Assessing the Adaptive Capacity of Idaho's Magic Valley As a Complex Social-Ecological System

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by

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Authorization to Submit Thesis

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Abstract

Similar to a majority of the Western United States, Idaho's Magic Valley region is predicted to experience future climate uncertainties, including a warming climate, variable precipitation events, and a decrease in water availability during prime irrigation months, as well as demographic and land use changes. With water users already encountering conflict in this water scarce region, the ability for the Magic Valley and its encompassing Upper Snake River Basin to adapt to future climate uncertainties is vital for ensuring the region can sustain its agribusiness economy. This research assesses the region as a complex social-ecological system and takes an explorative view into the evolution of the Magic Valley's institutions in charge of water administration and management to understand how they have increased their adaptive capacity over time in response to system disturbance. Observations from this research can help to highlight both the adaptive capacity of this region to respond to future disturbances as well as its vulnerabilities to inform future planning initiatives toward resiliency and sustainability for the region's water supply.

Dedication

"Whiskey is for drinking; water is for fighting over."

- Mark Twain

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1. INTRODUCTION: RESEARCH GOALS

This research sets out to explore Idaho's Magic Valley as a social-ecological system (SES) to assess the unique connection of social systems in the region to the water resource base. By doing so, this research can identify the characteristics and institutions specific to the region that help inform the region's adaptive capacity and its ability to manage resilience. Identifying the region's adaptive capacity is important to understand whether it will be able to sustain its economic base in the face of future uncertainties and retain its status as an agricultural leader for the state of Idaho. The results of this research can offer a method for other Western river basin-based SESs to assess their own adaptive capacity and ability to manage for resilience.

To perform this analysis, this thesis will be split into eight main sections, with this introductory section being the first. The second chapter will define an SES and will introduce the concepts of adaptive capacity and resilience. The third chapter will explore three frameworks that exist for analyzing SESs and the degree of their adaptive capacity. The fourth chapter will introduce Idaho's Magic Valley and the Upper Snake River Basin, and will highlight some of the basic geographic and hydrologic characteristics that are specific to the region and important to its function as an SES. The fifth chapter will explain the methodology that will be used to apply the framework for analyzing the region as an SES. The sixth chapter will discuss the evolution of the region over time and will explore the defining characteristics that fit within the framework of interest. Finally, using the results from the analysis, the seventh section will discuss the adaptive capacity of the Magic Valley as an SES and its ability to manage resilience and achieve sustainability in the face of future uncertainties.

2. THEORY: SOCIAL ECOLOGICAL SYSTEMS AND RESILIENCE

This section will introduce some of the theory behind the concept of SESs and how this theory can be applied to Western river basin-based systems.

Social-Ecological Systems

To begin discussing SESs and the frameworks available for assessing their adaptive capacity, it is important first to define what an SES is. As the name implies, an SES is a system that is composed of interconnected subsystems of both social and ecological nature–the social component commonly referring to the people and social institutions living and working within a society or region, and the ecological components consisting of the resource(s) that the society relies on for their livelihood (Anderies et al., 2004). Livelihood in this sense does not just include resources that are used for economic gains, but also for recreational, environmental, aesthetic, spiritual, and other values.

When assessing any SES, a boundary must be established to distinguish which components lie within the system and affect it more directly, and which lie outside and do not directly contribute to the state of the system. The boundary of an SES is considered to include the expanse of the landscape to which the ecological components, or the resource base, extend and the area in which the social component lives and works while interacting with the resource in question. For example, as SES in the form of a lobster fishery in Maine would extend to those areas where the lobster habitat is found and to those areas where the harvesters reside and the markets related with lobster harvesting are located (Ostrom, 2009).

Although often retained within a system boundary, there are many external factors that can affect the internal workings of the SES. For example, if state or federal legislation were to be passed that set a quota on how many units of lobsters could be harvested per season or declared that lobsters were to be protected from harvesting altogether, these external societal decisions would affect the internal workings of the lobster fishery as an SES. In the same way, if ocean acidification were to increase to the point that lobsters were no longer able to live to an appropriate harvesting age, this external ecological effect would also have an impact internally on the lobster fishery as an SES. When analyzing any focal SES, it is important to think of the subsystems as existing within SES boundaries but it is also important to remember that there are many overarching external societal and ecological factors that can impact an SES.

Thinking of the many connections between societies and their resources within an SES is important because societies are inextricably linked with the ecological systems in which they are embedded (Walker & Salt, 2006) – societies would not exist without the resources they depend on, and in turn, the actions of a society affect the condition of their resource base. In the Western United States, SESs have existed for centuries with the earliest examples being the settlement and use of the land and its resources by indigenous peoples. One well-known example of an early SES is the society of the Hohokam people in Arizona whose success can be attributed to their manipulation of scarce water resources to provide food and sustenance for their population. Through intricate irrigation networks, the Hohokam successfully watered their regional landscape and sustained their populace well for centuries (Murphy, 2012).

Today, the Western United States is peppered with SESs that are like the Hohokam irrigation systems in the way that they make use of scarce water resources by constructing irrigation networks for transporting water across arid landscapes to support societies, but on a much larger scale. These irrigation systems harness water through the construction of intensive man-made projects that manipulate the flow and timing of water to ensure the best use of water in times of need, and the storage of water when it is not needed. These irrigation-focused SESs are frequently found in river basin-based systems of an arid character that contain areas considered prime farmland. They consist of complex networks of dams, diversions, pumping systems and canals that transport water to be used for various agricultural, domestic, commercial, municipal, and industrial uses across the landscape (Grace, 2012; Worster, 1985). The maintenance and operation of these irrigation systems is overseen by many overlapping levels of governance, from local management on the field level to the regulation of water supply at a federal level. Daily administration of water to users, and the assurance that there will be a consistent supply of water, is essential to the economy of Western irrigation communities and requires frequent communication at all levels.

Although the Hohokam had an irrigation network that served their society well for centuries, their society collapsed after more than a thousand years of progression. Research into why this collapse happened suggests that as the society's population grew, infrastructure was enhanced to allow for larger-scale irrigation, and with this, a more hierarchal system of operation and maintenance was required to accommodate more advanced water administration (Murphy, 2012). A power imbalance developed as the management of irrigation networks became less user-oriented and locally based, and the miscommunication among parties about local conditions of the region resulted in an irrigation system that ultimately became vulnerable to seasonal variation in water supply (Anderies, 2006). Although at the time it may have been thought that a more centralized method of governing this water system would effectively improve distribution of water as demand for it grew, the Hohokam system changing from a user-oriented governance structure to one more centralized seems to have decreased the ability of the system to adapt effectively to external disturbance, eventually leading to the collapse of their society.

More modern-day irrigation systems are just as vulnerable as the Hohokam society to external disturbances, with water-based SESs in general being particularly vulnerable to climate change (Payne, Wood, Hamlet, Palmer, & Lettenmaier, 2004). The use of SES science to enhance and manage for the sustainability of these systems has gained value in recent years, with an emphasis on managing the resilience of these systems in the face of climate change (Cosens & Fremier, 2014). Resilience of systems is thought of in different ways, but for the purposes of this research will be defined as the properties of a system that influence its capacity to adapt to disturbances and changes in the environment and continue to provide a full range of ecosystem services in the face of change or the undergo nonlinear change in the face of that change (Holling, 1973). In regard to Idaho's Magic Valley as an SES, this research will focus on assessing the capacity of the system's social components – the individuals and groups that actively work to manage the state of the system (Walker et al., 2004) – to adapt and manage resilience of the region's economic base. Through assessing the adaptive capacity of the Magic Valley, this research aims to identify the institutions and the role they play in managing for resilience, and the ability of the system to continue to provide a consistent water supply while enduring various disturbance and system changes. The results of this research will offer insight for similar Western river basin-based SESs into assessing their own adaptive capacity and their ability to continue providing the ecological services vital to ensuring a sustainable system in the face of future uncertainties.

3. THEORY: FRAMEWORKS FOR SES ANALYSIS

Many frameworks have been developed to analyze the structure and interactions of SESs that inform their adaptive capacity and sustainable character through providing a common set of relevant variables, their subcomponents, and their interactions (Anderies et al., 2004; Ostrom, 2009). As a vital SES to the economic wellbeing of Idaho, it is important to identify the component parts of the Magic Valley and its encompassing Upper Snake River Basin (USRB), their interactions, and their responses in regard to changes in the system to identify the adaptive capacity of the region. In the face of projected changes, including climatic (Klos et al., 2014) demographic (IDOL, 2018), and land use changes that can all affect the region's future water supply and demand, assessing the adaptive capacity of the region will inform its ability to remain resilient and ensure a sustainable water resource base for all water uses.

Three general frameworks will be discussed that all collectively seek to classify systems and explore the individual characteristics that inform their ability to achieve resource sustainability. The first is a framework developed by Anderies et al. (2004) and defines an SES as an interconnected system that has four main components – the resource, resource users, public infrastructure, and public infrastructure providers. Emphasis in this framework is on the specific interactions that occur between these four components, specifically the role of designed social institutions, and how the robustness of the system is informed by this design (Anderies et al., 2004). The second framework is a set of eight principles offered by Elinor Ostrom that have been identified as beneficial to the successful management of common-pool resources. The eight principles are: clearly defined boundaries; congruence between appropriation and provision rules and local conditions; collective-choice arrangements; monitoring; graduated sanctions; conflict-resolution mechanisms; minimal recognition of rights to organize; and nested enterprises (Ostrom, 1990). The last framework is the theory of Complex Adaptive Systems, or those SESs with multiple levels and dimensions of interaction among their components that allow for flexibility in adjusting to change (Lansing, 2003; Walker & Salt, 2006). This framework involves identifying a system's panarchy and how its degree of complexity and the formation of adaptive cycles can inform instances of emergence and self-organization, and can either help or hinder a system's adaptive capacity and resilience. These characteristics – panarchy, adaptive cycles, emergence, and self-organization – have been identified in similar river basin-based SESs as important drivers of a system's ability to adapt and remain resilient (Cosens et al., 2018), making the CAS framework preferable for assessing the adaptive capacity of the Magic Valley.

