). Since individuals and organizations believe that they can depend on the constitutional rules to remain unchanged, those rules can provide the basis for stable interactions with others at the governance level.

Another important role of constitutional choice—choices made at the constitutional level—is its role in creating governance forums. Since constitutional-level institutions are used to create governance-level rules, it also falls to the constitutional level to prescribe forums of governance or specify how those forums may be created. Governance rules created at the constitutional level further develop these forums by creating rules for interaction between people within the forum, such as establishing who can be involved in modifying those rules and the procedure for doing so (E. Ostrom, 2005, p. 59). Of course, governance institutions are confined by the constitutional rules underlying them. While governance rules can flesh out the details for deciding operational rules, they cannot do so in a way that overrides the constitutional rules without first obtaining changes to those constitutional rules. Therefore, governance rules are more susceptible to change than constitutional rules, but are less so than operational rules (E. Ostrom, 2005, p. 59).

The inflexibility of constitutional institutions and their role in framing governance level institutions means that they are a natural focus for understanding how SES path dependence occurs. Since they create a high bar to their own alteration, the limitations that they place on decision-makers at the governance level are likely to constrain changes in a resource system's operational institutions. However, the limitations posed by constitutional rules should not overshadow the opportunities that can also be created by them for institutional innovation.

Determining where constitutional and governance level decisions occur and their effect on SES governance shifts the focus from analytical to structural distinctions between institutions. In SES path dependence analysis, there are two structural levels. The first is the *macropolitical*, which are the institutions and forums over nested jurisdictions, and where high-level issues are “discussed and determined” (Redford, 1969, p. 107; see True et al., 1999, p. 157). The second is political *subsystems*, which are the interactions of individuals and organizations focused on producing a good or service (Jones, 1994, p. 157; Redford, 1969, p. 83). In this analysis, the subsystem’s task is to manage the resource system. Subsystems nest within the macropolitical system and provide different forums for governance activities within a specific jurisdiction (Jones, 1994, p. 157; True et al., 1999, p. 157). The macropolitical system also indicates that not all decision activity happens within the subsystem (Agrawal, 2001, p. 1656). The differentiation between the two political spaces allows for the processing of several different issues at the same time while keeping them off the macropolitical agenda, therefore expanding the capacity of the governmental system (True et al., 1999, p. 158, 165). However, subsystems can share common interests or policy outcomes, even though they cannot directly interfere with one another (Jones, 1994, p. 157). They are confined to making policy only within the boundaries of their subsystem’s jurisdiction. Examples of the differentiation between macropolitical systems and subsystems include committees in the US Congress and the relationship of the state courts to the US Supreme court.

Constitutional level institutions at the macropolitical level can give powers to decision-makers at the governance level in a subsystem to create alternative institutional arrangements to solve collective problems (Oakerson, 1992, p. 48). These alternative arrangements can involve the development of their own constitutional rules for their specific policy field within the constraints of the initial constitutional institutions. In turn, these new constitutional rules can establish forums for collective action. These provide the basis for governance level institutions to prescribe, invoke, apply and enforce operational rules in the forum's jurisdiction. Whether these nested forums exist and how they operate are of great importance in analyzing SES institutions from the perspective of resource subsystems. They provide the means by which appropriators and managers resolve conflicts among themselves, create common understandings about resource system dynamics, and adapt to changing resource system conditions (Folke et al., 2002, p. 439; C. S. Holling, 2001, p. 399).[12]

While the subsystem's constitutional rules are constrained by the macropolitical realm's constitutional rules, this fact does not preclude the creation of other constitutions, such as the relationship of state constitutions to the US constitution. Opportunities can arise for multiple constitutional level institutions that apply to different areas of governance. The power of constitutional creation allows for the development of a polycentric governance system that may share some common forums but that which have subsystems that are shaped to the preferences of stakeholders (see McGinnis, 1999). These niche constitutions operate with a greater level of specificity than constitutions intended to serve a wider, more diverse jurisdiction. The ability for subsystem beneficiaries to create new constitutional level institutions for the subsystem is based on enabling powers given to them by the pre-existing constitutional rules at the macropolitical level (V. Ostrom, 1963, p. 102). If the constitutional rules grant beneficiaries this power, the new constitutional rules for the subsystem are built within their restrictions. These constitutional rules then act as the basis for new governance rules outlining new forums for interaction. Since macropolitical constitutional rules provide the basis for governance rules directly at the macropolitical level and indirectly at the subsystem level, they also define the connection between the newly formed subsystem governance level and the past macropolitical level.

Governance and constitutional level institutions thus weave the macropolitical system together with political subsystems. Information gathering at the operational level is transferred to governance level institutions at the subsystem and macropolitical levels through information rules (E. Ostrom, 2005, p. 206). The sharing and application of this information by participants at the governance level creates conceptions about the operations of the subsystem and impacts subsequent operational rule decisions within the governance level's jurisdiction (Baumgartner & Jones, 1993, p. 31).[13]

The institutional configuration described here can be seen in SES governance. State legislatures and state courts may function at the macropolitical level of an SES to decide about operational rules that apply to all or types of resource subsystems within the constraints provided by federal and state constitutional level institutions. While the resource subsystem cannot legislate for the SES, it possesses its own constitutional rules that create constraints for its local governance level institutions, which also alters operational rules within its jurisdiction. For example, in the case of adjudicated groundwater basins in California, the watermaster sets the safe yield for the basin through powers given to them by the adjudication (Blomquist, 1992, p. 80). The office of watermaster for one basin does not set the safe pumping yield for all groundwater basins; its powers are confined by the adjudication's reach. However, the constitutional powers of the watermaster, articulated through the governance rules within the basin, affect the operational rules of the basin. The powers reserved by the basin watermaster to set pumping rights does not interfere with the water rights scheme set for non-adjudicated basins in the state constitution, and the legislature retains the power to make changes to the rights scheme at the constitutional level (Blomquist, 1992, p. 83). Constitutional level institutions therefore create multiple forums for governance, both at the resource subsystem level and at the SES's macropolitical level, each with powers respective to its jurisdiction (E. Ostrom, 1990, p. 102).

From the above discussion, it is clear that analytical distinctions between institutions are relatively independent of structural distinctions in various ways. The formulation may dispel some misconceptions about how different methods for distinguishing institutions relate to each other. First, it is wrong to assume that macropolitical systems and their subsystems all share the same constitutional institutions. As mentioned earlier, it is plausible that some constitutional institutions exist only within a single political subsystem, not in the macropolitical environment. These sub-constitutional institutions exist in the context of the supra-constitutional institution that originated them. Thus, it can be said that the macropolitical system can be defined as a set of constitutional and governance level institutions common to all subsystems.

Second, it is equally wrong to assume that the macropolitical level corresponds to the constitutional level institutions and that subsystems correspond to the governance level. As some constitutional institutions may be unique to a subsystem, governance level institutions are also found at the macropolitical level. For example, a state legislature would be considered a forum whose governance level institutions give it the ability to legislate for the state. While the legislature may have some powers to propose constitutional amendments, it cannot modify the constitution directly. The legislature is constrained by the preexisting constitutional level institutions from doing so. However, the legislature could use its governance level institutions to enact legislation that applies across several subsystems. This does not equate to constitutional change, since the limits posed by the constitutional rules for either the macropolitical system or the subsystem are unaltered by the legislature's decision. Instead, legislators use governance level institutions within the scope of the powers granted to it by the constitutional institution, which also outlines the powers given to the subsystem for self-organization.

Examples of the interweaving of constitutional and governance level institutions can be seen in the state of California. These examples are relevant in the context of Southern California groundwater management discussed below. In California, there are two ways to establish municipal districts, one concerning districts for cities and the other for creating special districts that serve multiple cities. Districts for cities can be created through powers given to local governments to create public corporations by the State Constitution (CA Const. art. XI, § 11–13; V. Ostrom, 1971, p. 190). The powers of the state legislature were curbed by constitutional amendment to prevent it from using special legislation to create municipal corporations. Instead, local governments were given the powers to prescribe, apply, and enforce local ordinances provided that they do not violate state law (V. Ostrom, 1971, p. 190). In the context of subsystems and the macropolitical systems, the local government is considered the subsystem, and the state level is considered the macropolitical system (Baumgartner & Jones, 1993, p. 34). The distribution of powers to the subsystem and the macropolitical system are based on the state constitutional institutions. The constitutional rules prevent macropolitical interference in subsystem affairs, while granting powers to the subsystem to create constitutional rules specific to itself. Therefore, there are constitutional provisions shared by municipalities by their origin in the macropolitical system, yet each has some constitutional provision unique to itself alone. The same goes for governance level institutions; the municipalities share a common governance level forum in the legislature, but also have forums unique to them.

The formation of special municipal districts, while based on different governance level rules, is comparable to the creation of municipalities at the local level. The power to create special districts has been given to the legislature under the California state constitution, as determined by the state's supreme court (V. Ostrom, 1971, pp. 192–193). The principle also applies to water districts that serve more than one town or city. However, the constitution's orientation to self-government has fostered a practice where the legislature generally acts to authorize agreements made between local governments (V. Ostrom, 1971, p. 193). Like single city municipalities, the resource subsystem creates constitutional level institutions. However, in contrast to that creation method, the local constitutional institutions are subsequently approved at the macropolitical level through the legislature. That is because it is the only forum established by the state constitution that can create special districts. However, from the perspective of a macropolitical and subsystem analysis, both arrangements are relatively similar. They are constrained by the limitations placed on it by the state constitution, while the special district also has constitutional and governance institutions specific to it. The legislature is retained as a governance level forum for the creation of operational rules for the resource subsystem as well as other subsystems with similar provisions.

The power of the macropolitical system to influence multiple subsystems is important to consider in the context of SES path dependence analysis. In the following analysis, subsystems are related to the operational level in a single resource system, as well as the governance and constitutional levels tailored to that resource system. The macropolitical system relates to the constitutional and governance level institutions that are common to all resource systems within an SES.[14] Over time, issues emerge out of the resource subsystems constitutional institutions to become part of the SES's macropolitical agenda. There can be several possible factors that cause the issues to emerge, including the receptiveness of a higher forum over the resource subsystem's specific forum to an operational problem and cross-jurisdictional issues that neither resource subsystem involved has the power to remediate (Baumgartner & Jones, 1993, pp. 33–34). In either case, the emergent issues change people's understanding of the resource system at the SES's macropolitical level, as well as how an issue should be approached across the resource subsystems (Baumgartner & Jones, 1993, p. 6; True et al., 1999, p. 158).

The shift in perspective and in policy can then have two different consequences for the subsystem, but with similar results. First, decision makers at the macropolitical level create new, or modify preexisting, institutions either at the constitutional or governance level within the constraints set by constitutional rules. Since all of the subsystems are connected through common constitutional and governance institutions, the new governance or operational rules created at the macropolitical level are applied across all other similar subsystems (Baumgartner & Jones, 1993, p. 13). The new patterns of interaction created by the rules among appropriators and managers can create new resource system outcomes (Baumgartner & Jones, 1993, p. 13). This kind of change is the most often examined within agenda setting literature, often in terms of policy at the national level (see Baumgartner & Jones, 1993; Jones et al., 2003; Pierson, 2004).

Second, the shift is not immediately applied to the subsystems, but is implemented as subsystems resolve problems like that of the subsystem where the first instance of the issue emerged. In other words, the issue resolution at the macropolitical level sets the standard procedure for issue resolution. An example of this would be a judicial solution where the solution that was applied to the problem first becomes the method to resolve all problems like it in the future (Hathaway, 2003, pp. 125–126).

B. IAD and Structural Levels

As in the case of CPRs, IAD again offers some analytic tools for SES path dependence, this time in the context of institutions. Specifically, it offers avenues for examining change in respect to resource system behavior, such as the governance level's ability to modify operational rules. On this basis, the analysis draws on concepts from IAD about resource system and institutional change to examine decisions within SES governance.

1. Adaptive Governance

The most important concept of institutional change from IAD is adaptive governance (Dietz, Ostrom, & Stern, 2003). Adaptive governance occurs when people acting collectively adapt their institutional arrangements to changing ecological, social and economic contexts (Koontz et al., 2015, p. 2). Institutions can provide a structural framework for adaptive governance by fostering flows of information at the operational and governance levels, as well as fixed times to reassess operational rules or elect new representatives (Decaro et al., 2017; Dietz et al., 2003, p. 1910). By keeping institutional configurations adaptable, resources systems remain at stable and beneficial states and continue to provide services to stakeholders (Folke et al., 2004, p. 575).

2. Polycentricity

The institutional design principle connected to adaptive governance, and of most concern in this analysis, is *polycentricity*, characterized by independent organizations that can make mutual adjustments with each other within a system of rules (V. Ostrom, 1972, p. 57). Like adaptive governance, polycentricity is a subject in of itself, so only a brief overview can be offered here. However, the characteristics of polycentric systems are important to examine in order to understand different institutional contexts for SESs.

Polycentricity in the broadest sense allows for self-governing subunits to coordinate with each other within a larger legal and political context that constrains the actions that each subunit can take (V. Ostrom, 1994, p. 227). The subunits offer chances for democratic processes within a local area, such as public choices to build a school, electing a public official, or creating a municipality. A polycentric system in an SES would have institutional subunits distinguished by resource system, with each subunit possessing a unique governance structure and sometimes a constitutional level of decision making. These subunits are bound together by common governance and constitutional rules, which apply to the whole ecosystem. Higher-level governance forums regulate the subunits below them or act as forums for conflict resolution among them. In the context of an SES, such governance level institutions that cross several different resource systems within an SES should be considered the relevant macropolitical realm. The subunits are able to work within a specific resource subsystem, regulating appropriator and management activity.

In some cases, the jurisdictional boundaries of these governance level institutions overlap with each other, providing multiple avenues for institutional change and creation (Aligica & Tarko, 2012, p. 244). While the organizational system can seem chaotic from the outside, it offers distinct cost-to-benefit advantages to system users. By allowing the appropriators and mangers of a resource system to take advantage of large scale forums for some aspects of resource system governance and smaller forums for others, they can maximize the benefits to them for what they pay in the form of time and resources (Aligica & Tarko, 2012; Koontz et al., 2015; Oakerson, 1999). Polycentric systems then allow for adaptive governance by creating multiple options or avenues for governance change (V. Ostrom et al., 1961, p. 832).

Macropolitical institutions can foster polycentricity by various means. The most prominent way is to authorize the formation of an organization that can govern appropriation activity within a resource system (V. Ostrom, 1972, p. 59). In this scenario, appropriators are given the ability to act on behalf of other beneficiaries, giving them power to make decisions about appropriation and management on their behalf (Oakerson, 1999, p. 62). A practical example is the formation of a mutual water company, where several people who use water come together to augment the supply by creating a company to collect water on their behalf (V. Ostrom, 1962, p. 62). Part of the responsibilities borne by the designated appropriators may be met through these appropriators coming together to create an organization among themselves in order to manage a resource system collectively. In the case of multiple mutual water companies that use the same river, they may decide to create a river basin management organization to ensure a stable supply of clean water to their beneficiaries, as was seen in the creation of the Ohio River Sanitation Commission (ORSANCO) (Cleary, 1967).

The positives associated with polycentricity apply to SESs as well (Berkes, 2009, p. 1694; Koontz et al., 2015, p. 4). As in other institutional contexts, polycentricity allows for appropriators to modify their organizational and institutional arrangements to fit their specific needs. With the benefits of direct control over a resource system also come advantages to learning about alternative institutional arrangements. As people at similar levels of organizations share their experiences with their own system, people bring these ideas back to their own system (Koontz et al., 2015, p. 5; E. Ostrom, 2014b, p. 24; Wilson, 2002, p. 12). What allows appropriators to apply their new knowledge is their ability to adapt current operational and governance institutions. They can then act collectively at the governance and constitutional levels to implement new rules to see if they are beneficial to resource system stocks.

Tied to institutional modification is the integration of resource system information into institutions. These modifications are in integrated the same way that institutional learning is; appropriators and managers implement institutions that reflect the procedures needed to keep their resource system stable. As the resource system changes, governance arrangements that are responsive to the users of the resource system will change institutions accordingly (Decaro et al., 2017, p. 7). Polycentric systems therefore offer users the opportunity to craft their organizations considering new institutional and ecological knowledge.

In contrast to polycentric systems are monocentric systems. Monocentric systems are characterized by a single hierarchical structure responsible for all activities across multiple resource systems. In contrast to the bottom-up creation of polycentric systems, monocentric systems tend to foster the top-down creation of operational rules without the input of system users. Both polycentric systems and monocentric systems can be effective for the management of certain goods (V. Ostrom, 1972, p. 53). However, monocentric systems are not as adaptable as polycentric systems, since they are responsible for the governance of several different resource systems at the same time and are rarely able to create solutions unique to an area (V. Ostrom et al., 1961, p. 837). When the monocentric system does try to experiment with different ways of providing services, it applies the same parameters across all groups, some of which that have more to lose than to gain from the modification (E. Ostrom, 2014b, p. 14).

For SESs, which have multiple different resource systems with different needs, a monocentric system is sub-optimal. Creating the institutional framework for polycentric systems is therefore an important consideration when creating viable SESs. Such a framework would allow system appropriators and managers across multiple resource systems to establish organizational preferences responsive to their unique needs. While the institutional mechanisms for maintaining resource systems have been touched on here, the level of institutional decision-making needed to promote adaptive governance needs to be explored with greater depth.

Connected to issues with monocentric systems are panacea solutions to institutional design. Panaceas are institutional frameworks imposed on CPR beneficiaries by authorities external to the resource subsystem, often billed as universal solutions to

CPR management problems (E. Ostrom, 2007). Panaceas can be harmful for the sustainability of resource systems, since they do not necessarily fit the social or ecological characteristics of the SES (E. Ostrom & Cox, 2010, p. 2). The impositions also create inflexibility in institutional systems because they do not allow for the institutional or resource learning process to be implemented into institutional arrangements (E. Ostrom & Cox, 2010, p. 4).

The question of how to achieve institutional variation is straightforward in the context of the preceding arguments: system beneficiaries acting collectively can choose or create units to organize appropriation and management. This does not answer the question of by what institutional mechanisms this variation takes place. The answer, as hinted at earlier, is found in the governance and constitutional rules discussed in the beginning of this section. Constitutional level institutions at the macropolitical level can grant people powers to form their own governance units (E. Ostrom, 2005, p. 61). These constitutional rules, which apply across the SES, provide the groundwork for new governance level and constitutional level institutions, which regulate interactions between appropriators and managers with the resource system at the subsystem level (Oakerson, 1999, p. 19). An example of this would be groundwater adjudications seen in Southern California, which included all the pumpers of a groundwater basin in its jurisdiction and created new governance level rules (E. Ostrom, 1990, pp. 112–113). The construction of resource subsystems using constitutional tools for institutional creation precludes other future organizers from consolidating systems into a monocentric organizational model. This would be a case of path dependence, where past development precludes future development.

C. Looking Beyond IAD

IAD analysis provides significant theoretical resources toward providing an SES path dependence analysis. However, when used on its own, two weaknesses emerge of using a purely IAD approach to examine institutional change. First, IAD does not have a strong concept of time outside of repeated interactions between individuals and organizations under the present institutional system (E. Ostrom et al., 1994, p. 328). This means it only examines an institutional system at a point in time and not the dynamics of long-term patterns that determine institutional change (Baumgartner & Jones, 1993, p. 6; Pierson, 2000a, p. 263; Pierson & Skocpol, 2002, p. 13). The second reason why IAD cannot be applied on its own is connected to the first. IAD creates defined edges for the range of its analysis when examining an SES, in that it restricts the examination to a single resource system and corresponding institutional subsystem (E. Ostrom, 1999, p. 47). This creates very little discussion of the institutional relationships that resource subsystems share with each other. In this sense, IAD does not offer a thorough examination of an institutional level's relationship to other SES institutional changes over time. Based on this overview of IAD's weaknesses, it cannot be applied to SES path dependence analysis 'right out of the box'. However, there are other, complementary theoretical tools for approaching SES path dependence.

VI. SES Path Dependence Analysis

Path dependence is any process where initial decisions about a good or system have long term effects on the development of the good or system (Jones, 1994, p. 52; Pierson, 2000a, p. 252). In this definition, path dependence can apply to several different processes with different causes for each. Understanding why path dependence is important hinges on understanding how future development options are excluded. Option exclusion, or lock-in, occurs when the costs of choosing an alternative arrangement are too costly for beneficiaries to pay (Arthur, 1994, p. 116; Pierson, 2000a, p. 254). Positive feedback creates lock-in as the process progresses. Since products prone to increasing returns are subject to proliferation, other possibly superior options on the market become excluded and can no longer be pursued (Arthur, 1989, p. 116; David, 2007, p. 10). In the case of markets, this is the result of institutional dynamics, not the cost of alternatives. In institutions, such as in the case of governance and constitutional rules, the costs of alternatives acts as a constraint on innovation.

Path dependence becomes a concern when systems begin to produce or prefer sub-optimal resource outcomes in terms of quantity or quality, or in extreme cases, stop being productive entirely (Arthur, 1989, p. 116). While several different institutional systems across macro and subsystem levels demonstrate path dependent behavior, SESs are unique in that the limitations imposed on them are both institutional and physical. Permanent or practically permanent changes from self-reinforcing behavior in either system can impact the long-term development of the SES. Therefore, *SES path dependence* includes self-reinforcing behavior within a resource subsystem, which can lead to resource degradation as well as large scale institutional change caused by external resource subsystems.

Both the wider ecosystem path dependence and the path dependence which occurs at the resource system level need to be elucidated before proceeding into the theories applied in the analysis. The first of these is *subsystem path dependence.* Subsystem path dependence occurs when a resource system cannot produce desired resource units as a result of historical patterns of use. CPR systems are unique in that their characteristics are susceptible to path dependent behavior as resource attributes are altered or eliminated through manager and appropriator operations. When subsystems exhibit path dependence, resource unit productions is vulnerable, not only at a point in time, but also across time as various types of appropriator and manager decisions impact future uses of the resource. In these cases, "marginal adjustments of individual agents may not offer the assurance of optimization or the revision of sub-optimal outcomes" over time, meeting the criteria for path dependent behavior (Liebowitz & Molinga, 1995, p. 206).

To analyze resource system path dependence, the necessary conditions for resource system renewal need to be examined in terms of the relationship between the resource unit and resource system. Since Holling's adaptive cycle model (Gunderson & Holling, 2001; C. S. Holling, 2001) is well suited to mapping the progress of a single resource system from renewal to collapse in respect to attribute diversity, it is the primary way that subsystem path dependence is formulated here. Chains of causation, as articulated by Historical Institutionalism (HI), provides an analytical route to tie changes in the resource system presented in the adaptive cycle back to into the institutional development of the SES. Subsystem path dependence, as articulated in the analysis, exists at the convergence of good production and resource system limitations.

The institutional system of macropolitics and subsystems bound by governance and constitutional rules provides the starting point for the macropolitical component of SES path dependence. The starting assumption of macropolitical SES path dependence is that all resource systems over a certain area designated as the SES share a common governance and constitutional level at the macropolitical level. The resource subsystem may also have some constitutional and governance rules that are unique to it in addition to operational rules. As discussed in the previous sections, subsystems can be relatively independent from each other institutionally (Redford, 1969). In this configuration, institutional change at the subsystem's governance level is not out of the reach of appropriators or managers seeking to change operational rules. In other words, operational rule change poses fewer costs to those who interact directly with the resource. Where a constitutional level is within the subsystem, changing governance level rules may also be relatively straightforward for appropriators and managers to achieve, even though more difficult than changing operational rules. These changes occur solely within the boundaries of the resource subsystem, and do not affect the development of those institutions outside of it.

Altering the composition of constitutional rules, in contrast, is likely to be much more difficult and costly. New constitutional rules—those rules that allow subsystem actors to modify their governance rules—require an appeal to the preexisting constitutional level, or the possible alteration of how current constitutional rules apply within the subsystem. This may require appropriators and managers to take their issue out of the subsystem and into the macropolitical realm. To describe the process of institutional development through changes in the macropolitical system, punctuated equilibrium and sequence theories are employed from HI methods of analysis. These analyses provide the terminology for exploring the process of issue emergence and change across subsystems through the macropolitical level.

A. A Neutral View of Path Dependence

Path dependence is a phenomenon common in economic and political systems. It is not necessarily a negative outcome, though it is often painted as such (see Arthur, 1989; David, 1985; Liebowitz & Margolis, 1995). Often, this is as a result of looking back at what could have happened considering the consequences of previous actions. This tendency of path dependence analyses to reflect on themes of retrospective regret is perhaps the wrong way to approach the topic for two reasons. First, path dependence is all around us and often is beneficial. Positive feedback creates stability in institutional arrangements and helps guide individuals as they coordinate behavior with others (Pierson, 2000a, p. 259). In addition, path dependence can foreclose potentially negative routes for development. When the adopters of a technology or institution make choices about which option to pursue, the presence of the best version inhibits the adoption and development of worse alternatives (Liebowitz & Margolis, 1995, p. 212). Often path dependence is considered positive as an equilibrium settles at a point beneficial to all parties (David, 2007, p. 12). The positives of path dependence mentioned here indicate a principle akin to one from design: people notice path dependency only when the wrong choice has been made from a set of better options (Norman, 2013).

The framework presented here approaches path dependence as a neutral phenomenon. Since path dependence occurs as a decisions becomes solidified by market or institutional arrangements, it should be considered a force that acts at all institutional levels. In the right circumstances, path dependence can be leveraged to lock-in positive institutional relationships, while keeping other parts of the system open to adaptive change. This is especially important in the context of changing resource system conditions, as described in the previous section. While analysts are primarily focused on the roles of SESs as adaptive institutions, they recognize the importance of outside support in establishing long-standing institutional arrangements (Decaro et al., 2017, p. 5; E. Ostrom, 1990, p. 101). Locking in conditions that preserve recognition of subsystem authority over a resource system are of vital importance to establishing long-enduring SESs whose governance institutions are responsive to change.

This brings the focus back to constitutional choice rules. Internally, the constitutional choice rules within a subsystem can provide adaptive governance across an SES's jurisdiction. Externally, subsystem constitutional rules connect the SES's subsystems together through the macropolitical governance and constitutional rules to form the macropolitical system. The topic of institutional the analytical and structural levels is revisited again in the context of the two path dependent behaviors that define SES path dependence.

B. Historical Institutionalism and Path Dependence

In contrast to IAD, HI focuses on the macro scale of governance activities to understand their development in relation to time and the "combined effects of institutions and processes" (Pierson & Skocpol, 2002, p. 3; Steinmo, 2008, p. 151). It is worth clarifying from the outset that HI is less a theory of institutions than an approach to analyzing institutional performance and change (Steinmo, 2008, p. 150). The loose affiliation between pieces of scholarship in HI is due in part to the number of different concepts and traditions within it that are in conflict with each other at points (see Pierson, 2004 for an overview). As a result, claiming to do HI analysis means virtually nothing if the work does not refer to a strain of HI thought. However, loose structure does not mean that each concept within HI is independent of another, or that it is not as rigorous as IAD.

HI is predominantly focused on the temporal dimensions of institutional decision making. Specifically, HI analysts examine institutional arrangements or political organizations where new issues, or arrangements, are constrained by past events. From these observations, they make claims about the mechanisms behind the ways that change occurs in different institutional systems, and how the course of the system's development determines opportunities available for future development (Pierson, 2000a, p. 265). This type of analysis lends itself to making observations about path dependence using a diverse number of explanations or phenomena, each with its own basis.

As stated at the beginning of this section, IAD and HI concepts are not traditionally used in conjunction with each other. At the broadest level, they are based on different assumptions about the behavior of people within institutions and their effects on politics (Pierson & Skocpol, 2002).[15] For this reason, the analysis here is confined to only two parts of HI theory, the first being punctuated equilibrium. Punctuated equilibrium fits with IAD for three reasons. First, it narrows the scope of what is being drawn upon and therefore possible conflicts with other parts of HI. The analysis does not need to import every idea from HI to make sense of institutional change; doing so would not only open it up to unneeded criticism but would also overburden the theory. Punctuated equilibrium on its own is relatively independent of other theories included within HI, so it lends itself well to this analysis.

Second, punctuated equilibrium is the most developed theory both conceptually and empirically of those in HI. Over the years, the theory has been empirically tested successfully across several different settings in American national politics (Baumgartner & Jones, 1993; John, 2006; Jones, 1994; Jones et al., 2003; True et al., 1999). It has also been expanded upon outside of the US Congress to include SES systems (see Wood, 2006). The application of punctuated equilibrium lends itself to an examination of the macropolitical-subsystem dynamic characterized by SESs in a well-developed institutional context.

Third, punctuated equilibrium is also viewed as a type of institutional theory akin to but distinct from IAD (P. Sabatier, 1999, p. 12).[16] As mentioned briefly in the beginning of this section, HI serves to provide a theory of institutions animated by time. Punctuated equilibrium theory is specifically focused on institutional change based on assumptions of human behavior and interactions between different political levels (Baumgartner & Jones, 1993). The theory is therefore not as concerned with the institutional design activities of people within the system, insofar as they construct the institutional system that change occurs within. IAD, in contrast, is focused precisely on institutional design by individuals acting collectively (E. Ostrom, 1990, p. 27).

The second concept applied in the path dependence part of the analysis are path dependent sequences and chains of events. Sequences and chains are not theories of change as much as they are different descriptors of how path dependent change unfolds over time. The logic of applying sequences and chain of events in conjunction with IAD is like that used to apply punctuated equilibrium. Sequences and chains of causation are common ideas used across several different strains of HI theory (Capoccia & Kelemen, 2007; Hogan, 2006; Hogan & Doyle, 2007, 2009; Pierson, 2004, pp. 87–90; Pierson & Skocpol, 2002, p. 5; Shepsle, 1986). Again, not all the theories attached to sequences or chains of causation are imported into the SES path dependence theory. Like punctuated equilibrium theory, sequences and chains are a well-tested concept across multiple different contexts. Lastly, the theoretical assumptions made about institutions in respect to sequential and causational change are not, at this broad level, largely different from those made by IAD. Theories associated with IAD have in fact examined similar mechanisms for change, such as in studies of sequence (see Shepsle, 1986). While it cannot be ignored that these methods of analysis have rarely been used together, it is not out of the question to use them at this basic level.