A Framework for Analyzing the Robustness of Social-Ecological Systems

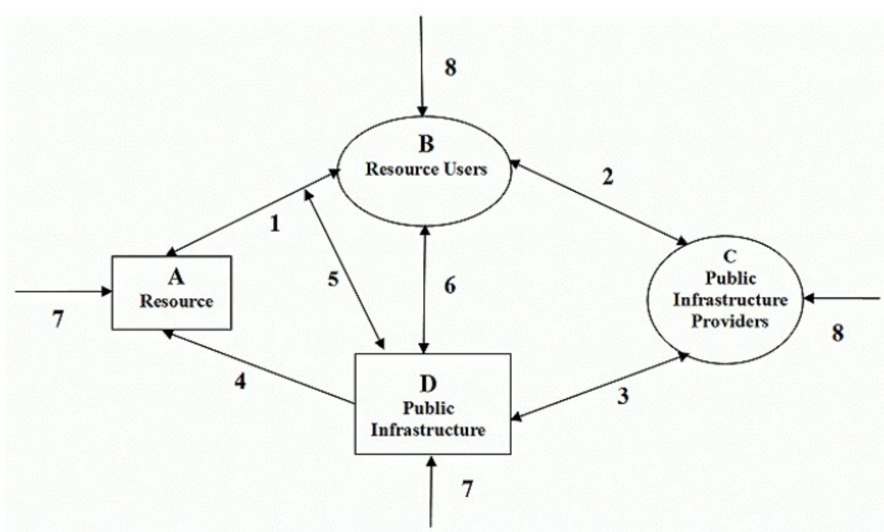

Figure 3.1: Conceptual Model used by Anderies et al. in their framework for analyzing the robustness of social-ecological systems (From Anderies et al. (2004) n.p.)

Anderies et al. (2004) define an SES as an ecological system intricately linked with and affected by one or more social systems, with the interconnections between the two substantially influenced by their institutional design. Their framework involves identifying the four major components that are common to SESs with designed social institutions - primarily the resource, resource users, public infrastructure, and public infrastructure providers - and where relationships often exist between these four components (Figure 3.1). By offering a framework to identify what kind of relationships exist between a system's components, the authors provide a method for observing the designed aspects that influence these relationships. Importance is given to the design of institutions that facilitate how resource users interact with the individuals that provide the public infrastructure facilitating the harvest the resource in question.

The process for applying this framework is to first organize a system into the four main components of an SES identified in Figure 3.1 as well as their interactions (denoted as numbers 1-8 in Figure 3.1) that exist among these components. A description of these interactions corresponding to the numbers in Figure 3.1 is provided in Table 3.1, with a descriptive example of what that interaction would look like in an irrigation community. By following the conceptual model above, the authors intend to provide a framework that can help identify the often overlooked key drivers in SESs that are important to understanding the robust nature of a system. The authors argue that these often-overlooked key interactions include the strategic actions between agents, the rules devised to constrain the actions of agents, and the collective-choice process used to generate the rules. These key interactions are often consciously designed rather than the result of natural processes, such as the checks and balances and self-organization of a forest in succession. Emphasis on the design of SESs reiterates the need to explore more of the institutional side of SESs rather than focusing on ecological factors such as the ability of a resource to bounce back in the face of disturbance.

Table 3.1: Interactions that exist between the main components of social-ecological systems

#	*Interaction*	*Example*
1	Between resource and resource users	Appropriation of water by water users
2	Interaction of resource user with public infrastructure providers	Voting for public infrastructure providers; public infrastructure providers assessing fees to users for the distribution of water; water user participation in rule development
3	Between public infrastructure providers and public infrastructure	The operation and maintenance of irrigation infrastructure by irrigation company; monitoring and enforcement of rules
4	Between public infrastructure and resource	Unlined canals resulting in surface water infiltrating to ground water resources; diversion structures; presence or absence of structures for return flow; dams
5	Between public infrastructure and resource dynamics	Alteration of low timing by dams; alteration of water quality by dams and return flows; reduction in minimum flow by diversions
6	Between resource users and public infrastructure	In smaller systems, this interaction is seen when water users have a more active role in the operation of infrastructure
7	External forces on resource and infrastructure	Disturbances including climate change, drought, flooding; lack of funding; policy incentives driving cropping patterns, therefore altering irrigation demands
8	External forces on social actors	Disturbances including major changes in political system, rising populations and increasing demand for water

By focusing on the role of institutions in SESs, Anderies et al. (2004) choose to use the concept of 'robustness' as a measure for SESs rather than using resilience and self-organization. Resilience is described by Anderies et al. as "the amount of change or disruption that is required to transform the maintenance of a system from one set of mutually reinforcing processes and structures to a different set of processes and structures". By using this definition stemming from ecology (Holling, 1973), the authors argue that it is difficult to apply this measure to systems that are consciously designed, such as SESs that develop institutions to lead resource management initiatives. Rather, they use the concept of robustness as a more appropriate measure, which they define as "the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment". By using robustness as a measure and focusing on the institutions within an SES, Anderies et al. (2004) suggest that a system is robust if the designed components can prevent the ecological components of the system from moving into a state in which it is no longer able to support a human population, or that will cause long-term suffering. It is important to note that Ostrom's (1990) eight design principles, which are discussed in the next section, had heavy influence in the development of this framework by Anderies et al. (2004). The authors argue that the existence of these design principles within systems increases their overall robustness and ability to achieve long-term sustainable resource management.

Ostrom's Eight Design Principles

Ostrom (1990) discusses the management of common-pool resources (CPR), which she defines as natural or man-made resource systems that are large enough to make it difficult to exclude potential beneficiaries from the use of resource benefits. Her research into successful CPR management was in support of responses to the common assumption that the best management strategy is a top down approach in which a centralized entity is empowered with management decisions and enforcement, and the assumption that the fouling of a resource can be avoided by sectioning resources into private property. This strategy has been considered a preferable management scheme in order to avoid the 'tragedy of the commons'

(Hardin, 1968), a situation in which CPR systems experience the tendency of appropriators to free ride by over-appropriating and shirking their individual role in the management responsibilities. It is argued that in a CPR system, the rational decision of a resource user is to act selfishly and gather as many units for themselves as possible without consideration for others, resulting in the degradation of the resource. A top-down approach is commonly implemented as a means to avoid this result (Ostrom, 1990).

In order to identify those qualities that are present within successful CPR systems, Ostrom (1990) explores several case studies of these systems in which the management of a resource has successfully endured over a substantial period of time with users obtaining their share of the resource and the supply of the resource sustaining itself. The case studies suggest that successful systems of management are often those that do not have a top-down, centralized approach to resource allocation, but that share a collection of eight common design principles that are representative of more collective action decision-making and more localized governance (Ostrom, 1990). These eight principles are listed and described in Table 3.2.

Table 3.2: Ostrom's eight design principles for successful common-pool resource management (From Ostrom (1990) p. 90)

1	The common-pool resource system has a clearly defined boundary and the individual appropriators have a clearly defined right to use of the resource.
2	Rules related to resource appropriation are related to local conditions and to provisioning rules.
3	The individuals who are affected by the rules of the CPR system are involved in the development of the system's operational rules.
4	The parties involved in the monitoring of the CPR conditions are either the appropriators themselves or are held accountable in some way to the appropriators.
5	Graduated sanctions are imposed on those individual appropriators who do not comply with the operational rules either by other appropriators, by officials that are held accountable by the appropriators, or by both.
6	In times of conflict, the appropriators and relevant system administrators and operators have a low-cost and easy-to-access venue available for conflict resolution.
7	Individual appropriators are given the right to form their own institutions without challenge from external government authorities.
8	Governance activities across the CPR system are organized into nested enterprises. This design principle is relevant to CPRs that are a part of larger systems.

These eight design principles that Ostrom (1990) has identified are key characteristics that CPR systems benefit from having, and identifying whether these characteristics exist within a system helps one to identify where CPRs are well-designed or where they may have room for improvement. Although not the focus of this analysis, these eight principles will be discussed further when assessing the role of smaller-scale water institutions in the Magic Valley.

Anderies et al. and Ostrom

Although Anderies et al.'s (2004) framework and Ostrom's (1990) eight design principles are valid frameworks for assessing SESs, they differ in ways that make the Complex Adaptive Systems framework preferable for this analysis. In the framework offered by Anderies et al. there are four main components that are mentioned as essential to identify when assessing an SES – the resource, resource users, infrastructure, and infrastructure providers. Although these four components are often found within SESs and can be found within the Magic Valley, there are many more system components found on multiple levels that are imperative to the Magic Valley's success in resource management. Rather than applying Anderies et al.'s framework to the entire Magic Valley, it would be more appropriate to apply it to the smaller subsystem components, such as irrigation districts. For this reason, Anderies et al.'s framework will not be used.

In addition, Anderies et al. argue that the term robustness is more appropriate when assessing SESs, and that resilience is more appropriate when referring to a system's ecological components. As was discussed in Section 2, the characteristic of interest in this assessment of the Magic Valley and the USRB system is resilience, which for the purposes of this research is defined differently from Anderies et al.'s definition of resilience. This research defines it as the 'capacity of a system to adapt to disturbances and changes in the environment and continue to provide a full range of ecosystem services in the face of change', and focuses on the entire system rather than just the ecological components' resilience. Although this definition is similar to Anderies et al.'s definition of robustness, rather than focusing more on the role and design of institutions, this research is interested in the role institutions and individual actors, the infrastructure, and the natural aspects that affect the resource and how all of these interact to inform the adaptive capacity of the system and its resilience.

Ostrom's eight design principles offer some key components that have been found in successful long-enduring systems of sustainable resource management, but like Anderies et al.'s framework, these principles are identified in smaller scale SESs such as irrigation districts or a forest management operation run by a village whose system boundaries are small enough to implement these principles. Although these design principles can be found throughout the small-scale water institutions such as irrigation districts and canal companies, this analysis is interested in the adaptive capacity and resilience of the greater Magic Valley region and the USRB collectively, not just on a small-scale. In addition, some of these design principles are absent from the institutions within the Magic Valley, such as graduated sanctions and cheap and easily accessible venues for conflict resolution.