C. Theories of Path Dependence

The discussion of the resource subsystem is structured in three topics. First, sources for resource system alteration and collapse are explained in the context of appropriator and manager actions. These behaviors will inform the second section on how changes in the resource system alter the governance of the SES as the resource system fails to provide the units necessary for beneficiaries. The first two topics form the basis of SES path dependence by providing the mechanism for chain causation through appropriator and manager actions and its feedback into the governance level through shifts in the resource system. The third section discusses how the formation of constitutional level rules can be an emergence event in certain institutional settings. These events can come about as a result of changes in the resource system. This is the point at which institutional path dependence can prevent or encourage subsystem path dependence.

1. Punctuated Equilibrium

Punctuated equilibrium is a pattern consisting of a long period of stasis, or equilibrium, broken by rapid political change, until a new point of stasis is reached (True et al., 1999, p. 156).[17] The pattern is a characteristic of institutional change in analytically multilevel institutions where the macropolitical system can be disrupted by change in the several subsystems attached to it (Baumgartner & Jones, 1993, p. 13; True et al., 1999, p. 156). An issue, as defined here, is a change in the people's perspective about their collective action activity—either what the goals of the organization are and how they should be pursued (Baumgartner & Jones, 1993, p. 21). Usually, the operations of a subsystem are in stasis, since they are constrained by the existing institutions and perception of current issues held by those in the subsystem (Baumgartner & Jones, 1993, p. 15). What alters the subsystem are shifts in the attention of the people within the subsystem, either based on new information or perspectives on the issue (Jones, 1994, p. 95). Changes in the views shared by people within the subsystem do not necessarily mean that policy goals of the subsystem have changed (Jones, 1994, p. 14). Instead, they have changed how they believe they should reach their goals, such as altering a certain rule or creating a new organization (Jones, 1994, p. 99).

The institutions as well as the perspectives of people within the subsystem tend to suppress alternative understandings of the issue until disruption occurs (Jones, 1994, p. 171). Stasis can be reinforced by current governance and constitutional level rules, which constrain the creation of new operational rules. Disruption can take the form of a political mobilization within the subsystem, the issue's advancement on the political agenda, or positive feedback from the macropolitical system (True et al., 1999, p. 162). Political mobilization and positive feedback are the main issues that SES path dependence examines as presented here. Political mobilization occurs as subsystem interests search outside of the subsystem to alter political arrangements within the subsystem (True et al., 1999, p. 159). To do so, they seek alternative higher-level forums that are acceptable to the new issue perspective in order to create change within the policy subsystem (Baumgartner & Jones, 1993, p. 34). Subsystem issues then become macropolitical issues. Note that the issue at the macropolitical level is considered not only by the subsystem from which it emerged but also by all the subsystems connected to the macropolitical system. New institutions or subsystems can form that affirm the new understanding of the issue, creating a "snowball effect" of institutional creation precipitated by an issue in a single system (Baumgartner & Jones, 1993, p. 38).

The second phase of punctuated equilibrium is positive feedback and path dependence. Subsystems, as discussed before, can become dominated by single interest within the subsystem, keeping the system locked-in to set patterns of action (Jones, 1994, p. 170). As these issues are processed in the macropolitical level, issues begin to be processed by subsystem units sequentially (Baumgartner & Jones, 1993, p. 37; Jones, 1994, p. 157). The same principle applies to issue perspectives created in the macropolitical realm. An issue solution or perspective applied by the macropolitical system to the subsystems can be path dependent as new issue perspectives solidify and are no longer contested (Jones, 1994, p. 193).

2. Application of Punctuated Equilibrium to SESs

As mentioned before, SES path dependence looks at institutional path dependence both within the SES and the outside network of SESs. In SES path dependence analysis, punctuated equilibrium offers a theory for explaining how changes in the institutions of one resource system leads to similar changes across SESs. Resource subsystems, like normal political subsystems, are attached to the larger macropolitical level (Cleveland et al., 1997, p. 8; Jones, 1994). If the institutional structure of governance and constitutional levels are spread across the subsystem and macropolitical levels, then analysts can presume that punctuated equilibrium theory may be applicable within that context.

Change in an SES that results in changes across institutionally connected resource systems are presumed to follow the process outlined by punctuated equilibrium, beginning with changes in how an issue is understood. If appropriators become aware of changing circumstances within the resource system, they may respond to the crisis by acting collectively to create alternative arrangements (E. Ostrom, 2005). This is equivalent to the shift in perspectives that, while not being a shift in goals, alters how those goals are reached within the institutional framework.

After changes in awareness in the SES comes mobilization. People affected by the shift in the resource system come together to resolve the issue. In order to prevent free riders under the terms of their agreement, they create enforcement mechanisms to make sure everyone who uses the resource system is subjected to the operational rules (E. Ostrom, 1990). As outlined in the section on polycentricity, one of the routes to creating new units of governance is to use pre-existing constitutional rules to create new forums for governance that include all affected parties (Oakerson, 1999, p. 82). If these activities occur solely within the subsystem, then there is little chance that they would influence the macropolitical realm. However, within the SES there is room for non-authoritative horizontal connections between resource subsystems. These can take the form of learning about an issue or process based on the experience of one subsystem, or the presence of a small group of experts that reside in the SES that all subsystems draw on. In either case, the costs of processing the activity are reduced as more subsystems process the issue.

If institutional creation can only occur within a forum at the macropolitical level, it may be the case that a new institutional configuration emerges in the macropolitical space. This could occur if the pre-existing constitutional rules need to be modified, as in the case of Southern California groundwater management. In these cases, alterations to institutions can act as political mobilizations, and emerge into the macropolitical system. The arrangements they create within a resource subsystem can therefore change the course of the development of connected SESs through the shared macropolitical forum.

On the analytical side of institutional analysis, SES path dependence focuses either constitutional or governance rules. Recall that these are the institutions that facilitate the creation of new appropriator rights, including the limitations of those rights as well as where they are effective. There are two reasons for why they are the focus of the institutional side of path dependence analysis.

First, governance and constitutional rules are the basis upon which operational rules are made. Operational rules are modified within the subsystem at the governance level, which employs governance level rules in their creation. In order to change outcomes for the resource system, decision makers need to alter the operational rules. If they can do that within the preexisting governance forums, there is no reason for them to create different ones. In other words, the issue never percolates into the macropolitical system. However, if no forum exists to modify the operational rules to reach the desired outcome, then individuals need to create an alternative forum before implementing new operational rules. Since new forums are created through modifying governance rules at the constitutional level, or in some circumstances creating new constitutional rules altogether, these are the rules that allow for changes in the operational rules. Therefore, to understand entrenched patterns of institutional development, the focus needs to be on governance and constitutional rules.

Second, constitutional and governance level rules create the stasis seen in punctuated equilibrium. Since they provide the constraint on changes in operational rules, they prevent appropriators and mangers from altering resource system outcomes. Even when in relative stasis, the subsystem is still making decisions about how to modify operational rules. It is only when the governance and constitutional levels are disrupted that procedures for changing operational rules begin to change as well.

Punctuated equilibrium opens interesting possibilities with respect to resource system stability. If patterns of interaction among producers and system managers are allowing for adaptive governance, then the governance and constitutional rules are contributing to it by providing suitable forums for altering operational rules. This is especially of interest within polycentric systems. If the disruption event leads to the development of adaptable polycentric systems, the outcome could be transferred to other resource systems when they undertake governance or constitutional rule change. As a result, several resource subsystems would have their own polycentric organizational pattern that would help keep resource systems stable by combating the effects of introduced attributes or keeping the resource system from turning into a high depletion resource.

3. Types of Change

The most significant concept drawn from HI methods outside of punctuated equilibrium theory is the difference between path dependent sequences and chains of events. When thinking about time in relation to institutional change, analysts need to examine what relationship current events have to past events. Depending on the type of connection, the forces behind a path dependent phenomenon may be different. The distinction is especially important in the context of SESs, which can be subject to of path dependent behavior within the subsystem and in the macropolitical system. Noticing differences between them in terms of how structuring institutional events matters helps keep analysts from making fuzzy distinctions which muddle overall clarity.

HI describes path-dependent sequences as institutional changes “where different temporal orderings of the same events or processes will produce different outcomes” (Pierson, 2004, p. 68). In this conception of the change, each event in the sequence is independent of the occurrence of the other events. However, the event’s outcome increases the likelihood that a similar outcome will recur when an event similar to the first occurs (Capoccia & Kelemen, 2007, p. 348). The institutional forum where the event took place is restructured, based on the outcome of the first event, and causes the outcome to be reproduced in different circumstances. Past choices made at these junctures constrain future choices by posing limitations within the institutional system for making alternative arrangements (J. Mahoney, 2001, p. 113).[18]

What sequences all share is a forum in which events occur. For an event to alter an institution in such a way that the outcome is reproduced across time, the institutions that constitute the forum need to change as a result of the event. This means that the governance level or constitutional level rules are altered within the forum. Future decisions about operational rules are then constrained by higher level rules, determining future patterns of interaction.

A real-world example of this phenomenon can be seen in the development of precedent-based common law systems, as described by Oona Hathaway (2003). When a case (i.e., the event) is brought before the court, the decision (i.e., the outcome) is determined by the cases that came before it, otherwise known as the doctrine of *stare decisis* (Hathaway, 2003, p. 121). *Stare decisis* can create lock-in by establishing limited room for modifying the decision in new cases like the first, after a few earlier cases similar to it have been decided (Hathaway, 2003, p. 151). The prior case does not cause future cases to occur; instead, the decision of the prior case determines the decision in subsequent cases. It is also worth mentioning here that *stare decisis* doctrine is also evidence that path dependence should be considered a neutral phenomenon. *Stare decisis* is beneficial to the legal system by creating certainty in how cases are decided and by reducing the costs associated with creating a unique decision for every case (Hathaway, 2003, pp. 151–153).

In SES path-dependence analysis, sequence matters in connection to punctuated equilibrium. In the theory, issues emerge from the resource subsystems into the macropolitical system, resulting in modified governance and constitutional rules across the subsystems. When subsystems internally modify governance and constitutional rules, alterations made will not be the same as those reached by other subsystems. Before emergence occurs, each subsystem processes the issue irrespective of the other (Jones, 1994). When emergence does occur, those changes are passed on to other resource subsystems connected with the macropolitical system, determining how the resource subsystems subsequently process similar issues. The order in which issues emerge from subsystems into the macropolitical level therefore alters the course of development for the interconnected resource subsystems.

The second type of event relationship are chains, which are “tightly linked causal connections unfolding over time” (J. Mahoney, 2001; Pierson, 2004, p. 68). Unlike sequences, events in chains are not independent; rather, each is related to the other since the next event in the chain is the outcome of the previous event. In HI, the consequences of the chain are most often seen as the “byproducts” of the course of action taken to reach another objective (Pierson, 2004, p. 88). This approach to analysis may lead analysts to make unreasonable assumptions about the learning abilities and motivations of decision makers, which could allow them to prevent or encourage the consequences of a chain. However, it may be the case that, while participants would aim to prevent consequences of the chain, they may not have the necessary information or are focused on other objectives that they think are more pertinent or salient (Simon, 1957, p. 199). In either case, the consequences of the chain may impose high costs on individuals in the institutional system, either directly or indirectly through the subsequent costs to modify the institutional framework.

Long chains of interaction are often difficult to observe when seen solely through the lens of political science or institutional analysis, since the political process is rarely transparent and costs are difficult to measure (North, 1990a, p. 362 in Pierson, 2004, p. 37). Additional problems can also occur if each event has a varying degree of probability of occurring in the chain. As the chain gets longer, the probability that the chain occurs in a specific order decreases. Thus, in order to make a convincing causal chain argument, there needs to be a relatively small number of links and firm basis for thinking that the links between events are strong (Pierson, 2004, p. 88). There are also questions about where the chain begins or ends, which can be ambiguous in the context of HI (Pierson, 2004, p. 89).

4. Permanent Shifts in Resource Systems

Since the arguments for a causal chain need a firm basis in theory or empirical observation to be persuasive, institutional analysts need to look outside of their discipline to understand institutional change. External systems that form the basis of institutional systems can be a good place to start. If the related system has strong causal processes that are promoted by the institutional system, the effects of those causal processes may change the institutional system over time in the form of feedback. In effect, the behavior of the external system provides the chain mechanism in the institutional system.

For subsystems, changes in resource systems may provide the chain processes necessary to establish a causal argument to SES institutional development. As discussed in Section III, resource systems under duress experience a shift in attributes, with the crossing of a resilience threshold impacting the shift from an optimized to an unoptimized system.

Unlike economic path dependence analysis, subsystem path dependence does not focus on the adoption of a product, as there is no choice between pursuing one resource system unit over another resource unit.[19] Note also that, unlike the path dependence described in punctuated equilibrium, the constraints imposed on institutional change are not based on changes within the constitutional or governance level rules. While punctuated equilibrium's traditional focus is on institutional change in the context of organizational costs, resource subsystem path dependence is distinct in that it is based on physical attributes. Management and appropriation decisions are those that create chains of causation within the resource system by selectively modifying resource system attributes through appropriation and management operations. As the resource system fluctuates, the change in resource system conditions can determine the options available for future system functioning. Such changes can shift a resource from a renewable resource to a non-renewable resource through increased depletion use as resource units no longer reproduce.

It is worth noting that subsystem path dependence is not dependent on institutions remaining inflexible or completely dependent on resource system conditions. To some extent, appropriator and manager activity can change over the course of resource system degradation as it modifies patterns of interaction (Ostrom et al., 1994). What matters is that the resource system attributes are continually degraded even under alternative methods of appropriating resource units. As the resource system shifts, the operating cost of appropriation will increase dramatically compared to the number of resource units it is able to extract. Beneficiary communities may be able to outlast the degradation of the resource system from which producers are extracting resource units, but rarely at no cost (Anderies et al., 2004). Depending on the costs, beneficiaries will alter who appropriates on their behalf to compensate for the change, or will incur new costs of provision. In either case, the change in the resource system permanently alters the possibilities available for producing the good. While the institutional system can change, the resource system constrains future decisions because of past decisions.

Subsystem path dependence can be seen to encompass several different phenomena where resource systems become degraded as a result of resource attribute reconfiguration. Multiple sources of subsystem path dependence can exist in a single resource system, and the ability to diagnose those issues may be a key strength of this type of analysis when looking at SESs.