Complex Adaptive Systems Framework

The final framework that will be discussed is one that assesses systems that are of a certain complex nature and that exhibit characteristics of panarchy, adaptive cycles, emergence, and self-organization, all of which inform the adaptive capacity of the system. Within these systems, the interconnected parts are closely linked through nested feedback loops, and the resulting communication from all parts allows the system as a whole to adapt to external and internal stressors. Constant adaptation incorporating all subcomponent parts enables the system as a whole to ebb and flow and stay within a preferred stable state, one in which it is still able to continue to provide its ecosystem services, therefore maintaining resilience. This framework will be termed the Complex Adaptive Systems (CASs) framework and draws its main concepts from resilience theory and the idea that the resilience of a complex system is informed by constant adaptation among its many hierarchal components, both ecological and social, at various scales (Gunderson & Holling, 2002).

The idea behind the ability for CASs to persist in the face of various disturbances is that multiple levels of interaction between system components create a complex network of feedback loops at various scales that result in constant communication and adaptation. These feedback loops increase the systems adaptive capacity and ability to manage resilience. The degree of complexity among these component parts can determine just how adaptive the system can be, with less complex systems finding themselves unable to adapt due to the absence of interaction, and systems that are too complex leading to chaos. The goal of an SES is to be right on the 'edge of chaos' where it is not either too complex or not complex enough, and it has just the right number of nodes and connections to incorporate input from all components of the system. A system can be seen alternating through an adaptive cycle as a whole, but a system with complexity is affected by many smaller-scale adaptive cycles, or micro-adaptive cycles, occurring at various scales that help it stay within a stable state. These micro-adaptive cycles are typically interacting across both social and ecological components, with responses from multiple components simultaneously influencing others and sharing information across scales. For this reason, it is important that the subsystems of CASs are not thought of in isolation from one another – ignoring these cross-scale effects is one of the most common reasons for failures in natural resource management systems (Holling, 1973).

An adaptive cycle with a complex SES has four phases that make up both the 'fore loop' and 'back loop' of the cycle. The fore loop is generally a period of time where there is low potential for changes within the system, with the first phase of rapid growth referring to the period of time in which the actors in a system use the available resources to their maximum potential (Gunderson & Holling, 2002). This phase is also referred to as the 'exploitation' phase with actors tending to exploit the resources available as there are few constraints to their use. This phase is often made possible by an absence of regulation due to the abundance of resources and untapped potential (Fath et al., 2015).

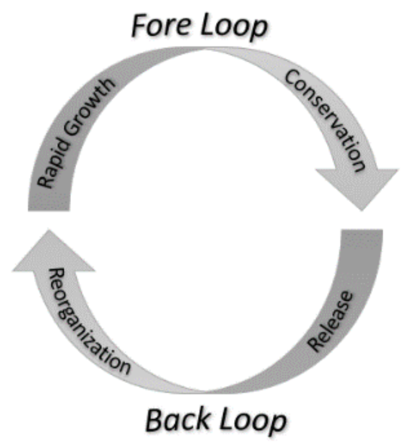

Figure 3.2: Simple representation of an adaptive cycle. The adaptive cycle generally has two opposing modes, with a 'fore loop' representing development within a subsystem, and a 'back loop' that represents the release and reorganization of a subsystem. The back loop is the time of greatest potential for the initiation of either destructive or creative change in the system (From Walker & Salt (2006) p. 82).

As actors continue to exploit a system's resources, the system incrementally moves toward a phase termed conservation, the second phase of the fore loop, where resources become constrained and any further development is more controlled. The conservation phase is characterized by a system moving toward a state of equilibrium where there is no longer an abundance of inputs compared to outputs. Resources are increasingly locked up as actors design the system in a way that achieves a specific, most efficient outcome. By being designed to operate efficiently and achieve outcomes that are reasonably predicted, there is little room for innovation left and a system loses its flexibility to respond to outcomes that are not predicted. As the conservation phase continues, loss of flexibility in a system leaves it vulnerable to disturbance due to a loss of diversity in system processes (Gunderson & Holling, 2002).

The rigidity developed in the conservation phase can eventually cause a system to lose functionality and possibly collapse, leading it into the back loop of the adaptive cycle. In the back loop, the first phase of release is entered when a system is impacted by one or more internal or external stressors and the current structure of the system is unable to respond effectively. During this release phase, a system can either experience collapse or can take advantage of new opportunities in the system and successfully enter the final phase of reorganization. The release phase is usually marked by resources that had been previously locked up in the conservation phase being released and allowing for new system properties to emerge and organize in this final phase. In social systems, taking advantage of newly released resources can be seen in the implementation of new laws or institutions to adapt to the disturbance in question.

Through reorganizing, a resilient system can effectively survive through the release stage, avoid collapse, and can enter a new rapid growth phase, thus completing the adaptive cycle. The adaptive cycle concept has been adopted to identify resilience in both ecological and social systems (Fath et al., 2015; Gunderson & Holling, 2002), with resilient systems being those that are able to persist in the face of extreme disturbances experienced during the transition from the conservation to the release phase while also maintaining system processes and functionality; resilient systems are those that can navigate the adaptive cycle. To illustrate, Table 3 includes an example of the adaptive cycle as seen in a forest undergoing succession.

Table 3.3: The following table includes examples of what a system would look like in different phases of the adaptive cycle using a forest in succession from pioneer species to climax species. (Taken from Walker & Salt (2004) p. 83).

Phase	*Example*
Rapid Growth	At the beginning of forest succession, the new pioneer species can easily use the resources available including water and nutrients. The forest floor begins to populate with these species that experience rapid growth.
Conservation	Over time, the species learn to become more efficient in their resource use. The forest floor continues to grow in a predictable manner. As the trees grow and become more efficient, the forest resources are increasingly locked up in the trees.
Release	As the trees grow larger, the forest grows less resilient to shocks and disturbances. Eventually a disturbance such as a wildfire or a pest outbreak will lead the forest to collapse and release the nutrients and biomass that have been accumulated over time.
Reorganization	After this release of resources, the forest has the ability to reorganize itself and begin a new cycle and a new process of succession.

The adaptive cycle is not fixed however, and it is possible for it to jump to different phases and to even move backwards in the cycle. Observation of systems and their place in the adaptive cycle have demonstrated that transitions are possible between all phases except from the release or reorganization phase directly into a phase of conservation (Gunderson & Holling, 2002; Walker & Salt, 2006). This is illustrated in Figure 3.3.

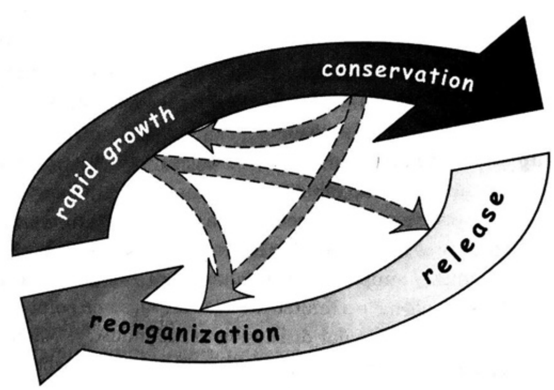

Figure 3.3: Transitions are possible (and have been observed) between all phases except from the release or reorganization phases directly to the conservation phase. (Taken from Walker & Salt (2004) p. 83).

The ability of adaptive cycles to move to different phases in an unfixed pattern is the result of the multiple cross-scale interactions and feedback loops that exist in CASs among their subsystem components. These various levels of interaction happening within CASs create a panarchy within the system, or a nested collection of cycles both small and large that influence each other across multiple scales through feedback loops (Figure 3.1) (Gunderson & Holling, 2002). The phase that any one subcomponent is in is the result of interaction with all other subcomponents in the system and the feedback loops that are developed, which further emphasizes the fact that subsystems should not be thought as isolated from one another. This idea is represented in Figure 3.4.

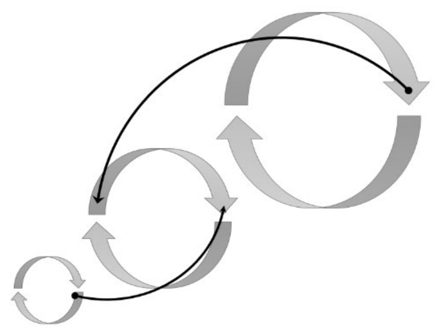

Figure 3.4: Simplified image showing the cross-scale effects of nested adaptive cycles that exist within the panarchy of complex adaptive systems (From Walker & Salt (2006) p. 91).

In CASs, observing the system's panarchy, its feedback loops, and the phase of the adaptive cycle that it is in is important to understanding how the system can respond to disturbances and to identify times where there may be greater leverage to change. Although the release phase of the adaptive cycle can be catastrophic in some cases (in the case of forest succession in Table 3, a wildfire or pest outbreak has the potential to completely wipe out acres of forest), it is also an opportunity for a system to reevaluate its current trajectory, and re-organize into a more effective system structure.

One advantage to systems that have more complex cross-scale interactions and feedback loops between multiple subsystem components is the tendency for these systems to show emergence. Emergence in systems is a key characteristic of CASs, and for the purposes of this research will be defined as the collective characteristics seen among aggregated system components that do not usually exist nor can be predicted from observation of these system components on their own (Lansing, 2003). In CASs, multi-scalar interactions among system subcomponents emphasize the inclusion of feedback and knowledge from the local level. With emphasis on the incorporation of local level knowledge in these nested systems, new system properties can emerge that are catered more to the specific nature of the system at hand. The success of these new emergent and informed system properties results in the facilitation of more flexible management regimes over time that can respond more effectively to rapid ecological changes in the system (Chaffin & Gunderson, 2016). Emergence can include instances of collaboration and cooperation (Cosens, 2016), the adoption of agreements and negotiations that stray from the rigidity of law (Fiege, 1999), and 'self-organization', or the unification of individual system components to form an emergent whole in an effort to adapt to system disturbance (Holling, 2001). An example of self-organization is the emergence of leadership that occurs when actors not tasked with leadership roles will informally assume key positions during a crisis (Fath et al., 2015).

A simple illustration of the concepts of emergence and self-organization within complex systems is illustrated by scientists creating computer simulated systems governed by a set of rules ranging from simple to complex. Researchers found that when the rules within a binary network are of a simple nature, the interactions within these binary networks would fall into fixed patterns of interaction or would resemble periodic changes in their interactions that would eventually become fixed again (Capra, 1996; Lansing 2003). By introducing more complex rules to govern network interactions, the simulated system absorbed disturbances while remaining functional due to the complex nature of its connections that allowed the system to reorganize itself through feedback loops. The theory of CASs therefore emphasizes the importance of complexity and its role in allowing smaller-scale system components to reorganize spontaneously to absorb changes and disturbances (Lansing, 2003), experiencing the phenomena of self-organization.