Appropriation and management patterns are subject to lock-in as the use of the destructive strategy continues, possibly resulting in a poorly configured resource system (Pierson, 2000a, p. 258). In other words, resource units have either disappeared from the system entirely or exist in a form that cannot be used by appropriators. Examples of this include wood that cannot be used for timber, contaminated water, or fish that have no market value. Modifying the resource unit or the resource system would have prohibitively high costs, preventing necessary changes (see Green, 2007).

Manager and appropriator operations result in resource system path dependence by modifying system attributes. This can happen in four different ways: attribute subtraction, dysfunctional endemic engineered attributes, self-proliferating introduced attributes, and negative effects on cross-system attributes. The first type of activity that can cause resource system path dependence is subtraction by appropriation. Classic examples of this can be found in overgrazing a grassland (see Ludwig, Walker, & Holling, 1997) overfishing a fishery, (see Berkes, 1992), or excessive logging (Hart, 1998, p. 67). In these cases, the resource system either collapsed and stopped producing resource units, as in the case of the grasslands that converted into shrub bush land (Ludwig et al., 1997) and fisheries that could no longer produce fish (see Berkes, 1992). In some cases, they began to produce resource units that were unusable by beneficiaries, such as hardwood succession of pine forest (see Hart, 1998, p. 67). In these cases, resource subsystem governance allowed for appropriation activity that reduced the diversity of system attributes. The management activities undertaken by the subsystem also did not allow the resource attribute to recover with the support resource system or did not provide an artificial counteractive activity to replenish the system attributes.

Resource subsystem path dependence by attribute subtraction occurs through a reduction of the number of attributes in the same functioning group. The loss of a single attribute, while compromising the redundancy of the resource system to maintain function after a stochastic event, is unlikely to move the resource system into a collapse phase. Comparable resource units can be found as an alternative for the lost attribute, such as in the case of fisheries that move from focusing on one type of fish to another (E. Ostrom, 1990, p. 173). While the management method has not collapsed the resource, the behavior is considered path dependent since the change in the resources permanently raises costs for the beneficiaries. A threshold for overall system stability has also been crossed with the loss of an attribute, and if institutional actors are not responsive, it could result in the collapse of the resource system. (Folke et al., 1996, p. 1022). As the management method becomes widely adopted, it experiences increasing returns, and as more thresholds are crossed, the range of future management strategies become increasingly limited (C. S. Holling, 2001, p. 322). In the adaptive cycle model presented in Figure 2, this would be represented by a gradual move from r to k as the system losses attribute diversity and begins to fail.

The second source of subsystem path dependent behavior is through engineered endemic attributes. This type of resource system path dependence arguably bears the most resemblance to traditionally recognized path dependence, since it examines the historical effect of choosing a product on subsequent iterations of management strategy. Engineered endemic attributes play a structuring role in resource system patterns of interaction and create path dependent behavior in that, once they are integrated, they cannot be easily eliminated. The integration of an engineered attribute into a resource system implies that an engineered attribute must be durable to be able to create path dependent behavior. For example, the Zanjera system of irrigation in the Philippines (E. Ostrom, 1990, p. 82) cannot be described as displaying path dependence inherent to engineered systems since the infrastructure, the dam that impounds irrigation water, is destroyed annually. However, structures like dams can often be considered path dependent given the large investment required to build and their durability.

Pieces of infrastructure may also be subject to increasing returns in that they need to be integrated at a large spatial and temporal scale to be effective. Smaller engineered attributes may be easier to remove or modify when management strategies need to shift, but at a certain size the consequence of eliminating them may come at the expense of other systems or may simply be impractical. The problems associated with dam removal to give salmon greater access to breeding grounds in the northwest may be an example of resource system path dependence with such endemic attributes (Protection Committee on Salmonids Management of Pacific Northwest Anadromous, 1996). Thus, management strategies after the dam is built become relatively inflexible in some areas, leading to sub-optimal output.

The third type of resource system path dependence comes from introduced attributes. Attributes are sometimes introduced by managers or beneficiaries to modify the resource system in some way. Ecology provides several different examples of introduced attributes having severe effects on endemic attribute processes, such as the zebra mussel's effect on Great Lakes infrastructure (O'Neill, 1997) and runoff from nitrated fields into a lake (Mäler, 2000, p. 651). In these cases, managers and appropriators created sub-optimal outcomes for their resource system. As in the case of endemic attributes, introduced attributes are assumed to be relatively durable and have persistent effects on the resource system processes. However, while introduced attributes do not play a key role in resource system structure since they were not present at system formation, they can affect key system attributes by reducing their quantity or what effect they have on the system.

Appropriators and managers in these cases are not the ones propagating the attribute; the resource system's internal processes scale up the effect of the attribute on resource system functions. Introduced attributes can then begin to degrade the current resource system, and in the event of resource system failure become integrated into a new resource system that may not produce the desired resource units for appropriators. The costs to institutional actors are from efforts to reduce the introduced attribute's effects, since elimination is rarely if ever feasible. Governance is then challenged either to create manager and appropriator operations that have efficient returns to scale or to introduce a "crutch" for the resource system. Ecological examples of attribute control include crutches such as lampricide in the Great Lakes ("Lampricides and Sea Lamprey Control," n.d.), purple loostrife in Ontario (Warne, 2016), and the brown-headed cowbird in Texas (Siegle & Ahlers, 2004).[20] In these cases, the cost of eliminating the new introduced attribute may be prohibitively expensive for managers and appropriators.

The fourth source of resource system path dependence is cross-system attribute modification. In these cases, changes in an ecosystem's attributes that are innocuous or beneficial to one resource system affect the governance of another to create an irreversible resource system decision. Often, this is a key structuring element for resource system functions (Walker, 1992, p. 20). Cross-system effects may arise out of governance decisions that fail to adopt an ecosystem management strategy or that prioritize the wellbeing of one resource system over another. An example of a single attribute having effects across multiple resource systems is a 'keystone species', a single species that is essential to normal ecosystem functioning. If appropriators and managers reduce the keystone species, related resource systems would begin to fail, or produce suboptimal results, due to interference in resource system processes.

Often, the preference for one resource system over another is a result of increasing returns. If as appropriators and managers increase or decrease a certain attribute, the greater is the benefit for the priority system. As other surrounding resource systems become degraded, managers are compelled to keep focusing on the priority resource system, reducing their ability to pursue other ecosystem management strategies. Such ranking of resource systems by priority can also emerge out of chance occurrences in governance arrangements. For example, the water quality and recreational opportunities in Hamilton Harbor in Ontario, Canada, have been limited by a constitutional level rule in the harbor's charter, in the account by Sproule-Jones (1993). The provision made the harbor independent from national regulation and subsequently gave full priority to shipping interests. As a result, there are few ways to regulate water pollution from ships since water quality does not naturally or institutionally impede shipping operations. The subsequently poor water quality reduces recreational options in the harbor, as well as effecting the other resource systems that provide services to public health. The range of choices for those resource systems is therefore reduced and can become permeant.

VII. SES Path Dependence Case Illustration: Groundwater in Southern California

Southern Californian groundwater management has become a classic example of public entrepreneurship, polycentricity, and institutional robustness (Blomquist, 1992; E. Ostrom, 1990, Chapter 4). One of the reasons for the region's success has been the prevention of two of the subsystem path dependent phenomena discussed above: subtractive path dependence from water withdrawal and cross-system path dependence from other subsurface systems. System managers have been able to combat sources of path dependence to some extent by virtue of the area's social and economic resources. As a result, they have been able to undo what in many areas would be considered permanent damage to the groundwater system (Green, 2007). However, given the large amount of time and resources it takes managers to finish the cleanup process of a basin, managers have consistently sought to avoid strategies that could limit the use of groundwater in the future.

Appropriators in this context are water producers, either private well owners or those who pump water for consumption by the wider public. Producers have developed flexible strategies and collaborations to prevent themselves from creating path-dependent situations (see Antos, 2016). Part of the system's adaptive nature is due to the development of polycentric arrangements, which gave producers the ability to adopt operational rules through a system of governance and constitutional rules within the subsystem (Blomquist, 1992).

This section will apply the analysis language developed over the course of explaining SES path dependence, illustrating the concepts of SES path dependence up to this point. While this is not a fully-fledged case study, it offers insight into what future analysis may look like as well as the way it can be integrated into traditional institutional analysis. It also points to alternative dynamics for institutional development not usually seen in SES analysis, as well as further avenues for deepening the analysis.

A. Southern California's Subsurface Ecosystem

The ecosystem examined here is the subsurface system of rock, fault lines, oil deposits and groundwater basins which underlie Southern California. In the analysis, it is divided up by the different groundwater basins that underlie different parts of it, each of which is considered a distinct resource system. While this method may seem analytically arbitrary, it is not, considering the type of ecosystem that is being analyzed. Distinguishing resource systems by groundwater basins offers a way to look at distinctive systems in terms of attributes, while each system has enough in common to be compared.

Groundwater basins also share attributes with other kinds resource systems in the wider ecosystem, each with its own set of resource attributes and functioning groups, as well as excludability and subtractability characteristics. Different governing units have responsibilities over different aspects of the ecosystem and coordinate different aspects of their activities. Some groundwater basins are also interconnected, leading to producers in different basins having to coordinate through their respective basin governance systems.

1. Attributes and Functioning Groups

Groundwater basins have several different attributes that provide stability for the system and give it the characteristics of a renewable resource. The functioning group of appropriable attributes within a groundwater system, is, of course, water. However, the water in a groundwater basin's stock is replenished by various means. Basins are fed by rain, overlying rivers, snowmelt and water spreading as it percolates through the soil and into the aquifer (Quevauviller, 2008, p. 4). Inflows have specific qualities based on their source, such as high-quality recycled water and impure runoff from streets and roofs (Green, 2007). Thus, the water also gives the basin certain chemical characteristics, such as salinity, depending on how much water is in the basin (Vengosh, 2003). Water can exit the resource system as it accumulates in the basin over time. As the basin becomes saturated, water can flow through it to create underground flows that act like rivers (Quevauviller, 2008, p. 6). Water can also leave the resource system through appropriation. Water is accessed through pumping from wells where water is drawn out of the ground based on well depth and groundwater level (2008, p. 6).

The second major functioning group is soils, ranging in characteristics in terms of chemical composition, space between particles, and spatial position within the basin (DWR, 2003, p. 83). Basin soils are difficult to decontaminate and exist within the basin for centuries without certainty of success in any remediation efforts (Scholz & Schnabel, 2006).

The third group of attributes are geological formations. The geological attributes, such as basin size, fault lines, and undulations, create the structure of the basin, and affect how water flows through it (Winter, 1999). Geological attributes, like soil composition, are highly durable, since they cannot be modified at all by managers. Water attributes are configured based on these geological and soil attributes and their subsequent effects on water flow and quality.

B. Groundwater Basins as CPRs

Groundwater in Southern California, as in most places, is considered a CPR given its low natural excludability and high subtractability. Since groundwater basins have no natural barriers that limit pumpers on overlying land from drilling into the earth to create the shafts needed to draw water, they are considered to have low excludability. The subtractions from the groundwater system can be ascertained through two different phenomena. First, water appropriated by one appropriator cannot be used by others. Second, water appropriation can cause the water table to fall if there are insufficient inflows into the basin. If the groundwater flow gets too low, the basin could become susceptible to compaction and salinization (Galloway, Jones, & Ingebritsen, 1999; Vengosh, 2003). Using the subtractability language described in Section III, the resource can be described as having high instance use and, depending on the condition of resource attributes, high depletion use. The resource can be permanently altered through the actions of appropriators and managers failing to prevent the destruction of the resource system, as the resource system fails to replenish the stock of resource units. The groundwater basin can therefore be described as a CPR that, depending on use, can shift from a renewable to a non-renewable or less-renewable resource system.

1. Groundwater Subsystem Path Dependence

In the case of groundwater basins in Southern California, subsystem path dependence manifests itself in the form of higher costs imposed on beneficiaries. As mentioned earlier in this section, groundwater basins are fed by surface water percolating in through rain, snowmelt or riparian flows. Most or all reservoirs are replenished in this manner. Without storage, water simply flows to the ocean and cannot be used by appropriators. While this may not be a significant problem for beneficiaries who live in temperate climates, available storage capacity is critical in arid zones, such as Southern California. It is important to understand that deserts are never completely devoid of water; they experience periods of little to no rainfall punctuated by high volume flows (Childs, 2001). Even if pumping decreases over periods of drought, a lack of inflows will increase the time it takes for the basin to reach full capacity (Seo, Mahinthakumar, Arumugam, & Kumar, 2017, p. 38). Capturing surplus surface water for later use as well as recycling water for re-use has been a focus for system managers in Southern California hoping to even out the availability of water for supply (Green, 2007, p. 153).

Groundwater basins are valuable not only for their ability to capture water but also for their water storage capacity. Surface water storage is expensive—about $1700 to $2700 for an acre foot (an acre foot is about 326,000 gallons, which would supply a little over a thousand families for a day) (Choi, McGhee, & Rohde, 2014). In contrast, groundwater replenishment costs around $90 to $1100 for the same amount (Choi et al., 2014). At the lowest end, then, groundwater storage costs are at least 35% less than comparable surface water storage. Groundwater also composes most of the water storage in California, somewhere between 850 million 1.3 billion acre feet as compared to 50 million acre feet held by the state's largest reservoirs (Choi et al., 2014). Groundwater has additional advantages over reservoirs. First, groundwater storage puts the water source closer to the point of consumption. This means that less fragile and expensive infrastructure is needed to move water from storage to beneficiaries, making it less prone to unavailability in the event of an earthquake (Green, 2007, p. 151). Second, since groundwater is stored underground, it is not lost to evaporation. Evaporation not only subtracts from the amount of water available in the reservoir over time through non-productive processes, it can change the chemical composition of water which makes its more expensive to treat (Green, 2007, p. 42). Both phenomena lead to increasing costs per acre foot of water stored in the reservoir, as compared to the groundwater basin.

The advantages of groundwater storage have led to the water production strategy known as conjunctive use (Blomquist, Heikkila, & Schlager, 2004, p. 926; Green, 2007, p. 151). In a conjunctive use arrangement, system managers put imported, recycled, or surface water into the basin so producers or appropriators can pump it later (Green, 2007, p. 152). Since local storage allows producers to store large amounts to of water on site, they can produce or purchase water as it becomes cost-effective based on its supply. This approach to organizing water resources is called a "portfolio" approach, where the system managers integrate the probability that a water supply is available into the expected costs of producing water (Hanak & Lund, 2015; Wolff, 2008). Different resources can be compared for the cost of producing a unit to the benefits of the unit produced and, from this information, can be used interchangeably or packaged with other resources in order to meet their needs (Wolff, 2008, p. 101). Groundwater basins are thus a very useful tool in smoothing the costs of storage, as compared to the cost of building additional reservoirs for the same purpose (Hanak & Lund, 2015, p. 162).

The loss of groundwater storage therefore having a significant impact on the costs to beneficiaries. To compensate for the loss in storage, producers would have to build additional reservoirs, which would increase the price of water for ultimate users or consumers. The number of water sources would also be reduced, decreasing a source of reliable water for system managers to draw on within their portfolio of resources.