In these simulated experiments, although a higher level of complexity allows for this self-organization and system flexibility, systems that are too complex can enter a state of chaos where the entire system can change to a new and possibly undesirable state. In binary network simulations, this is represented by increasing the complexity of the rules governing the response of the two-dimensional components to a level where the binary network can no longer sufficiently communicate through feedback loops. When the network rules become too complex, the pattern of the system becomes neither fixed, periodic, or complex – it is simply chaotic (Figure 3.3). The concept of CASs emphasizes the functionality and resilience of systems as they exist within this sweet spot, or Langton's edge of chaos (Holling, 1973; Lansing, 2003), where a system is neither too simple nor chaotic, but is complex.

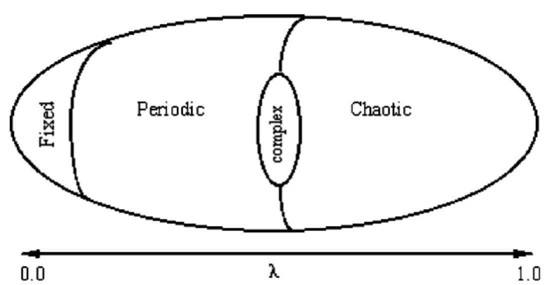

Figure 3.5: This model represents the 'edge of chaos' in which a system functions the most effectively. The lambda represents the fraction of rules that affect a systems path towards non-quiescence (Taken from Lansing (2003) p. 191).

Within CASs, the feedback loops within a system's panarchy and the resultant communication, emergence and self-organization allow these more complex systems to continuously adapt to changes. Therefore, there is never one preferred complex structure of system in which it reaches an optimal equilibrium and stays there. Rather, there is a basin of attraction, or preferred stable state, that a CAS moves around in as it continuously adapts and absorbs disturbances. Within this basin, the system tends toward a state of equilibrium but never quite reaches it as it constantly adapts, remaining in a state of resilience. As mentioned earlier, this can be thought of as a system navigating through the adaptive cycle and surviving the release phase all the while continuing to provide needed system outcomes. Having insufficient complexity among system components reduces emergence and self-organization and decreases the ability of an SES to absorb various disturbances and remain in the basin of attraction. This makes it more likely for a system to shift so far from equilibrium that it crosses the basin threshold into a new and often undesirable state (Holling, 1973; Walker et al., 2004; Walker & Salt, 2006), essentially collapsing during the release phase.

It is often these times in which the system experiences a shift to an undesirable state, or comes close, that emergence and self-organization occur. Therefore, one method for applying this framework to an SES in question is to observe changes in the adaptive cycle of a system over time and identify how it has responded to past disturbances and stressors and whether the response indicates resilience and increasing flexibility in responding to crisis. Identifying the ability of a system to navigate the adaptive cycle in the past can inform its ability to continue to navigate it in the future.

Discussion of Frameworks

The three aforementioned frameworks present different views of the structure of SESs and the connections that can inform their resilient or robust character, yet all share significant common themes. Among these is the emphasis that all authors give to the importance of the social component of SESs, specifically of social institutions and their design, in the management of resources. Anderies et al. and Ostrom emphasize the importance of how the social component of an SES designs the institutions managing the resources and the implications this has to the resilience of the system - or in Anderies et al.'s words, to the robustness of these systems. Emphasis is also given throughout all frameworks to the importance of including local knowledge into institutional design.

Weight is also given to the concept of self-organization of SESs, another significant theme found across all frameworks. Although Anderies et al. stress that the design of systems should be focused on observation of the robustness of an SES, the authors also acknowledge the value of self-organization on local levels. Ostrom mentions the importance of self-organization in her emphasis on the role of collective-action in resource management, or the efforts of individuals organizing themselves and working collectively to manage a resource knowing that they will all benefit from this cooperation. Within the CASs framework, this concept of self-organization is one of the guiding concepts for increasing adaptive capacity because its existence informs the ability of a system to emerge and respond to crisis in more resilient ways, but it incorporates the importance of self-organization on all levels, not just locally.

Although all three frameworks highlight important characteristics of SESs, the CAS framework's discussion of the adaptive cycle and whether or not a system can navigate through it is seen as a significant indicator of the resilience of a system both in the past and in the face of future disturbance. By observing adaptive cycles within a system, this framework also provides a process for identifying previous emergence and self-organization within a system that informs its ability to emerge and self-organize in the future. The CASs framework also emphasizes the role complexity among components in informing a system's ability to communicate and adapt across multiple scales. This concept is important in this research due to the large extent of this river-basin based system.

4. SCOPE: IDAHO'S MAGIC VALLEY

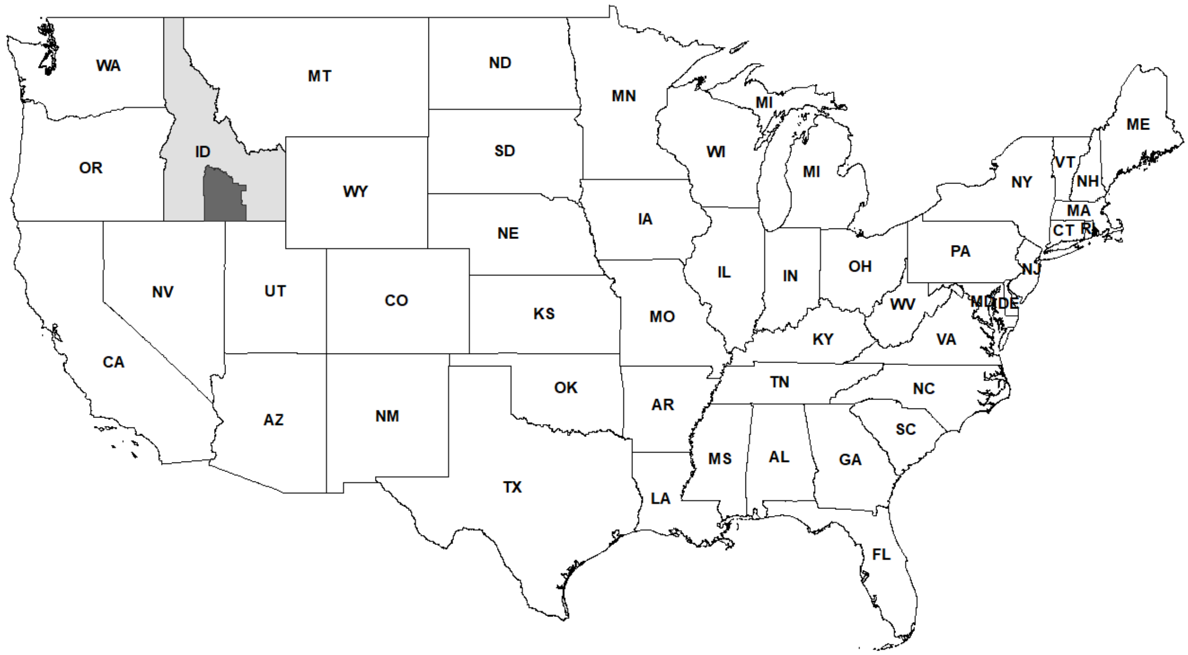

Figure 4.1: View of the United States with Idaho shaded in, and with Magic Valley shaded in a darker hue within Idaho.

The Magic Valley of Idaho lies within the southwestern portion of the Upper Snake River Basin in south-central Idaho (Figure 4.3). Magic Valley is characterized as a semiarid region that experiences a mean annual precipitation of 280 mm (Tasumi & Allen, 2007), with annual precipitation readings at the Twin Falls[1] Agrimet weather station reading at 132 mm for the year 2013 (Kelly et al., 2016). Scarce water supplies and a high desert climate did not dissuade early settlers who came to the region, but rather encouraged them to implement irrigation technology to help harness the agricultural potential of the existing landscape. By doing this, settlers could manipulate the flow of water by diverting it and subsequently

[1] Twin Falls Agrimet weather stations has been chosen to represent the weather that exists within the Magic Valley because it is the largest municipality in the region and is surrounded by irrigation agricultural and can be considered an agricultural hub. It is also significant because although the Magic Valley as a whole has a higher amount of annual precipitation, it is important to note the difference in precipitation in the Twin Falls area because in this area and other irrigated areas along the Snake River, the elevation is much lower and warmer, so using Twin Falls weather station reading is a more accurate representation of the precipitation occurring at the field level.

transporting it to their respective properties – sometimes miles away. There, water could be used for drinking and other domestic purposes, but its most significant use on the landscape was for crop production. The name 'Magic Valley', which for the purposes of this research will include the six primary economic counties in south-central Idaho, is derived from the fact that this irrigation technology turned the region, predominantly a sagebrush plain when settlers first came to the area, into an 'Irrigated Eden' that grew acres of crops including alfalfa, sugarbeets, and Idaho's famous potato (Figure 4.2) (Fiege, 1999).