2. Sources of Groundwater Resource System Shifts

Groundwater systems can susceptible to subsystem path dependence based on the durability of attributes and system dynamics within the resource system. Durable attributes are difficult for resource system managers to alter, with some attributes having permanent negative effects on resource system processes. While not immediately causing these changes, such attributes may do so over time as more water is removed from the basin. By the time the effects are noticed by production and system managers, irreversible damage to storage capacity and basin functioning may have occurred (Langridge, Brown, & Rudestam, 2016, p. 163). Over-pumping therefore lowers the resilience of the basin, creating a shift that may progress as the practice continues. In the language of path dependence, this is a "lock-in" effect, where future resource use options or management strategies are foreclosed due to initial practices.

Polluting a basin through non-extractive activities can also have unalterable effects on groundwater systems by permanently altering water quality, such as chemical contamination through improper waste storage (Langridge et al., 2016, p. 151). Often, these issues emerge as attributes in one of the groundwater resource system's functioning groups are incorporated into another resource system's set of attributes. In the case of chemical contamination, soil attributes that contain waste are the same attributes that give water certain chemical properties. The overlaps in functioning groups meet the criteria for a cross-system governance effect. These attribute effects can be dramatically increased by appropriator and manager actions. For example, the continued pumping of water by appropriators close to a chemical contamination site often spreads the pollutant, affecting more appropriators and making chemical issues widespread (Ali, 2016; Green, 2007). While basins can be cleaned, it comes at extremely high out-of-pocket and decision-making costs, along with lower resource system productivity. Chemical characteristics can be highly durable and have a large effect on future appropriator activity.

Another cross-system management issue can occur through the elimination of an attribute from the groundwater resource system, such as precipitation and riparian inflows as a result of surface paving. In this case, the groundwater system shares a portion of its functional groups for soils and water inflows with riparian resource systems. Porous topsoil facilitates riparian inflows of water into the groundwater basin and are part of that attribute's characteristics. In Southern California the riparian resource system has been heavily modified by resource system managers for the purposes of flood control (Antos, 2016, p. 70). A part of the riparian system manager's operations has been to pave streams and drainage areas, in effect solidifying the topsoil to create an engineered attribute that prevents water infiltration. Since pavement and chemicals are durable and cannot be easily changed, they continue to affect the functioning of groundwater resource systems negatively.

The results of cross-system shifts featured in the resource subsystem are to some extent affected by the actions of managers. However, it is worth noting that managers of riparian systems are at times distinct from those managing groundwater systems. In other words, they are separated by their resource subsystems, even though their activities with respect to attributes may overlap. Their point of institutional intersection may be at the macropolitical governance level, where disputes between them can be resolved. However, until the issue between them is raised to that level, they operate in reaction to what the other is doing. Therefore, groundwater managers have to react within the institutional framework of governance and constitutional rules in their subsystem to adapt their activity in response to resource system shifts. Like the reduction of pumping and restocking of the groundwater resource system, established forums to prescribe, invoke, apply and enforce rules at the macropolitical governance and constitutional levels can have operational impacts. The ability to resolve conflicts between different agencies is dependent on the ability of the multiple organizations to modify patterns of interaction across the resource system in order to prevent permeant shifts.

C. Groundwater Macropolitical and Subsystem Levels

As mentioned earlier, the land area overlying a specific groundwater basin is the subsystem unit in the analysis. Water production units in a groundwater basin are located above the basin area, creating a distinct boundary separating appropriators from non-appropriators. In this aspect, the governance and constitutional level institutions that are created and used by producer units correspond to the area of the basin, the field within which producers act collectively.

The macropolitical system consists of the shared sets of governance and constitutional arrangements by all subsystems. While the California State Legislature would be one of these forums, the focus here is the California Court System. The courts are accessible by all appropriators, and historically have offered a forum where they could create new constitutional rules for their basin. They also could create agreements enforceable against all the parties within an area’s boundaries area, even if the boundary did not correspond to an existing jurisdiction, as well as decide cases on the basis of equity (Blomquist, 1992, p. 76). Both characteristics gave the courts an ability to define subsystems within the SES without action by the legislature and, moreover, bound by established common law principles if it was clear that they would lead to an inequitable result. Such a forum was able to create new constitutional rules for a resource subsystem through the participation of litigants.

1. Water Rights and Original Management

Before the basins were adjudicated, there were two different legal categories of water in California that were applicable to a groundwater basin. A water right holder that owns land above or beside the water source has an overlying right, in contrast to non-overlying right, which is classified as appropriative (Green, 2007; Blomquist, 1992, Wendell, 2015). In Southern California, overlying pumpers were usually farmers, and the appropriative rights holders were municipalities (E. Ostrom, 1990, p. 107). Appropriative rights are inferior to overlying or riparian rights and can only be invoked if the overlying or riparian producers have excess water (Blomquist, 1992; Hanemann, Dyckman & Park, 2015; Wendell, 2015).[21] For all types of rights, the principle of 'first in time, first in right' also applies. Senior water producers have a superior right to junior producers and therefore can receive water before them if the flow begins to dissipate (Blomquist, 1992; Hanemann, Dyckman & Park, 2015). Inferior rights holders can come to possess a superior right if they take more than their allocation to water over a five-year period without the superior holder taking them to court. After five years, the right solidifies into a superior right to the increased water allocation.

These rights were the default constitutional rules deciding who had the ability to appropriate from the groundwater basin and how allocations were assigned (see Blomquist, 1992, Chapter 4; Hanemann, Dyckman, & Park, 2015 for a historical overview of rights development). Over time, the differences between the types of rights created distinct path dependence issues for groundwater appropriators, the largest being through so-called “pumping races,” as they withdraw water independently. The races occurred as junior appropriative rights holders sought to solidify their right to water over senior overlying holders by taking excessive amounts of water (E. Ostrom, 1990, p. 107). In response, overlying owners also tried solidify their rights, fearing that if they took the appropriative right holders to court that the appropriator would be within their rights to surplus water or that appropriator’s right would have solidified into a permanent right (Blomquist, 1992, p. 68). Coupled with uncertainty concerning the resource unit stock in the groundwater basin, all producers tended to overdraw from the resource system, hoping to extract the most they could from an uncertain right (E. Ostrom, 1990, p. 110).

The scenario presented follows the pattern of extraction seen in an unrestricted CPR appropriation setup in game theory (Gardner, Moore, & Walker, 1997, p. 222; E. Ostrom et al., 1994). In this scenario, since there are no rules to limit how much appropriators draw from the resource system, the pre-existing rights system serves to deplete it. The costs to appropriators also cause the system to tend toward a subsystem path dependent result. While the resource system is being depleted, the appropriation actions taken by appropriators within the resource subsystem leads to increased costs in pumping for each appropriator (E. Ostrom, 1990, p. 108). In other words, the cost is borne by all the appropriators in the subsystem, instead of just the one. Since no one appropriator has responsibility, and there are no rules to assign the costs of basin degradation to the appropriators, the costs accrue to the subsystem in total while no one acts (E. Ostrom et al., 1994). The rights system also encourages a pumping race by making appropriators value only the water they appropriate in the short term over the water they could get in the long term (Negri, 1989, p. 9; E. Ostrom, 1990, p. 109).

Both the dispersion of increased pumping costs and the high valuation of water pumped would lead to basin collapse. The cause of this phenomena was that the current costs to the institutional system from the pumping race did not reflect the costs of future resource units through the diminishment of resource attributes. Gradually, the renewability of the resource system would diminish, until failing completely. The groundwater rights system in this scenario would become meaningless, as appropriators would have to look elsewhere to get water. Future opportunities to operate the resource as renewable would be foreclosed, as well as the possibility of lowering costs for water production.

2. Groundwater Agencies and Institutional path Dependence

The first basin to come under adjudication, both in Southern California and the rest of the state, was Raymond basin (Green, 2007, p. 29). Arbitration was initiated by the City of Pasadena in 1937 in the California Superior Court against other major basin pumpers due to the increased costs they were experiencing from falling water levels and the possibility of importing water (Blomquist, 1992, p. 76). A basin report, requested from California's Division for Water Resources by the parties involved, found that they were in critical overdraft (Blomquist, 1992, p. 77). The new information reframed how producers in the basin perceived their activities. They realized that if they did not modify their institutional arrangements, they would lose the basin completely, which would dramatically increase the costs of producing water (Blomquist, 1992, p. 78). This event, in the language of punctuated equilibrium, was a policy shift in light of new information. Producers within the subsystem now considered the costs of basin collapse and had greater incentive to create new institutional arrangements.

After the report, the adjudication expanded to include all the pumpers within the groundwater basin. Agreement was reached through the consultation of attorneys and engineers, and the basic "mutual prescription" agreement signed by the judge stipulated the following:

> (1) [I]n an overdrawn basin there is no surplus water; (2) the rights of users are invaded by the lowering of water levels once an overdraft occurs; (3) water withdrawn from an overdrawn basin for nonoverlying use continuously, openly, notoriously, and under claim of right for five years, is no longer water claimed under an appropriative right but water claimed by adverse use; (4) as to overlying users, their use of an overdrawn basin constitutes an invasion of each other's right to reasonable use; (5) therefore, all users who have been taking water under claim of right for a consecutive five-year period from an overdrawn basin are mutually prescripting against each other; (6) a continuation of the situation would result in waste of the resource and irreparable harm, and protecting the resource requires limiting the amount taken to the basin safe yield; and (7) the coequal status of the users provides for this limiting through a proportional reduction in their rights to withdraw water. (Blomquist, 1992, p. 80)

Since the decision modified the standing water rights, it was essentially a modification of constitutional rules created uniquely for the Raymond Basin resource subsystem. The California courts were acting at the SES's macropolitical level, and the arbitration, which included all of the appropriators in the basin, was the 'emergence' of the issue.

The decision solidified the rights scheme in California law, and established a line of precedent that could be adopted by future appropriators. Some pumpers, wanting to keep their current, non-prescriptive rights pumping rights, appealed the decision to the California Supreme Court. The court ruled that the adjudication was valid while not overturning the water law established in the state. Since the decision applied to every pumper in the basin, each was placed under similar constraints. On the basis of the new rights scheme, the decision also created various operational rules, including a watermaster to monitor water use in the basin, stipulations for the recording of water levels by pumpers, and a water exchange where pumpers could trade parts of their rights (Blomquist, 1992, pp. 82–83). After the adjudication, Raymond Basin appropriators created a municipal water district and asked that it be annexed to the Metropolitan Water District (MWD), which currently serves as a supplemental supply of water that permeates into the basin for use at an later date (Blomquist, 1992, p. 88).

After the establishment of the Raymond Basin adjudication, others based on its principles followed. The next was West Basin, which, while larger and having additional problems with saltwater intrusion, was dealing with similar issues with appropriator over-pumping (Blomquist, 1992, p. 99). While West Basin formed a municipal water district first, it went to the courts to gain basin-wide compliance to reduce pumping by initiating a "Raymond Basin-like" adjudication, which began with a fact-finding mission (Blomquist, 1992, p. 106). As in Raymond Basin, the referee's report shifted the pumpers' understanding of the resource system, and it required appropriators to take a mutual pumping reduction as stipulated by the adjudication (Blomquist, 1992, p. 107). The organization of the groundwater pumpers also gave them the ability to work with other basins, once a process for forming replenishment districts was established by the California State Legislature in 1955, well as to construct a water barrier to prevent saltwater intrusion using membership fees (Blomquist, 1992, p. 116). Over time, the basin watermaster adjusted rights to account for basin cleanup efforts and reclaimed water, but the basis of constitutional rules has remained relatively unchanged.

Central basin followed the model developed by West and Raymond Basin, though reluctantly. Like West Basin, appropriators formed a replenishment district, but they hoped that they would be able to avoid adjudication by supplementing groundwater supplies (Blomquist, 1992, p. 147). Creating the replenishment district was in of itself an important step in resource governance within the basin through establishing new basin-level constitutional rules. It required that pumpers create a mechanism for purchasing water from MWD through requesting annexation, and the ability to collect fees from pumpers within the basin (Blomquist, 1992, p. 132). The collective action within the district created a precedent for future action within the adjudication.

However, the cost of water from outside the basin was still too high, and it did not keep appropriators and producers within the basin from over-pumping (Blomquist, 1992, p. 123). While appropriators initially thought that the costs of adjudication were too high, it proved to be less costly because of the experience in West Basin (Blomquist, 1992, p. 147). As in the cases before it, the adjudication started with a fact-finding mission about the basin. It provided the basis for the mutual adjustment of each pumper's claim after the majority of pumpers signed on to the adjudication, as well as created the position of watermaster (Blomquist, 1992, p. 148). The basin's governance structure differed from West's in that water rights could be leased, as well as a different formula for how to pay the watermaster. However, the fundamental structure of rights within the resource subsystem was like that created by previous adjudications.

By the time the San Gabriel adjudication occurred, the accumulative lessons from Southern California adjudications had reduced the costs of pursuing them (Blomquist, 1992, p. 157). The basin adjudication process followed a now established pattern of creating a replenishment district, then going into adjudication based on the water basin data now easily available through the replenishment districts. The rights were again decided on the basis of mutual prescription, with the San Gabriel Watermaster assigned to oversee whether pumpers were operating within the safe yield (Blomquist, 1992, p. 172). An institutional innovation that San Gabriel added was a pump tax to fund data collection activities within the basin, but, again, the basic structure of rights remained relatively unchanged (Blomquist, 1992, p. 174). By the time adjudication ended, lawyers and engineers in Southern California thought of the San Gabriel Adjudication as a "formula" that other basins could adopt to prevent the depletion of water basins (Blomquist, 1992, p. 186).

3. Overview of the New Basin Governance System

In each of these cases, the groundwater basin was saved from collapse through the establishment of new high-level rules unique to an individual basin by the appropriators themselves. The critical function of the new rules was to reduce pumping as well as to supplement the flow of water into the basin through imports. To meet these ends, the adjudication always included a fact-finding mission by the watermaster. The data produced by the study created a common understanding of how the basin was operating, which was available to all appropriators, as well as suggested curtailments to water use. The new adjusted rights formed the basis for the basin's new constitutional rules, establishing who was a member, what their share of the water was, and what their responsibilities were to each basin authority—the fees they needed to pay, the pumping data they needed to submit, and the meetings they needed to attend. In other words, the new rights provided a legal basis for constitutional and governance rules, since they could be enforced through collective action based on the terms of the adjudication (Blomquist, 1992, p. 10).

After the adjudication, the appointed water-masters, who had acted as a third party in the adjudications, shifted to a quasi-judicial figure within the governance rules. Their duties now included the collection of information from pumpers, administering pumping rights, and moderating the creation and implementation of new operational water quality rules (Green, 2007). Within this framework, the appropriators established an institutional system to govern their activities and adjust operational rules over time as the resources they depended on fluctuated (Blomquist, 1992).

There were also several features of constitutional and governance rules unique to each basin in terms of the institutional characteristics and the place in the order which adjudications occurred. First, the new system of groundwater rights created within a basin were unique to that basin, forming a resource subsystem governed by a unique set of constitutional rules. These rights made pumpers a part of a unique groundwater organization, a new governance level forum, created by the adjudication (Blomquist, 1992). Second, each basin had different ways to support the monitoring activities of the watermaster. Methods of raising money for the monitor varied from basin to basin, as well as who filled the position of watermaster. In most cases, the Department of Water Resources (DWR) acted as the watermaster, but other times the role has been assigned to a more local entity, such as in the case of the Main San Gabriel Watermaster (Blomquist, 1992, p. 174). Third, each basin had a different time for when it began to receive the supplemental supply of water. Raymond received water supplements after the adjudication, while West, Central and San Gabriel received supplements before adjudication.

Note that conjunctive use requires a different institutional approach than pumping limitations for multiple appropriators sharing a basin. In these cases, producers need to create the position of system manager within the constitutional rules, so that they can support the resource system while allocating the costs among all benefiting units (Schlager et al, 1994, p. 308). Moreover, they also need to craft institutions that can respond to changes in the resource system, such as contamination events that could spread rapidly through the basin as water is infiltrated and extracted (Green, 2007, p. 152).

D. Patterns of Constitutional Adjustment

All the adjudications described followed a similar model. Part of this can be explained through the process of adjudication itself. For the pumping rate reduction to be effective, all the pumpers in the basin needed to be restricted to prevent free riding behavior. Thus, the adjustment of pumping rates in any case would require the creation of new water right. However, looking at the cases purely from this perspective ignores the aspect of the change in costs for adjudication over time. The Raymond Basin case did two things for the wider network of basin resource subsystems: legitimizing a principle for rate adjustment through mutual prescription and providing experience with the process. After the mutual rate adjustment was held to be legal under California's pre-existing water rights system, the costs for applying it in other circumstances were lowered (Langridge et al., 2016, p. 56). When future basins were adjudicated, they could invoke the established principle instead of creating a new one that would likely be subject to legal challenge. The public nature of the adjudications and the small pool of experienced lawyers drawn on to draft them also led to learning on the part of the drafters. When they were approached with the new adjudications, both the lawyers and the appropriators going to court knew established methods for reaching successful agreements. It was therefore not only that the adjudication costs decreased but also that the process for creating rules prescribed in the adjudication decreased by drawing on a common set of accepted rules. The process gradually became easier to the point where the costs of replication came down over time through increasing returns, leading to adjudications becoming the established method for creating constitutional rules.

The empowerment of distinct resource subsystems gave rise to a pattern of adaptive governance through polycentricity. Since the readjustment of rights to match the safe yield or allocated amount through adjudication, it became the established pattern of constitutional rule formation. As the costs of adjudicating lowered, the alternative methods for preventing basin collapse remained underdeveloped. Providing a supplemental supply of water was critical; it was rarely ever developed to the extent that no appropriation rights had to be adjusted. While Central Basin tried at first to pursue this method, it was eventually forced to adjust rights because it was thought to be cheaper than supplementing water. In fact, only one basin in Southern California was never adjudicated (Orange County), and they came to the resolution through creating a replenishment district before Raymond basin came to adjudication. The system of water rights equal in legal status but differing in amounts, which gave appropriators the opportunities to form stakeholder-driven groundwater governance, has led to the creation of a diverse set of public agencies that vary in scope, rules, and regulations (Blomquist, 1992). These agencies are often used to coordinate supplemental supply for the water trades, water spreading, saltwater intrusion barriers, basin decontamination, and other services that could not be handled by individual appropriators or smaller groups (Blomquist, 1992; Green, 2007).

E. Analysis

Groundwater governance in Southern California stood at a critical juncture in the 1940s to the 1970s. Up to that point, they had adhered to a pumping management strategy based on the existing water rights structure in California. Had it continued, this process would have reduced the overall resilience of all groundwater basins. Without significant inflows, basins would have been vulnerable to irreversible damage, such as compaction or salinization, from drought or other external system events. While the water rights system would have remained intact after the degradation of the groundwater system, it would have become peripheral in the wider options available to water managers to obtain a long-term supply. In the language of HI analysis, the chain of causation created by the producers and reinforced by the groundwater basin system would have led to permanent change in the production system. The effective elimination of pumpers as water producers could have significantly altered the organizational landscape. Without getting too deep into hypotheticals, this could have led to the development of an alternative and possibly less polycentric water governance through massive and expensive efforts for water supply.

However, this situation never occurred. Instead, several basins had an objective information gathering apparatus through the courts, and the fact-finding missions realized that their collective pumping was going to permanently alter the resource system. A polycentric system of distinct water agencies formed that continues to provide pumpers with water and providers of water services with options to maintain water supply using bundles of intersecting resource systems. The adjudications have proven remarkably durable, making it unlikely that the system would be able to be rolled back (Langridge et al., 2016, p. 56). The development of an alternative system was happily foregone.

While the diverse systems of governance did preserve many basins, the diversity of design may have been hampered by the institutional path dependence that occurred. As noted by Blomquist (1992), the Mojave River Basin's attempt to adapt the San Gabriel Model of water adjudication failed miserably, and contributed to the system's failure. This occurrence is consistent with the critique touted by Elinor Ostrom against "panaceas" and one-size-fits-all solutions to governance problems (E. Ostrom, 2007, 2014a; E. Ostrom & Cox, 2010). Polycentricity is a remedy for panaceas, but even polycentric solutions can become too path dependent, foreclosing needed options.

Despite the development of effective water agencies and new approaches to management, groundwater systems are not functioning well in some areas of California. Before the effects of waste dumping on groundwater quality were well known, a significant quantity of toxic substances was unsafely deposited in many basins around Southern California (Blomquist, 1995; Atwater, 2002; Green, 2007). The effects of basin pollution on groundwater production vary, but with current technology, certain basins will take a long time to clean up (Green). While appropriators have been good at preventing the spread of contamination by collective action, the loss of storage will continue to impact future water use due to resource subsystem path dependence (Green 2005, Pinectl 2016, Porse 2016). While the adjudications have been effective at limiting the appropriation of water from the basin, reducing the effects of cross-system subsystem path dependence still poses a threat to resource system development over the long term. More institutional development may be needed to develop the capacity needed to prevent permanent damage.

VIII. Conclusion

SES path dependence looks at how both the physical and institutional characteristics of an SES constrain future opportunities for its development and use. This is done through an examination of SES's subsystems, which govern the different resource systems, and the macropolitical system, which connects the subsystem's together. When a resource subsystem cannot access or create governance level forums to alter operational rules, subsystem path dependence is based on the *physical constraints* of the resource system. The physical limitations caused by the subsystem development associated with resource governance results in the degradation of the resource system from renewable to non-renewable. Ultimately the system suffers from the diminishment or elimination of resource units for appropriation.

At the subsystem level, the changes in resource system functionality, and the constraints it poses on resource subsystems, are best understood by analyzing a resource system's component parts, i.e., its resource system attributes. Analyzing the attributes helps analysts determine the characteristics and function of the attributes within the resource system, as well as groups of attributes that create redundancy within the resource system. By finding the relationships between resource attributes, including those that are appropriable resource units, the approximate effects of management can be examined for each set of operations pursued by appropriators and managers. Examples of poor resource governance leading to system degradation include resource unit over-appropriation as well as the introduction of durable attributes or the loss of other resource attributes. The focus of resilience and the adaptive cycle on attribute diversity and redundancy is key to understanding the degradation process and the point at which resource systems fail to produce desired resource units. They also demonstrate that shifts occur as the system passes irreversible thresholds within which resource stability is maintained, presenting a causal chain of events that can be analyzed through the lens of historical institutional (HI) analysis. Since resource degradation is difficult to undo, it leads to subsystem path dependence in the form of higher costs for goods that require the lost resource units. While the result is suboptimal, the costs of reaching a more optimal equilibrium are too high for the subsystem to bear. An example of potential subsystem path dependence can be seen in the case of Southern California groundwater management, as managers sought to prevent attribute loss and keep management strategies flexible. By recognizing the potential for resource subsystem path dependence, based on physical degradation of the resource, managers and appropriators can avoid sub-optimal resource unit production and resource system destruction.

In addition to subsystem analysis, SES path dependence also includes the analysis of path dependence in the macropolitical realm. Institutional innovations in response to perceived threats in resource system stability can move structurally upward into the macropolitical realm, innovations that can become self-reinforcing across the network of resource subsystems. In these cases, the sequence in which solutions emerge matters for the overall development of the SES. These institutional changes across an SES can also become difficult to undo, creating path dependence by increasing costs to reformers who want to see institutional change across all of the resource systems. Institutional path dependence was seen in California groundwater governance with the formation of the “San Gabriel Model,” which had its basis in the first ever groundwater adjudication in state history, and was implemented in subsequent adjudications. While the costs of adopting the model were low, the current costs to changing the arrangement are quite high. The adjudication processes also allowed for the development of constitutional and governance rules unique to each basin, allowing for greater flexibility of operational rules as a result.

The paradox of a flexible system of governance that has inflexible rules is resolved when parsing the different levels of institutional analysis into structural and analytical levels. The constitutional and governance rules at the macropolitical level, while remaining constant, allow for subsystem adaptation to changing circumstances in the resource system. Thus, while the macropolitical system remains stable, subsystems are constantly adjusting rules for their own internal governance.

SES path dependence distinguishes between institutional causes for path dependence and physical causes for path dependence, as well as how these forces interact with each other. The analysis can therefore be presented as two related phenomena: one that looks at the resource system in connection to future subsystem development, the other that looks at alteration in the constitutional rules across several resources. While these phenomena are relatively independent, they exist within the same SES. For example, when appropriators realize that their resource system may constrain them later in the form of subsystem path dependence, their ability to adapt their institutions may emerge into the macropolitical system, precipitating institutional path dependence which may be beneficial. In some cases, the macropolitical constitutional rules may allow them to adapt or create governance rules in ways that support organizational diversity and expand the options for preventing resource system shifts. This is what was seen in Southern California with the development of groundwater management organizations that were governed by distinct sets of constitutional and governance rules. Alternatively, an arrangement could emerge where the subsystem is subsumed into a larger organization, establishing a precedent that eventually establishes a more monocentric system that may be less adaptable.

The last major question that needs to be asked is: how does understanding subsystem path dependence help us maintain resource systems? The answer appears to be that both subsystem and institutional path dependence hold potential to cement optimal resource system arrangements, especially in the case of institutional path dependence. As adaptive polycentric systems emerge, they prevent subsystem path dependence by giving resource system appropriators multiple avenues to alter institutional arrangements or their governance level forums. These institutional innovations can become part of the SES's established institutional configurations available to beneficiaries, and therefore can be transferred to other SESs through the macropolitical system. As more subsystems use the established model, a polycentric arrangement of institutions can emerge across the SES. Each subsystem's institutions would be operated either by the appropriators and managers themselves or those they appoint to act on their behalf. The maturation of adaptable institutions within subsystems would not occur through top down imposition, but through the organic development of institutions at multiple levels across time. To some extent this possibility has been borne out in the real world. As was seen in the Southern California groundwater management cases, institutional path dependence propagated the development of an adaptive, polycentric governance system. These systems provided resource units for the unique needs of the beneficiaries who lived within the basins, as well as maintaining the stability of the resource systems. As seen in examples such as this one, institutional systems early in their development may have opportunities to use macropolitical constitutional rules to create new rules unique to the subsystem, and then propagate the new system across the SES. For institutional designers hoping to establish a polycentric system, knowing such dynamics exist may open ways to encourage the development of effective institutional systems.

While the ability to exploit path dependent behavior may occur in the future, much more work needs to be done in the present. The next steps are to find ways of empirically verifying SES path dependence using the existing California groundwater case. The preexisting case literature should also be examined to find other possible accounts of SES path dependence, and from there, examine which outcomes are the most common. Game theoretical models may also be used to understand resource subsystem path dependence, and how it relates to institutional path dependence. In addition to the empirical studies, more clarification may be needed to distinguish the characteristics of institutional subsystems from macropolitical institutions. The language of resource attributes may also need to distinguish among the different kinds of resource attributes that may exist, as well as ground the effect that resource attributes have on resource system stability.

All this depends on the integration of historical analysis and ecological systems with an institutional perspective on organizations and governance. Future work can be developed only by integrating these distinct fields, in order to answer critical questions about the relationship of human actions to the changing world.

Bibliography

Agrawal, A. (2001). Common property institutions and sustainable governance of resources. *World Development*, *29*(10), 1649–1672. https://doi.org/10.1016/S0305-750X(01)00063-8

Ali, M. H. (2016). *Principles and Practices of Water Resources Development and Management*. Hauppauge, New York: Nova Science Publishers, Inc. Retrieved from http://proxy.houghton.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=1350573&site=ehost-live&scope=site

Aligica, P. D., & Tarko, V. (2012). Polycentricity: From Polanyi to Ostrom, and Beyond. *Governance*, *25*(2), 237–262. https://doi.org/10.1111/j.1468-0491.2011.01550.x

Allison, S. K. (2017). Ecological restoration and environmental change. In *Routledge Handbook of Ecological and Environmental Restoration*. London, UK: Routledge. https://doi.org/10.4324/9781315685977

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective. *Ecology and Society*, *9*(1), art18. https://doi.org/10.5751/ES-00610-090118

Antos, M. (2016). *Social-Ecological and Institutional Barriers to Adaptive Water Management*. University of California Los Angeles. Retrieved from https://escholarship.org/uc/item/0gt1n048

Armitage, D. (2008). Governance and the commons in a multi-level world. *International Journal of the Commons*, *2*(1), 7–32. https://doi.org/10.1080/10826079308019552

Arthur, W. B. (1989). Competing technologies, Increasing Returns, and Lock-in. *The Economic Journal*, *99*(394), 116–131. https://doi.org/10.2307/2234208

Arthur, W. B. (1994). *Increasing Returns and Path Dependence in the Economy*. (U. of M. Press, Ed.), ペインクリニック学会治療指針２. Ann Arbor, MI. https://doi.org/.1037//0033-2909.I26.1.78

Auditor, C. S. California Constitution 1879 (1879).

Barrett, K. R. (1999). Ecological engineering in water resources: The benefits of collaborating with nature. *Water International*, *24*(3), 182–188.

Baumgartner, F. R., & Jones, B. D. (1993). *Agendas and instability in American politics*. University of Chicago Press.