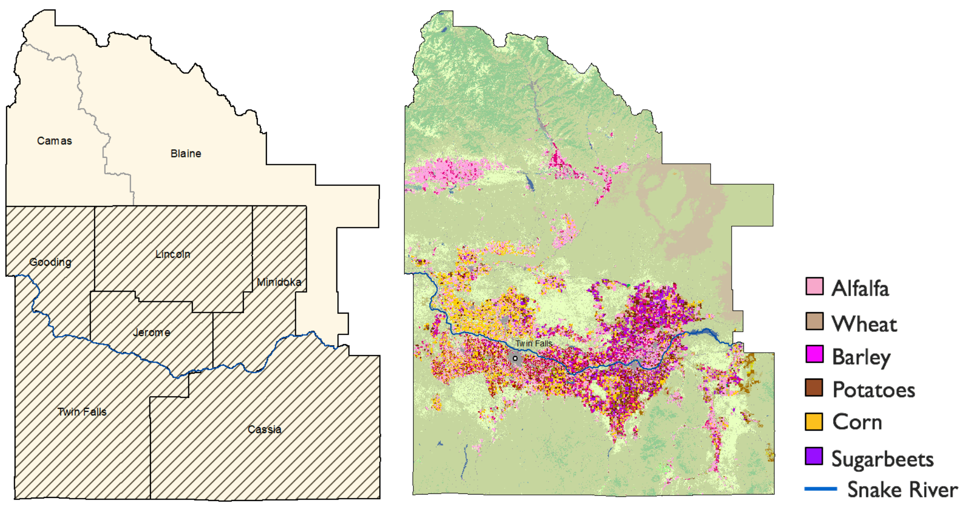

Figure 4.2: Comparison of two different schematics of the Magic Valley: a) Outline of the six primarily economic counties of interest; b) 2016 Cropland Data Layer showing the primary crop cover (From USDA (2016))

The Magic Valley today relies primarily on irrigation from the Snake River, its tributaries, and regional ground water sources. The success of the Magic Valley in harnessing the region's water supply has made it the most irrigated area in the Pacific Northwest and Idaho's largest agribusiness contributor. Magic Valley's six primary economic counties, those of Cassia, Gooding, Jerome, Lincoln, Minidoka, and Twin Falls, generated 44% of the state's agricultural value in 2012 (USDA, 2014), and in 2016, the agribusiness operations within the Magic Valley made Idaho the leader in the nation for the production of potatoes, barley, trout and Austria winter peas, second in the nation for the production of alfalfa and sugarbeets, the nation's third largest producer of cheese, and fourth in the nation for the production of milk (ISDA, 2017). In addition, the region has also become home to a variety of pre- and post-production agricultural activities and industries, including companies that supply feed, irrigation technology, fertilizer supplies and other agribusiness-related inputs, industries specializing in the management of agricultural equipment, and food processing facilities (MSWRC, 2018). The region's many agricultural enterprises, paired with these interrelated businesses have resulted in the Magic Valley region being ranked as one of the top 12 U.S. manufacturing communities (IDWR, 2015a), and provide many of the employment opportunities that support the region's population, with an estimated 3.6 direct and indirect agriculture-related jobs provided per 80 acres of irrigated farm land (MSWRC, 2018).

The success of Idaho's Magic Valley has been a direct effect of its ability to ensure the sufficient distribution and administration of the water within the middle reach of the Snake River. A disruption to this valuable water supply would be felt across all sectors of the economy (MSWRC, 2018), yet future predictions of climate change project just that. The accumulation of snowpack that the region relies on to provide water during the irrigation season is projected to decrease due to regional temperature increases, resulting in more frequent rain events during the winter months, and more variable springtime peak flows (Klos et al., 2014). This projection of more frequent rain events during winter months will result in earlier runoff rates from tributary locations, and melting events that occur before the irrigation season that will make it more difficult for snowmelt to be captured in reservoirs and stored for use throughout the summer months. This shift in climate and higher uncertainty related to weather events has significant implications for security of the region's water that sustains its agricultural, municipal, and industrial needs.

In order to understand future implications for continued water administration and distribution in an uncertain future climate, the Magic Valley of Idaho will be framed as a social-ecological system and its resilience will be analyzed in the framework of a CAS. The regional boundaries for purposes of assessing the ecological component of this analysis, which are described in more detail below, will be extended to the outer reaches of the Upper Snake River Basin, with a focus on the supply of water from the Snake River and the Eastern Snake Plain Aquifer. The social component of this analysis will include a range of many local, regional, and state actors and institutions. The process for applying the CASs framework will be to divide the development of the Magic Valley into crucial time periods that are responsive to the hydraulic complexity of the region represented by Figure 4.5 below, apply the framework of CASs to identify the historical adaptive cycles that have occurred and the evolution of panarchy, emergence and self-organization throughout the region within these cycles, and then to discuss how these factors inform the resilient nature of the Magic Valley. Finally, Anderies et al. and Ostrom's eight principles will be discussed to either support the resilient nature of the region during these time periods, or to identify where there are flaws in the region's institutional structure.

Eastern Snake Plain Aquifer

To understand the inherent complexity of the water supply to the Magic Valley, it is first important to discuss the complexity of the hydraulic connection between the Snake River, its tributaries, and the underlying Eastern Snake Plain Aquifer (ESPA). The USRB begins in western Wyoming where the headwaters of the Snake River are located and extends in a southwestern direction across southern Idaho, dipping briefly into northern Utah and Nevada. The Snake River runs almost directly through the center of the basin, with tributary rivers contributing to it from mountain ranges at the edges of the basin. The complexity of this region begins where these outer mountain ranges end and the landscape transitions into the Snake River Plain, a distinctively flat area compared to the mountainous edges of the basin that extends in a crescent shape across the entirety of southern Idaho (Figure 4.4). Where the landscape begins to flatten out, the ground is underlain by various volcanic and porous basalt features that results in a significantly high infiltration of water from the land down into the region's many underground aquifers. The porosity of the landscape has resulted in 'losing' reaches of rivers and streams where these water bodies simply disappear from the landscape, seeping into pockets of underground water storage.

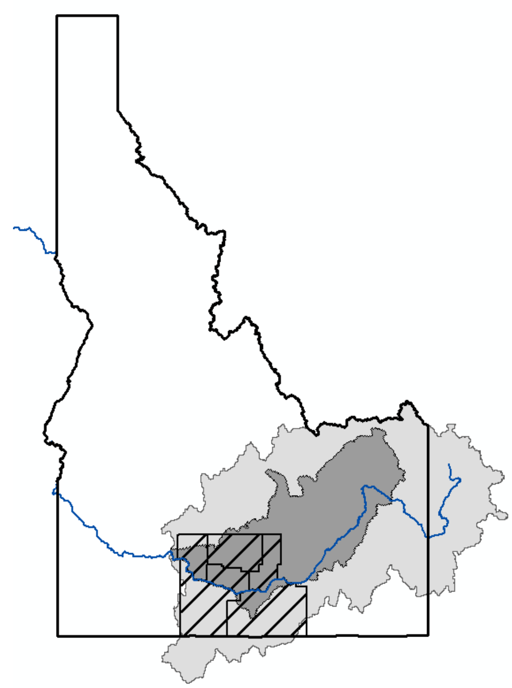

Figure 4.3: Spatial representation of the Upper Snake River Basin (light grey) and the underlying Eastern Snake Plain Aquifer (dark grey) within the southern portion of Idaho. The counties within the Magic Valley that contribute most to the agricultural economy are represented by the striped area.

The most significant of these various underground reservoirs is that of the ESPA that extends for 27,971 km^2 beneath the Snake River Plain, underlying the largest irrigated agricultural area in the Pacific Northwest (Ryu et al., 2012). The ESPA generally follows the same crescent shape of the Snake River Plain and the USRB and stores such a significant volume of water from precipitation and surface water infiltration into the porous landscape that the volume of its storage capacity has been compared to that of Michigan's Lake Erie. Like the flow of the Snake River, the ESPA flows underground in a southwestern direction where it eventually either 'gains', or reappears, back into surface water bodies and eventually the Snake River, or it spills out of the sides of the aquifer in the form of springs found along the north canyon walls of the Snake River canyon.

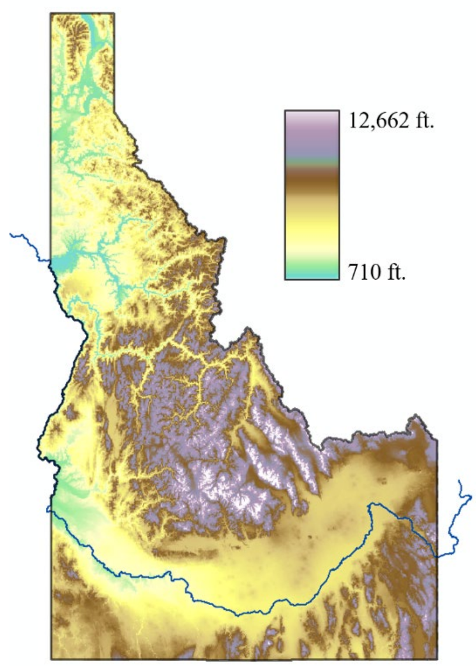

Figure 4.4: Visual representation of elevation differences across the state of Idaho. The distinctive crescent shape of the Snake River Plain can be seen in the southern portion of the state. The Snake River (blue) is added for reference.

The size of the ESPA and its complicated hydraulic connection with surface water bodies throughout the USRB often makes the overall administration of water throughout the region difficult because of the many competing water demands. As the region has grown into an agricultural leader over the last century, a main indicator of the complex nature of the aquifer and its water supply has been the Thousand Springs area found along the Snake River canyon walls in the Hagerman, Idaho area. As the name implies, this area is home to many springs that spill, in high volumes, out of cracks and fissures in the Snake River canyon walls and is a major outlet of water for the ESPA into the Snake River.

As such a contributor to water flow in the river and an indicator of water volume in the aquifer, the daily volume from these springs has been monitored starting in 1902 at the early years of agricultural development in the basin, primarily by the U.S. Geological Survey (USGS). Efforts to monitor flow from springs in this area has shown an overall positive correlation between the increasing and evolving agricultural endeavors across the region and the fluctuating discharge from these springs (Kjelstrom, 1995). For this reason, the records of these monitoring efforts by the USGS, which are visually represented in Figure 4.5, will be used throughout the analysis of the Magic Valley as an SES to help represent how the fluctuation of water discharge from these springs is an indicator of water use and supply changes, as well as a catalyst for emergence and self-organization.

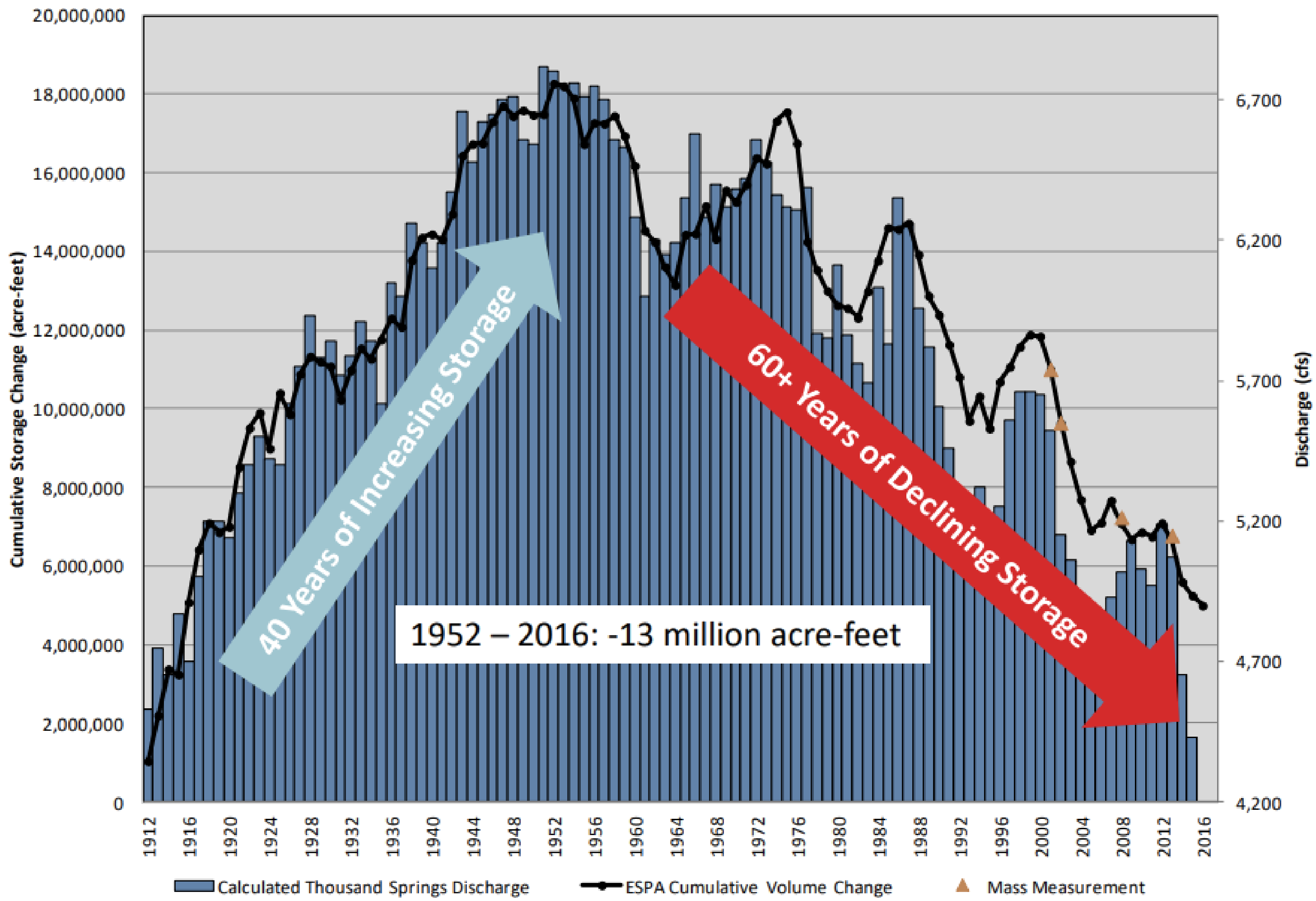

Figure 4.5: Visual representation of the volume of water flowing from the Eastern Snake Plain Aquifer at the Thousand Springs area of Idaho (From Idaho Department of Water Resources (2016) n.p.

Institutional Panarchy of the Magic Valley

As a reference throughout the proceeding analysis, Figure 4.5 will be used as a conceptual map to show the general institutional panarchy that exists within the Magic Valley in the present day and the connections that exist among social and ecological components important to this analysis. As discussed in the CAS framework section, the panarchy of an SES and its complexity can determine the adaptive capabilities of an SES, so the conceptual map will be used as a tool to visualize the panarchy that exists and grows throughout time to connect the system on multiple scales. Within the conceptual map, the various actors that have a part in water administration in the region are shown with their general hierarchal structure. Also included are arrows that represent the general flow of water, services, and money between these actors that also represent the smaller adaptive cycles affecting the state of the system. It is important to note that the boundary labeled 'system boundary' represents the area within which the control of water storage and distribution is maximized, and is referenced later in the analysis as 'Water District 01'. When water leaves this boundary as either surface or ground water, it is generally lost from the system and cannot be recovered. This is important to remember because the actors that are placed within the system boundary in this conceptual map generally have a direct role in the use and supply of water in the Magic Valley. Also important to note are the different colors assigned to different system actors.

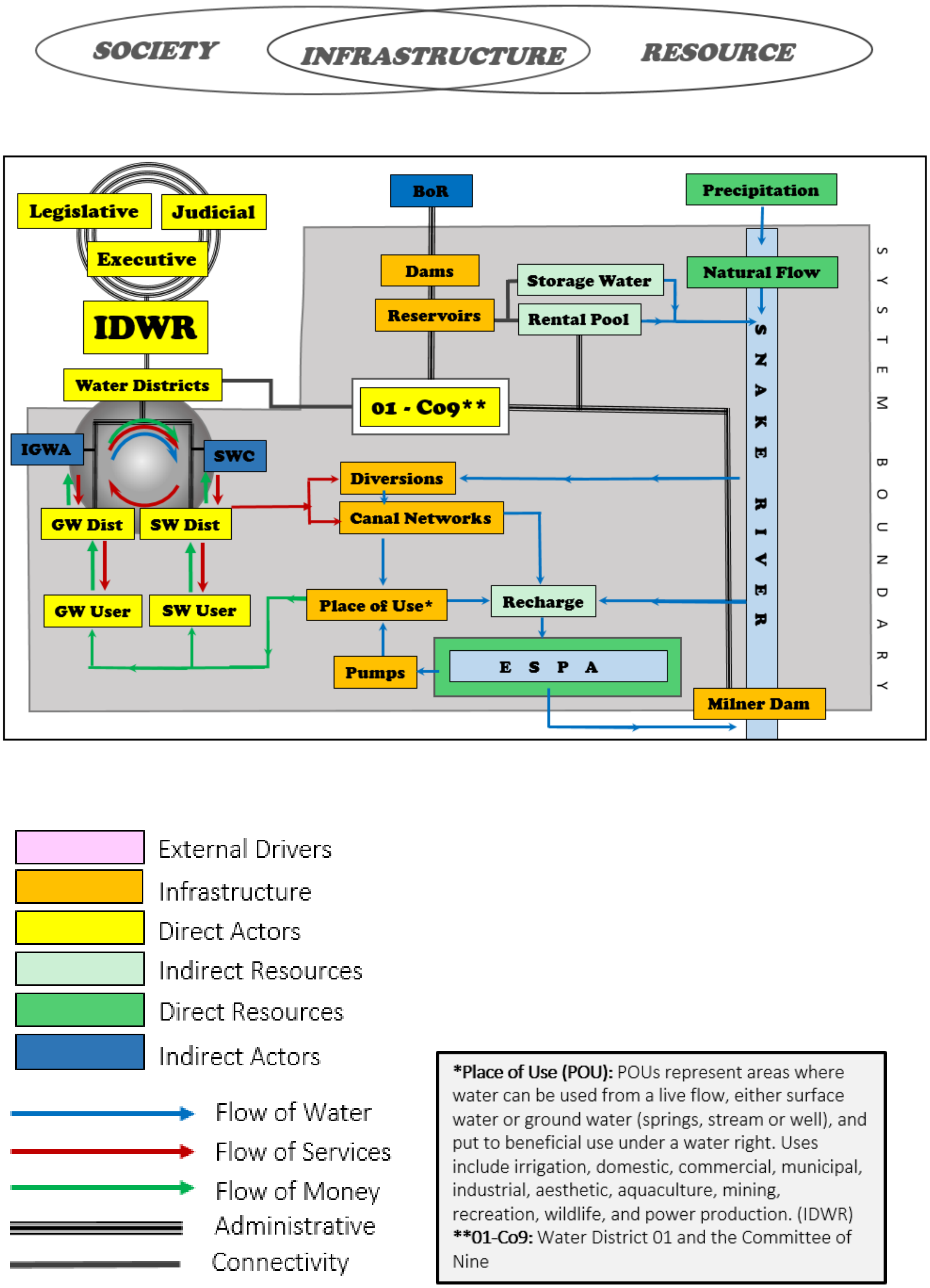

Figure 4.6: Conceptual map representing the interconnection between the social and ecological components of the Magic Valley as well as the infrastructure that connects them.

5. METHODS: APPLYING THE COMPLEX ADAPTIVE SYSTEMS FRAMEWORK

The proceeding analysis will follow the general timeline represented by the hydrograph in Figure 4.5 but will be broken up into three separate time periods that represent pivotal times in the development and growth of the region. These time periods are briefly discussed in Table 5.1, with the names of each 'era' having been decided by the researcher and therefore not representing any formally recognized periods of significance other than for the purposes of this research. Each time period has been chosen specifically because it correlates with a specific phase of either growth or depletion of the discharge volumes from the ESPA as represented by Figure 4.5 above, an ecological change that is deemed pivotal by the researcher.

Table 5.1: Brief description of each time period that will be used in the analysis of this research

Time Period	*Description*
Development Era 1862 – 1950	Period beginning with the passing of the Homestead Act by the U.S. federal government in 1862 and ending with the enactment of the Ground Water Act by the Idaho Legislature in 1951
Ground Water Era 1951 – 1987	Period beginning with the passing of ground water legislation and the growth of ground water pumping and usage throughout the USRB until 1987 when the state and the Idaho Power Company enter into the Swan Falls Agreement.
Modern Water Management Era: Adjudication and Conjunctive Management 1987 – 2015	Period beginning with the commencement of the Snake River Basin Adjudication and the adoption of the Conjunctive Management Rules and ending with the Settlement Agreement of 2015.

Since the resilience of an SES is a multi-faceted measure that changes over time (Walker & Salt, 2006), the CAS framework will be applied to the region by considering the evolution of the system over the past century in each era identified above. After a general background is given of the changes the region experienced in these eras, a discussion of how the region fits within the CASs Framework will proceed. In this discussion, how the region's complexity changes and the effects of this will be discussed, including identification of any instances of emergence or self-organization that have developed in parallel to system changes.