Berkes, F, Folke, C., & Colding, J. (1998). *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. (Fikret Berkes & C. Folke, Eds.) (1st ed.). Cambridge, UK: Cambridge University Press. Retrieved from https://books.google.com/books?id=Q9E_ngEACAAJ

Berkes, Fikret. (2009). Evolution of co-management : Role of knowledge generation , bridging organizations and social learning. *Journal of Environmental Management*, *90*(5), 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Blomquist, W. (1992). *Dividing the Waters: Governing Groundwater i Southern California*. San Francisco: ICS Press. https://doi.org/10.1080/00358535508451943

Blomquist, W., Heikkila, T., & Schlager, E. (2004). Building the agenda for institutional research in water resource management. *Journal of the American Water Resources Association*, *40*(4), 925–936. https://doi.org/10.1111/j.1752-1688.2004.tb01056.x

Bromley, D W, et al. (1992). *Making the Commons Work: Theory, Practice, and Policy*. ICS Press. Retrieved from https://books.google.com/books?id=OTmFAAAAIAAJ

CA Const. art. XI, § 11–13

Capoccia, G., & Kelemen, R. D. (2007). The Study of Critical Junctures : Theory, Narrative, and Counterfactuals in Historical Institutionalism. *World Politics*, *59*(3), 341–369. https://doi.org/10.1017/S0043887100020852

Childs, C. (2001). *The Secret Knowledge Of Water: Discovering The Essence Of The American Desert*. Back Bay Books.

Choi, J., McGhee, G., & Rohde, M. (2014). Recharge: Groundwater's Second Act. Retrieved October 25, 2019, from https://waterinthewest.stanford.edu/groundwater/recharge/

Cleary, E. J. (1967). *The Orsanco Story: water quality management in the Ohio Valley under an Interstate Compact*. John Hopkins.

Cleland, E. E. (2011). Biodiversity and ecosystem stability. *Nature Education Knowledge*, *3*(10), 14.

Cleveland, C., Costanza, R., Eggertsson, T., Fortmann, L., Low, B., Mckean, M., Young, O. (1997). A Framework for Modeling the Linkages between Ecosystems and Human Systems. *Beijer Discussion Papers*, (76).

Cox, M. (n.d.). Advancing a Diagnostic Approach to Addressing Environmental Problems, 1–20.

David, P. A. (1985). Clio and the Economics of QWERTY. *The American Economic Review*, *75*(2), 332–337. Retrieved from https://www.jstor.org/stable/1805621

David, P. A. (2007). Path Dependence: A Foundational Concept for Historical Social Science. *Cliometrica*, *1*(2), 1–26. https://doi.org/10.1007/s11698-006-0005-x

Decaro, D., Chaffin, B. C., Schlager, E., Garmestani, A. S., & Ruhl, J. B. (2017). Legal and Institutional Foundations of Adaptive Environmental Governance. *Ecology and*

Society, *22*(1). https://doi.org/10.1017/CBO9781107415324.004

Dietz, T., Ostrom, E., & Stern, P. C. (2003). The struggle to govern the commons. *Science*, *302*, 1907–1912. https://doi.org/10.1126/science.1091015

DWR. (2003). Basic Groundwater Concepts. In *CALIFORNIA'S GROUNDWATER UPDATE 2003 (DWR Bulletin 118)* (pp. 79–104). Sacramento: DWR. Retrieved from https://water.ca.gov/LegacyFiles/pubs/groundwater/bulletin_118/california's_groundwater__bulletin_118_-_update_2003_/bulletin118-chapter6.pdf

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B., & Norberg, J. (2003). Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment*, *1*(9), 488–492. https://doi.org/10.1890/1540-9295(2003)001[0488:RDECAR]2.0.CO;2

Erie, S. P., & Joassart-Marcelli, P. (2005). Unraveling Southern California's Water/Growth Nexus: Metropolitan Water District Policies and Subsidies for Suburban Development, *1*. https://doi.org/10.1533/9781845699789.5.663

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C., & Walker, B. (2002). Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. *Ambio*, *31*(5), 736. https://doi.org/10.1579/0044-7447-31.5.437

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C. S. (2004). Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology, Evolution, and Systematics*, *35*, 557–581. https://doi.org/10.2307/annurev.ecolsys.35.021103.30000021

Folke, C., Holling, C. S., & Perrings, C. (1996). Biological Diversity, Ecosystems, and the Human Scale. *Ecological Applications*, *6*(4), 1018–1024.

Gallopín, G. (2007). Linkages Between Vulnerability, Resilience, And Adaptive Capacity. In *Workshop "Formal Approache to Vulnerability."* Potsdam, DE: Potsdam Institute for Climate Impact Research, September. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Galloway, D., Jones, D. R., & Ingebritsen, S. E. (1999). *Land Subsidence in the United States*. Reston, VA. Retrieved from https://pubs.usgs.gov/circ/1999/1182/report.pdf

Gardner, R., Moore, M. R., & Walker, J. (1997). Governing a Groundwater Commons. *Econmic Inquiry*, *XXXV*, 218–234.

Green, D. (2007). *Managing Water: Avoiding Crisis in California*. Berkley, CA: University of California Press.

Gunderson, L. H., & Holling, C. S. (2001). *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press. Retrieved from https://books.google.com/books?id=o4u89akUhJMC

Hanak, E., & Lund, J. (2015). Chapter 7. Portfolio Approaches to Reduce Costs and Improve Reliability of Water Supplies. *Sustainable Water*, 151–177. https://doi.org/10.1525/9780520960879-010

Hanemann, M., Dyckman, C., & Park, D. (2015). California's Flawed Surface Water Rights. In A. Lassiter (Ed.), *Sustainable Water* (1st ed., pp. 52–82). Berkley, CA: University of California Press.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248. https://doi.org/10.1126/science.162.3859.1243

Hart, J. F. (1998). *The Rural Landscape*. Baltimore, MD: Johns Hopkins University Press. Retrieved from https://books.google.com/books?id=OqQ6K3lGGooC

Hathaway, O. A. (2003). Path Dependence in the Law- The Course and Pattern of Legal Change in a Common Law System, 101–165.

Hinkel, J., Cox, M. E., Schlüter, M., & Binder, C. R. (2015). A diagnostic procedure for applying the social-ecological systems framework. *Ecology and Society*, *20*(1), 32. https://doi.org/http://dx.doi.org/10.5751/ES-07023-200132

Hogan, J. (2006). Remolding the critical junctures approach. *Canadian Journal of Political Science*, *39*(3), 657–679. https://doi.org/10.1017/S0008423906060203

Hogan, J., & Doyle, D. (2007). The importance of ideas: An a priori critical juncture framework. *Canadian Journal of Political Science*, *40*(4), 883–910. https://doi.org/10.1017/S0008423907071144

Hogan, J., & Doyle, D. (2009). A comparative framework: How broadly applicable is a "rigorous" critical junctures framework? *Acta Politica*, *44*(2), 211–240. https://doi.org/10.1057/ap.2008.36

Holling, C. (1996). Engineering Resilience versus Ecological Resilience. In *Engineering Within Ecological Constraints*. https://doi.org/10.17226/4919

Holling, C. S. (1992). Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs*, *62*, 447–502.

Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-00

Holling, C.S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*, 1–23. Retrieved from https://www.jstor.org/stable/2096802

Holling, C.S. (2001). Understanding the Complexity of Economic, Ecological, and Social

Systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-00

Holling, C S, Allen, C. R., & Gunderson, L. H. (2009). *Foundations of Ecological Resilience*. Washington, DC: Island Press. Retrieved from http://proxy.houghton.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=382538&site=ehost-live&scope=site

Holling, Crawford S. (1986). The resilience of terrestrial ecosystems: local surprise and global change. *Sustainable Development of the Biosphere*, *14*, 292–317.

Inland Empire Utilities Agency. (2019). Personal Interview.

Jacob Weger, Walker DePuy, Katie Foster, Anya Bonanno, Suneel Kumar, Kristen Lear, … Laura German. (2019). Environmental Governance: Broadening Ontological Spaces for a More Livable World. In *Workshop on the Ostrom Workshop 6* (p. 37). Bloomington, IN: Digital Library on the Commons. Retrieved from https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/10455/Environmental governance ontologies %28Paper%29.pdf?sequence=1&isAllowed=y

John, P. (2006). The Policy Agendas Project: A review. *Journal of European Public Policy*, *13*(7), 975–986. https://doi.org/10.1080/13501760600923870

Jones, B. D. (1994). *Reconceiving decision-making in democratic politics: Attention, choice, and public policy*. University of Chicago Press.

Jones, B. D., Sulkin, T., & Larsen, H. A. (2003). Policy punctuations in American political institutions. *American Political Science Review*, *97*(1), 151–169. https://doi.org/10.1017/S0003055403000583

Koontz, T. M., Gupta, D., Mudliar, P., & Ranjan, P. (2015). Adaptive institutions in social-ecological systems governance: A synthesis framework. *Environmental Science and Policy*, *53*, 139–151. https://doi.org/10.1016/j.envsci.2015.01.003

Lampricides and Sea Lamprey Control. (n.d.). Retrieved from http://www.glfc.org/lampricide.php

Langridge, R., Brown, A., & Rudestam, K. (2016). *An Evaluation of California's Adjudicated Groundwater Basins*. Santa Cruz, CA. Retrieved from https://escholarship.org/uc/item/71n7v525

Liebowitz, S. J., & Margolis, S. E. (1995). Path Dependence, Lock-In, and History. *Journal of Law Economics and Organization*, *11*(1), 205–226. https://doi.org/10.2139/ssrn.1706450

Ludwig, D., Walker, B., & Holling, C. S. (1997). Sustainability, stability, and resilience. *Conservation Ecology*, *1*(1).

Mahoney, J. (2001). Path-dependent explanations of regime change: Central America in comparative perspective. *Studies in Comparative International Development*, *36*(1), 111–141. https://doi.org/10.1007/BF02687587

Mahoney, James, & Thelen, K. (2010). “A Theory of Gradual Institutional Change” Explaining Institutional Change: Ambiguity, Agency, and Power. In *Cambridge University Press* (pp. 1–37). https://doi.org/9780521134323

Mäler, K.-G. (2000). Joseph Schumpeter Lecture | Development, ecological resources and their management: A study of complex dynamic systems. *European Economic Review*, (44), 645–665. Retrieved from https://esanalysis.colmex.mx/Sorted Papers/2000/2000 SWE -Hyd Econ.pdf

Mcginnis, M. D. (2010). Building a Program for Institutional Analysis of Social-Ecological Systems : A Review of Revisions to the SES Framework.

McGinnis, M. D. (1999). *Polycentricity and local public economies : readings from the Workshop in Political Theory and Policy Analysis*. *Institutional analysis*. Ann Arbor: University of Michigan Press. Retrieved from http://bvbr.bib-bvb.de:8991/F?func=service&doc_library=BVB01&local_base=BVB01&doc_number=008938435&line_number=0001&func_code=DB_RECORDS&service_type=MEDIA

Menzies, C. R. (2006). *Traditional Ecological Knowledge and Natural Resource Management*. (C. R. Menzies, Ed.). Lincoln, NE: University of Nebraska Press. Retrieved from https://books.google.com/books?id=0l5YfKgEV_wC

Negri, D. H. (1989). The common property aquifer as a differential game. *Water Resources Research*, *25*(1), 9–15.

North, D. C. (1990a). A transaction cost theory of politics. *Journal of Theoretical Politics*, *2*(4), 355–367.

North, D. C. (1990b). *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press. Retrieved from http://proxy.houghton.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=510978&site=ehost-live&scope=site

North, D. C. (1991). Institutions. *Journal of Economic Perspective*, *5*(1), 97–122. Retrieved from https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.5.1.97

O’Neill, C. R. (1997). *Economic Impact of Zebra Mussels-Results of the 1995 National Zebra Mussel Information Clearinghouse Study*. *Great Lakes Research Review* (Vol. 3). Retrieved from https://cybercemetery.unt.edu/archive/nisic/20110630015418/http://www.aguadelastrobrasil.org.br/arquivos/31.pdf

Oakerson, R. J. (1992). Analyzing the Commons: A Framework. In Daniel W. Bromley & D. Feeny (Eds.), *Making the Commons Work: Theory, Practice, and Policy*. ICS

Press.

Oakerson, R. J. (1994). The Logic of Multi-Level Institutional Analysis. In *Workshop on the Workshop conference, Indiana University, Workshop in Political Theory and Policy Analysis, Bloomington, Indiana, June* (pp. 15–19).

Oakerson, R. J. (1999). *Governing local public economies: Creating the civic metropolis*. ICS Press.

Oakerson, R. J. (2004). The Study of Metropolitan Governance. In R. C. Feiock (Ed.), *Metropolitan Governance: Conflict, Competition and Cooperation* (pp. 20–57). Georgetown University Press.

Oakeron, R. J., & Walker, S. T. (1997). Analyzing policy reform and reforming policy analysis: an institutionalist approach. In D.W. Brinkerhoff (Ed.), *Policy Analysis Concepts and Methods: An Institutional and Implementation Focus*, (pp. 21–53), JAI Press.

Osens, B. A. C., Gunderson, L. A., & Haffin, B. R. C. (2014). The Adaptive Water Governance Project : Assessing Law , Resilience And Governance In Regional Socio- Ecological Water Systems Facing A Changing Climate. *Idaho Law Review*, *51*(1), 1–27. Retrieved from https://poseidon01.ssrn.com/delivery.php?ID=203111070087069013002108108098067075015044057006032032065030126076013069081007028028002059037127043063028106070100106125089028103023040033028127106086081123020094001023077088030112018000109118077008104024010100 0

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action* (1st ed.). Cambridge, UK: Cambridge University Press. Retrieved from https://books.google.com/books?id=4xg6oUobMz4C

Ostrom, E. (2005). *Understanding Institutional Diversity*. Princeton NJ: Princeton University Press. Retrieved from https://books.google.com/books?id=-s5tQgAACAAJ

Ostrom, Elinor. (1999). Institutional Rational Choice: An Assessment of the Institutional Analysis and Development Framework. In P. Sabatier (Ed.), *A Comparison of Frameworks, Theories, and Models of Policy Processes* (pp. 21–64). Boulder, CO: Westview Press.

Ostrom, Elinor. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15181–15187. https://doi.org/10.1073/pnas.0702288104

Ostrom, Elinor. (2014a). Beyond markets and states: Polycentric governance of complex economic systems. In *Nobel Lectures: Economic Sciences: 2006 - 2010* (pp. 408–444). https://doi.org/10.1142/9789814635585_0004

Ostrom, Elinor. (2014b). Do institutions for collective action evolve? *Journal of Bioeconomics*, *16*(1), 3–30. https://doi.org/10.1007/s10818-013-9154-8

Ostrom, Elinor, & Cox, M. (2010). Moving beyond panaceas: A multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation*, *37*(4), 451–463. https://doi.org/10.1017/S0376892910000834

Ostrom, Elinor, Gardner, R., & Walker, J. (1994). *Rules, games, and common-pool resources*. University of Michigan Press.

Ostrom, V. (1962). The water economy and its organization. *Nat. Resources J.*, *2*, 55.

Ostrom, V. (1963). Property, Proprietorship and Politics, (47), 16. Retrieved from http://hdl.handle.net/10535/1044

Ostrom, V. (1971). *Institutional Arrangements in Water Resource Development*. *NWC-SBS-72-034*. Arlington, VA. https://doi.org/10.2307/3144627

Ostrom, V. (1972). Polycentricity (Part 1). In M. D. McGinnis (Ed.), *Polycentricity and Local Public Economies* (pp. 52–74). Ann Arbor, MI: University of Michigan Press.