After identifying how each era fits within the CASs framework, a second discussion will follow explaining which phase(s) of the adaptive cycle each era experiences. For the purposes of this analysis assessing a region that is defined primarily by its irrigated agricultural endeavors, each of the four phases will be referred to as growth and development, maximum productivity, economic hardship, and institutionalization, rather than rapid growth, conservation, release and reorganization.

The adaptive cycle discussion will primarily focus on how the system as a whole goes through the phases of the adaptive cycle rather than incorporating any substantial discussion of micro-cycles except for important ones identified in the Modern Water Management Era. Rather, small adaptive cycles will be referenced more in the CAS framework discussion due to their influence of emergence and self-organization in the systems.

6. ANALYSIS: ADAPTATION OVER TIME

Development Era (1880s – 1950)

This section will include information related to early settlement and irrigation development in the region. It starts with a discussion of the early efforts of irrigation that began around the 1880s and ends around the period of time when ground water pumping technology was introduced and the Ground Water Act was passed to deal with this new era of water acquisition and use. In Figure 4.5, this time period reflects a time when the Thousand Springs discharge was steadily increasing starting in 1902 and ending around the early 1950s. A primary source of this information regarding the history of development is gathered from Fiege (1999).

Background

Settlement within the Snake River Plain began in the latter half of the nineteenth century, with the implementation of irrigation gaining momentum around the turn of the century as resources such as federal funding became available. Settlers who first came to the region were determined to turn the naturally sagebrush-covered plains into a lush agricultural paradise after seeing how the geologic makeup and landforms made it feasible to implement gravity-fed irrigation methods to transport water from its sources in rivers and streams to grow water-thirsty crops. Early efforts to harness the natural shape of the landscape and improve water distribution to properties for farming involved the construction of irrigation systems from earthen material, such as dams built with rocks and diversions using wood planks (Fiege, 1999). For these early settlers residing primarily along the upper reaches of the Snake River, this method worked well due to the flatter, southwestern sloping characteristic of the landscape, and through hard work and cooperation, farmers could work together to manipulate the landscape and assemble a gravity-driven system of irrigation where water could be diverted and was transported to water crops in the absence of electricity or pumping technology.

One move instrumental to the success of irrigation efforts in Idaho was the departure of the state, a territory at the time, from the use of the riparian doctrine as the body of law for governing the administration of water. In the Eastern United States, the riparian doctrine is the common law for water allocation which allows the use of a water source only by those that own property upon which the water source exists or is adjacent to the water source. The Riparian Doctrine also requires that the water be returned to its source in the same amount and quality so that it can be used by other riparian landowners downstream (Harrington, 2012).

A majority of Western states implemented the prior appropriation doctrine instead to establish an appropriative system where water rights were created by applying diverted water to a beneficial use. The prior appropriation doctrine was first implemented in California during the gold rush and influenced many of the Western states with its principles of first possession. Through the concept of first possession, one could acquire a mining claim and associated claim to water on a priority basis by posting a valid notice. This ensured that mining remained productive or that the water was continuously put to a beneficial use (Fiege, 1999; Goble, 2001). This principle ensured that any properly recorded claim was valid against any other claim to come afterward, creating a system of priority in times of scarcity, such as droughts. In 1861, the first signs of implementing first possession principles in Idaho were seen within the Oro Fino Mining District where the earliest mining laws developed required that water be distributed in priority as long as it was used beneficially. Settlers incrementally implemented additional principles of the prior appropriation system, allowing water to be diverted and used on lands that were not riparian and establishing that water did not need to be returned to its source. All of these initial water allocation principles were complete deviations from the riparian doctrine and influenced Idaho's eventual adoption of prior appropriation as the state's official doctrine of water administration.

Although the prior appropriation doctrine was first introduced in Idaho through the influence of early Western mining in areas such as the Oro Fino Mining District, it was first implemented in the Snake River plain by irrigators who were primarily members of the Church of Latter-Day Saints (LDS). As LDS members migrated north from the Salt Lake Valley region in Utah, they brought with them principles of water administration that were based on prior appropriation. Prior appropriation was practiced in irrigation communities of Utah as a way of establishing priority in water rights and to enable the flooding of fields (Boyce, 1987), a method of gravity irrigation that required water to be diverted a considerable distance from crop fields so that it could travel using gravity to non-riparian lands. Departure from the riparian doctrine enabled the distribution of water through canal systems that were seldom adjacent to the lands on which the water was applied, allowed priority to be established on the basis of beneficial use, and allowed crop production on lands that were not riparian to a sufficient water source, all advantageous factors to the success of early agricultural efforts by members of the Church of LDS (Boyce, 1987).

Some of the earliest canal systems incorporating prior appropriation principles for the administration of water within the territory of Idaho were built in 1880 on the South Fork of the Snake River and its tributaries (Fiege, 1999). In 1881, territorial courts recognized prior appropriation as the primary method of water allocation (Fiege, 1999), and after Idaho became a state, the doctrine was formally adopted into the constitution in 1890. Guaranteeing 'first in time, first in right' for water allocation on the condition that the water in question was put to a 'beneficial use' was advantageous thereafter to both members of the Church of LDS and to subsequent irrigators and settlers as they began to populate the basin.

For the purposes of this analysis, the prior appropriation doctrine will be thought of as a 'bedrock principle' because it is established as the common body of law for water administration. It is significant not only because of the security that 'first in time, first in right' gives to water users, but also for the significance of the 'beneficial use' requirement found in the state constitution. The beneficial use clause is important because as the agricultural landscape begins to evolve over time, what constitutes as a beneficial use also evolves. Over time, the inclusion of the beneficial use clause becomes a tool that the state can use to ensure the proper management of water as the landscape's evolution begins to raise questions in regard to what use of water is in the public interest and what is in fact 'beneficial' (Cosens, 2016).

Although the prior appropriation doctrine helped guarantee water to those that could bring water to their property, it did little for those settlers that did not have the resources to divert and carry water to their properties in the first place to begin fulfilling the beneficial use requirement. Recognizing that this was essentially creating a barrier to the full expansion of the American West, the U.S. Congress stepped in to help encourage successful homesteading with two crucial pieces of legislation - the Carey Act of 1894 and the Reclamation Act of 1902 (Fiege, 1999). In Idaho, the Carey Act helped support homesteaders by giving tracts of land to settlers and vesting power in the State Land Board to contract with private entrepreneurs to finance the construction of irrigation projects to bring water to these lands with financial help offered by the federal government. When these projects were finished, the control and operation of these projects would be given to the irrigators so that the management of the use and distribution of water was in their hands. The Reclamation Act further supported the provision of water to settlers by providing additional assistance in building infrastructure to support the storage and transport of water (Lovin, 1987).

Of all of the western states, Idaho has been the most successful in taking advantage of the opportunities provided by the Carey Act (Worster, 1985). One irrigation project of great significance was the Twin Falls-South Side Project (TFSSP), which was orchestrated by Ira B. Perrine of the Twin Falls area and made possible by investors from outside of the region. One reason for the immense success of the TFSSP was the construction of the Milner Dam in 1905, which completely diverts the Snake River from its natural course to irrigate agricultural lands to the south and north of the Snake River. Downstream from the Milner Dam, the Snake River enters into a deep canyon, making use of the river's waters unfeasible at the time due to the lack of pumping technology (Fereday et al., 2018). Therefore, it was the vision of Perrine to divert water at this point so that it could be directed to gravity-fed irrigation networks that would water acres of farmland, essentially what is today the North Side Canal Company and Twin Falls Canal Company in the Magic Valley region. From here, water for irrigation would largely be lost as seepage due to the volcanic geology of the landscape and would find its way underground into the ESPA. Irrigation water in these early years of development was a significant source of recharge due to the infiltration that resulted from the practice of flooding fields and the fact that early canals were rarely lined, allowing for copious amounts of water to be lost before reaching its field of purpose. From here, infiltrated water would follow the natural southwest flow of the ESPA eventually to the Thousand Springs area where it would leave the ESPA as spring discharge and would once again be rejoined with the Snake River.

This path that water from Milner Dam takes - across the plain through irrigation canals to agricultural fields and then into the aquifer and back into the river again when it leaves the Thousand Springs area – is essential to keep in mind to understand the complex hydraulic makeup of the Snake River plain. The unique hydrologic connection that the Snake River and Eastern Snake Plain Aquifer have, which was accentuated by the construction of Milner Dam, led to the “two rivers” concept. This was the idea that the portion of the Snake River upstream of Milner Dam was essentially separate from the portion of the Snake River downstream from Milner, leading to separate administration of water rights and distribution on these two different sections of the river (Strong & Orr, 2016). For reference, the expanse of the USRB, the TFSSP, Milner Dam, and the Thousand Springs area are all represented in Figure 6.1 for visual purposes.