Ostrom, V. (1994). *The meaning of American federalism: Constituting a self-governing society*. ICS Press.

Ostrom, V., & Ostrom, E. (1977). Public Goods and Public Choices. *Alternatives for Delivering Public Services: Toward Improved Performance*, 7–49. https://doi.org/10.1007/978-3-662-44143-5_5

Ostrom, V., Tiebout, C. M., & Warren, R. (1961). The organization of government in metropolitan areas: a theoretical inquiry. *American Political Science Review*, *55*(4), 831–842.

Peterson, G., Allen, C. R., Peterson, G., Allen, C. R., & Holling, C. S. (1998). Ecological Resilience, Biodiversity, and Scale. *Ecosystems*, *1*, 6–18.

Pierson, P. (2000a). *Increasing Returns, Path Dependence, and the Study of Politics*. *Source: The American Political Science Review* (Vol. 94). Retrieved from https://www.jstor.org/stable/pdf/2586011.pdf

Pierson, P. (2000b). The Limits of Design: Explaining Institutional Origins and Change. *Governance*, *13*(4), 475–199.

Pierson, P. (2004). *Politics in Time : History, Institutions, and Social Analysis*. Princeton: Princeton University Press. Retrieved from http://proxy.houghton.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=390519&site=ehost-live&scope=site

Pierson, P., & Skocpol, T. (2002). HISTORICAL INSTITUTIONALISM IN

CONTEMPORARY POLITICAL SCIENCE. In *Political Science: State of the Discipline* (pp. 693–721).

Protection Committee on Salmonids Management of Pacific Northwest Anadromous. (1996). *Upstream: salmon and society in the Pacific Northwest*. Washington, DC: National Academy Press.

Quevauviller, P. (2008). *Groundwater Science and Policy : An International Overview*. Cambridge: Royal Society of Chemistry. Retrieved from http://proxy.houghton.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=496355&site=ehost-live&scope=site

Redford, E. S. (1969). *Democracy in the administrative state*. New York: Oxford University Press.

Rietkerk, M., Dekker, S. C., Ruiter, P. C. De, & Koppel, J. Van De. (2004). Self-Organized Patchiness and Catastrophic Shifts in Ecosystems, *305*(September), 1926–1929.

Sabatier, P. (1999). The Need of Better Theories. In P. Sabatier (Ed.), *A Comparison of Frameworks, Theories, and Models of Policy Processes* (pp. 3–17). Boulder, CO: Westview Press.

Sabatier, P. A. (Ed.). (1999). *A Comparison of Frameworks, Theories, and Models of Policy Processes*. *Theories of the Policy Process*. Boulder, CO: Westview Press. https://doi.org/10.1081/E-EPAP2-120041405

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, *413*(October), 591–596.

Schlager, E., Blomquist, W., & Tang, S. Y. (1994). Mobile Flows, Storage, and Self-Organized Institutions for Governing Common-Pool Resources. *Land Economics*, *70*(3), 294–317. https://doi.org/10.2307/3146531

Schmidt, V. A. (2010). Taking ideas and discourse seriously: Explaining change through discursive institutionalism as the fourth 'new institutionalism.' *European Political Science Review*, *2*(1), 1–25. https://doi.org/10.1017/S175577390999021X

Schmitz, O. J. (2010). *Resolving ecosystem complexity (MPB-47)* (Vol. 51). Princeton University Press.

Scholz, R. W., & Schnabel, U. (2006). Decision making under uncertainty in case of soil remediation. *Journal of Environmental Management*, *80*(2), 132–147.

Seo, S. B., Mahinthakumar, G., Arumugam, S., & Kumar, M. (2017). Assessing the resiliency of surface water and groundwater systems under groundwater pumping. *Hydrology and Earth System Sciences Discussions*, 1–47. https://doi.org/10.5194/hess-2017-402

Shepsle, K. A. (1986). Institutional Equilibrium and Equilibrium Institutions. *Political Science: The Politics of Science*, 51–81. https://doi.org/10.1177/0951692889001002002

Sheridan, M. J. (2009). The Environmental and Social History of African Sacred Groves: A Tanzanian Case Study. *African Studies Review*, *52*(1), 73–98. Retrieved from http://www.jstor.org/stable/27667423

Siegle, R., & Ahlers, D. (2004). *Brown-Headed Cowbird Management Techniques*. *US Department of the Interior, Bureau of Reclamation,*.

Simon, H. A. (1957). *Models of man social and rational: mathematical essays on human behavior in a social setting*. Wiley.

Sproule-Jones, M. (1993). *Governments at work: Canadian parliamentary federalism and its public policy effects*. University of Toronto Press, Toronto CA.

Steinmo, S. (2008). Historical Institutionalism. In D. Della Porta & M. Keating (Eds.), *Approaches in the Social Sciences,* (1st ed., pp. 150–178). Cambridge, UK: Cambridge University Press. Retrieved from http://spot.colorado.edu/~steinmo/HI.pdf

True, J. L., Jones, B. D., & Baumgartner, F. R. (1999). Punctuated Equilibrium Theory: Explaining Stability and Change in Public Policymaking. In P. A. Sabatier (Ed.), *A Comparison of Frameworks, Theories, and Models of Policy Processes* (pp. 155–187). Boulder, CO: Westview Press.

Vengosh, A. (2003). Salinization and Saline Environments. In *Treatise on Geochemistry* (Vol. 9, pp. 1–35). Elsevier. https://doi.org/10.1016/B0-08-043751-6/09051-4

Vergne, J., & Durand, R. (2010). The Missing Link Between the Theory and Empirics of Path Dependence: Conceptual Clarification, Testability Issue, and Methodological Implications. *Journal of Management Studies*, *47*(4), 736–759. https://doi.org/10.1111/j.1467-6486.2009.00913.x

Walker, B. H. (1992). Biodiversity and Ecological Redundancy. *Biology*, *6*(1), 18–23. Retrieved from https://www.jstor.org/stable/pdf/2385847.pdf

Walters, C. (1986). *Adaptive Management of Renewable Resources*. (W. Getz, Ed.) (1st ed.). New York, NY: Macmillan Publishing Company. Retrieved from http://pure.iiasa.ac.at/id/eprint/2752/1/XB-86-702.pdf

Warne, A. (2016). *Purple Loosestrife: Best Management Practices in Ontario*. *Ontario Invasive Species Council*.

Wilson, J. (2002). Scientific Uncertainty, Complexe Systems and the Design of Common-Pool Institutions. In P. Stern, E. Ostrom, T. Dietz, & N. Dolsack (Eds.), *The Drama of the Commons* (p. 534). https://doi.org/10.17226/10287

Winter, T. C. (1999). Relation of streams, lakes, and wetlands to groundwater flow systems. *Hydrogeology Journal*, *7*(1), 28–45. https://doi.org/10.1007/s100400050178

Wolff, G. (2008). Calculating constant-reliability water supply unit costs. *Water Policy*, *10*(1), 95–104. https://doi.org/10.2166/wp.2007.032

Wood, R. S. (2006). The dynamics of incrementalism: Subsystems, politics, and public lands. *Policy Studies Journal*, *34*(1), 1–16. https://doi.org/10.1111/j.1541-0072.2006.00153.x

Zittoun, P., & Peters, G. (Eds.). (2016). *Contemporary Approaches to Public Policy*. *Contemporary Approaches to Public Policy*. https://doi.org/10.1057/978-1-137-50494-4

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[1] There may also be unique characteristics for resource systems that provide different goods or services.
[2] In her analysis, Elinor Ostrom refers to governance level as the collective choice level (Ostrom, 2005, p. 58)
[3] Positive feedback as used here is analogous to increasing returns (Pierson, 2000a, p. 254)
[4]Vergne & Durand (2010) recommend that further empirical analysis be done to conclusively demonstrate the existence of path dependent behavior. The author believes that the rule theory established in *Understanding Institutional Diversity* (2005) can provide the framework for creating such a test, and it would be beneficial as supporting evidence in this article. However, this analysis remains to be fully explored.
[5] Resource system attributes are assumed to not be resource systems themselves. While they can have features of an adaptive cycle, like what Holling (2001) ascribes to species, they do not consistently display these qualities, such as in non-living attributes such as soil chemical composition and air quality. While it is possible in this framework to divide and subdivide resource system elements, such divisions may give false ideas about the reach of management decisions and create incorrect causality.
[6] The process by which attributes are given relationship to each other can be self-organized (see Folke et al., 1996), or be intentionally designed to include elements of self-organization as proposed in ecological engineering (see Barrett (1999) for an example of ecological engineering as applied to water systems). Elements of both could in this frame work be possible within an ecosystem, but it is outside the scope of my argument to make a claim about what an appropriate approach might be.
[7] Understanding resource systems in this component-based way is analogous to the building block approach used to simplify ecosystems in ecology (Schmitz, 2010, p. 24). By adopting a model of ecosystems like the building blocks model, it is natural that similar criticisms can be lodged at the former as they can with the latter. In this case, the solution is not entirely satisfactory since it reduces complex interactions between attributes to a system that can be easily understood by stakeholders. This observation is critical considering the argument I goes on to make, that in certain resource systems the stakeholders cannot easily understand the forces at play in their resource system. However, for understanding the relationship of resource system attributes in connection with institutions, the solution can be considered adequate as it addresses the relationship of an operational rule to the resource system.
[8] Resource cycles can be conceived as being nested, where one smaller adaptive cycle is within a larger adaptive cycle. However, it should be noted that this analogy may create a misconception that there are clear boundaries that separates one cycle from another. This is not the case, and as it is with many models, the separation between adaptive cycles might lead some to lead to overly broad generalizations.
[9] The characterization of events external to the ecosystem refers to events that the ecosystem plays a role in, such as climate. In this framework it is possible to expand the analysis to wider spatial and temporal scales.

However, at those points the number of attributes that would drive resource system and ecosystem functions would be too large for any single management legislation.
[10] The difficulty of separating attributes into different systems may mean that a thorough language about attributes needs to be developed. However, the language here has been deemed adequate for this discussion.
[11] Thanks to Ronald Oakerson for helping me clarify this distinction.
[12] These actions by individuals and organizations within the subsystem are analogous to 'policy images' discussed in Baumgartner and Jones 1994, Pg. 31, and 'agenda setting', page 5.
[13] The institutional tradition being drawn on here is punctuated equilibrium theory, a major institutional analysis method drawn on in this work. Readers familiar with this theory will note that the conception of constitutional and governance level institutions does not traditionally occur within this body of scholarship, leading one to question its presence here. To some extent this question is justified. Since Punctuated Equilibrium theory does not usually include general specifications about what institutional level decisions are occurring at, it is understandable why some would object to their inclusion here. From this perspective, it is forcing the theory to consider aspects of institutions that it was never developed to do. However, the author feels justified in the inclusion of institutional levels for two interrelated reasons. First, the presence of institutional levels does not exclude the existence of macropolitical systems or subsystems. They instead offer greater specificity of the institutions being considered at each level in the analysis. Second, Punctuated Equilibrium theory takes the existence of forums for communication and decision-making for granted. The creation of policy images within political subsystems is precluded on the existence of institutions that form the basis of policy forums, which are outlined on governance level institutions. The points here are supported by the characterization made by Sabatier in his comparison of the two frameworks, discussed on page #, and Jones in *Reconceiving Decision Making in Democratic Politics*, Pages 158-161.
[14] Some macropolitical institutions may span multiple SES's, such as in the context of the state constitution which covers multiple ecological regions. However, for the analysis of SES path dependence, this definition is workable. Adding further complexity would only serve to make the analysis impotent by breaking institutions into smaller and smaller categories, to the point where it becomes unworkable.
[15]The degree to which IAD and HI are in contention with each other is well outside of the scope of my argument, but a few comments should be made nonetheless. The two biggest differences between the two is their assumptions about the rationality of actors and the equilibrium of institutions. IAD assumes that individuals and organizations within an institutional system are intendedly rational as they pursue selected goals with limited information (P. A. Sabatier, 1999, p. 12). The premise of intended rationality seems to draw analysts to focus on stakeholder learning and the intentional design of institutions and organizations to cope with SES challenges (Berkes, 2009, p. 1692; Koontz et al., 2015, p. 7; Wilson, 2002, p. 6). Most of the research is therefor done on institutions that provide frameworks for adaptive governance (Decaro et al., 2017; Koontz et al., 2015, p. 5; Osens, Underson, & Haffin, 2014; Also see Walters, 1986). In contrast, HI views rationality as being bounded by the focus of the individual based on given information (Simon, 1957). These assumptions tie into the concept of agenda setting.
Any contrast between the two methods is made clearer when examining their views in respect to institutional design. IAD puts significant emphasis on the ability of individuals and organizations to create institutions that serve their collective intrest through implementing mechanisms to incorporate new information (Berkes, 2009, p. 1699; E. Ostrom, 1990, p. 61; Ostrom, 2014b, p. 14). Institutions and governance organizations, in other words, change in response to system conditions over the governed system. While they can assume new or distinct operations, they do not deviate from the directives of the designers. The HI method, on the other hand, presumes that institutions can evolve over time in ways that the designers did not intend (Pierson, 2000b, p. 477).
These theories are not incompatible if we allow individual preferences to change over time as institutions to evolve. In comparison to other institutional theories that are branded as "rational choice", IAD offers significant more flexibility. Such changes are simply assumed in IAD rather than the primary focus of analysis.
[16]See footnote 5
[17]Punctuated equilibrium can be better thought of as a metaphor from ecology
[18]The language here is borrowed from the term 'critical junctures' used in the HI method. Critical junctures are not so much of a theory as it is a way to describe the political mobilization process related to path dependence. A critical juncture is "a period of change, which typically occurs in distinct ways in different

countries (or other units of analysis) and which is hypothesized to produce distinct legacies" (Collier & Collier, 1991 quoted in Capoccia & Kelemen, 2007, p. 347). Critical junctures is the primary way that sequential events are described in the analysis.

[19]The framework for analyzing resource systems in terms of resource system attributes and adaptive cycles could be used to analyze the choices made between what resource units to maximize, and long-term consequences. However, this other type of path dependent behavior, if it can be called that, lies outside of the scope of my paper.

[20] The brown-headed cowbird is endemic to Texas, but managers have begun to treat it like an invasive due to its effects on songbird populations.

[21]The history of California water rights, while not essential to a basic understanding of the rights system that was created, is worth mentioning here given the nuance it adds to the basic structure of rights in the wider state. Pre-1914 riparian and riparian appropriative rights do not have specific limits on the amount allotted to producers. For all intents and purposes, they are unlimited (Hanemann, Dyckman & Park, 2015). Pre-1914 rights are also considered to be the most senior of rights, meaning that the only solution for a conflict between two pre-1914 rights is adjudication, given that both of their seniority is equal (Hanemann, Dyckman & Park). However, these issues do not have significant impact on Southern California, and have a larger impact in the central part of the state. The one major seniority debate that has occurred within southern California was Los Angeles's senior rights to the Los Angeles River and the waters flowing from the San Fernando Valley to Arroyo Secco (Green, 2007; Blomquist, 1992) from the original mission's rights.