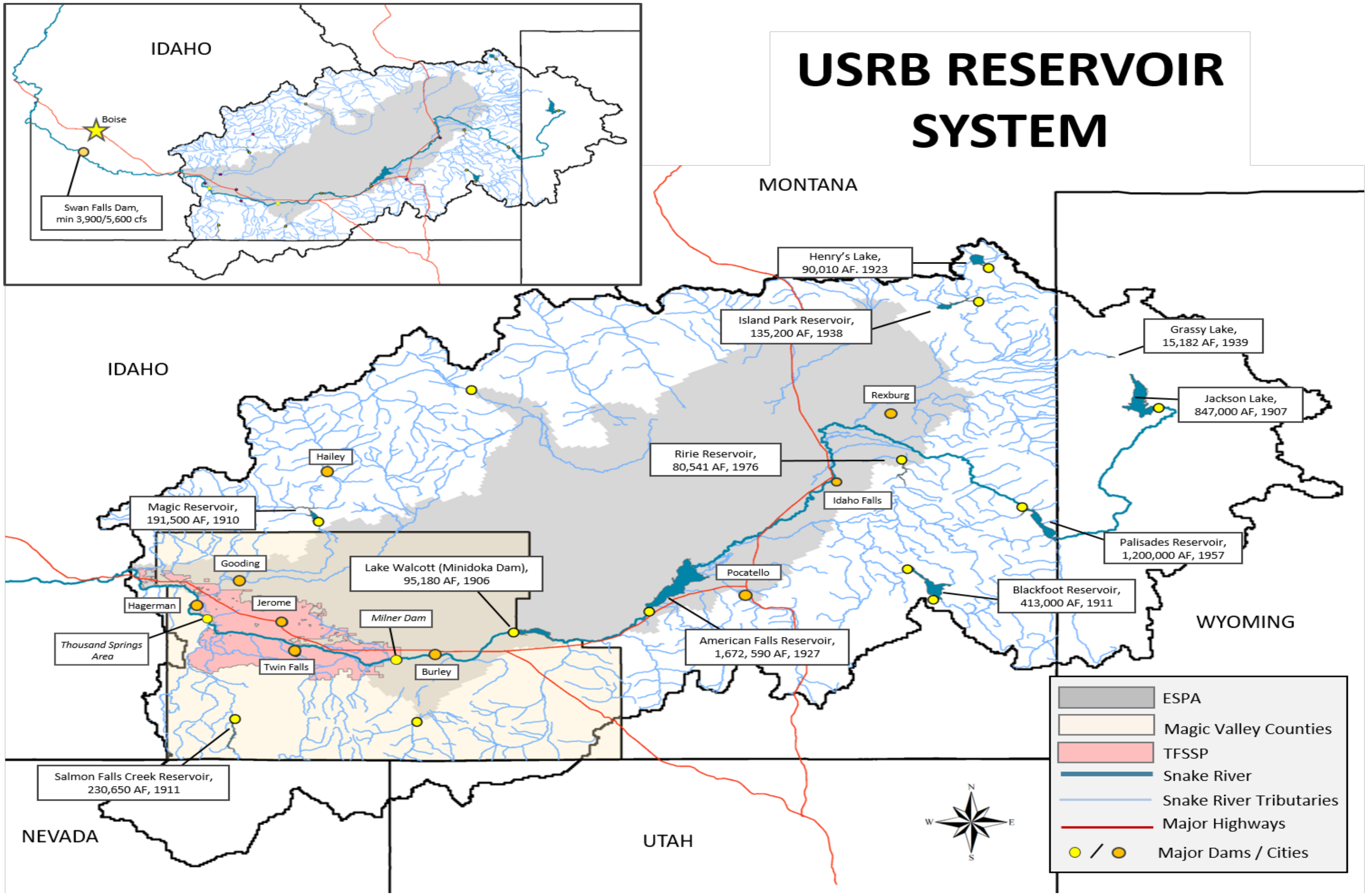

Figure 6.1: Map of the Upper Snake River Basin and areas of particular importance in relation to irrigation infrastructure. Dates and numerical values denoted by 'AF' correspond to dates of construction and storage capacity in 'Acre-Feet', respectively.

The Reclamation Act of 1902 further allowed Idaho to grow as an agricultural leader. This federal legislation allowed for the construction of federal infrastructure projects such as dams and canals to be built by the U.S. Reclamation Service (USRS) with the requirement that water users would repay the construction cost of the projects from which they received benefits. One of the USRS's earliest projects in Idaho was the Minidoka Project that was built primarily to bring irrigation water and hydropower to residents in the Snake River plain. Over time, this project brought to the region five reservoirs including American Falls and Jackson Lake in Wyoming, diversion dams, hydropower facilities and hundreds of miles of canals significantly increasing the irrigation capacity of the landscape (BOR, 2010)

A crucial result of Idaho's efforts in implementing an irrigation society through its own funding initiatives as well as those offered by the federal government was the ability for local entities to have power over the operation and maintenance of these irrigation systems after construction, while the federal government acting primarily through the USRS, the predecessor to the BOR, kept control over the operation of dams and reservoirs. Upon the completion of projects, an irrigation district or canal company would take over the ownership and management of the constructed infrastructure and would obtain water rights from the state for water distribution within the boundaries of the infrastructure project. The authority to distribute water was granted by the state, and the process of distribution was generally governed by a set of rules decided by a governing body in conjunction with district members. In the early twentieth century, these irrigation districts were commonly formed after construction of irrigation infrastructure was completed, although in the present day, these sorts of districts can be formed for a variety of reasons. The irrigation districts founded in southern Idaho are some of the earliest water institutions in the state created to govern the distribution of water to irrigators. They exemplify the effective management of water at the smallest scale.

Although irrigation districts and canal companies had the authority to administer water distribution within their boundaries, state-wide water rights were administered by the overarching authority of the Office of [the] State Engineer, which was created by the Idaho Legislature in 1895 and led by the Idaho State Engineer. This agency was created for the purpose of providing a governing body through which individuals could submit an application to appropriate water within the state (IDWR, 2019). This institutionalized the administration of water within the state and ensured the proper recording and regulation of water rights. This agency was the predecessor to the modern day Idaho Department of Water Resources (IDWR). Within the modern-day version of this agency, the IDWR administers water rights within water districts. Within water districts, a water master is in charge of distributing water to users, and although they operate under the authority of the IDWR, they are a locally elected official who acts as an agent for a local committee of irrigators. This hierarchy of early water institutions and actors can be seen in Figure 6.2, with ‘SW Dist’ referring to the early surface water irrigation districts and canal companies, ‘Water Districts’ referring to the administrative areas run by water masters, and the IDWR referring to the Idaho Department of Water Resources. Seen above this agency in the figure are the three balanced branches of government within the state that all play a part in the evolution of water administration and institutionalization in Idaho throughout time.

As the success of irrigation brought the southern Idaho landscape to color, the region experienced an influx of settlers whose accompanying demands for water began to highlight the difficulty the region would have in guaranteeing supply. Between 1900 and 1910, the state's population doubled as a result of settlers realizing the agricultural potential of the southern Idaho landscape due in part to the success of the Carey and Reclamation Act paving the way for irrigation expansion throughout the Snake River plain. In some areas, this expansion of irrigation resulted in a shift in crop production from those crops that required less water, such as hay, to those that required copious amounts of water, such as sugarbeets. This expansion in irrigation acreage across the plain, paired with shifts in volume of crop water demand, posed issues in years that the Snake River system began experiencing periods of drought. In various reaches of the Snake River, conflict began to arise among irrigators as water use increased and water volumes that were typical of the upper Snake River began to decrease.

Although the prior appropriation doctrine was adopted in order to guarantee irrigators security in water use by guaranteeing 'first in time, first in right', its legal enforcement did not appease irrigators. This was due in part to some of the early water users in the basin often having little concern for the proper accounting of their water rights when they first put water to a beneficial use. For example, when practicing flood irrigation, it was common to continually let water flow through canals and to divert this water to fields only when it was needed and in amounts that were difficult to quantify (Fiege, 1999). This poor management in the use of water was partially due to the assumption of infinitely high volumes of water being available in the Snake River and its tributaries in the early periods of settlement. When low water supplies and drought became an issue and it came time to enforce the prior appropriation doctrine, it was difficult without a clear record of water rights. This resulted in some irrigators hoarding water that they had access to in order to prevent downstream users from using it (Fiege, 1999).

In the area of Rexburg, Idaho, the conflict that arose among irrigators resulted in the Rexburg Irrigation Company filing suit against the Teton Irrigation Canal Company in 1901 for the purposes of clarifying who owned what water rights on the Teton River, a tributary of the Snake River. This suit resulted in the Rexburg decree, the first official adjudication of water rights in the basin that provided a basis for proper water rights accounting and security among users in their right to use water. Completed in 1911, the security provided by the Rexburg decree not only made irrigators less greedy in their water use during the irrigation season, but also resulted in the first recorded occurrences of water rights transfers among irrigators in 1913 (Fiege, 1999).

Although the Rexburg decree helped to confirm water rights, the adjudication was a time-consuming process that took a decade to complete and could not immediately appease conflict between water users. In 1906, upper Snake River irrigators spoke with the USRS about getting rights to water in Jackson Lake Dam but were denied on the basis that water in the lake was guaranteed for the Twin Falls and Minidoka Projects downstream, and that any potential for gaining water rights for upper Snake River irrigators would have to be a future project. This complicated the management of the Snake River's waters because after the construction of Jackson Lake, the water released from its reservoir, which was storage water, would have to travel more than 300 miles downriver to the Twin Falls and Minidoka Projects, passing many upriver irrigators, and often getting confused with natural flow in the Snake River that was distinct from stored water. Complications with managing the entire Snake River were exacerbated by the dry summer seasons and the hydraulic complexity of the river where the unique geology of the basin would often cause the river to either lose or gain volumes of water at unknown areas. Although the Rexburg decree was completed by

1911, irrigators began to dispute that the Office of [the] State Engineer was doing its job, or that the USRS was properly regulating Jackson Lake Dam.

An additional water conflict arose in the Burley, ID area where an irrigator, who had used the flows of the Snake River to create power for transporting water to his land since his water right was appropriated in 1895, claimed compensation for the loss of the river's current after Milner Dam was constructed and slowed the river's flow. The irrigator, Schodde, claimed that he had a riparian right to the current of the river through principles expressed in the riparian doctrine. This case went all the way up to the U.S. Supreme Court where Schodde's arguments were rejected due to the fact that Idaho had adopted the prior appropriation doctrine, therefore rendering riparian doctrine claims irrelevant to Idaho's water administration. It was also confirmed that as an appropriator, Schodde was commanding the entirety of the river in order to ensure a certain current, which was unreasonable and went against the grain of the 'reasonable use' requirement essential to the establishment of an appropriation (*Schodde v. Twin Falls Land & Water Co*., 1912). If Schodde had been allowed to command the flow of water necessary for his irrigation purposes, a massive barrier would have been created to the development of the arid west's scarce water resources, particularly the construction of dams. The decision in this case introduced the important concept that the enforcement of prior appropriation not only considers an appropriator's priority in right, but also whether their appropriation is reasonable and non-wasteful in consideration of other appropriators (Tarlock, 2012). This set the stage for further water conflicts by ruling that no appropriator was absolutely protected in their means of diversion because this would defeat the purpose of the state's policy to ensure the water of flowing streams for the benefit of the public. (*Schodde v. Twin Falls Land & Water Co*., 1912).

In 1916, Jackson Lake Dam was finally expanded by the USRS allowing for more water to be secured by upriver irrigators, but still the exact hydrology of the basin was never fully understood. After years of trying to appoint individuals to determine the hydrology and consistently getting unsatisfying answers, irrigators across the basin decided that rather than trying to find an exact answer to how to perfectly manage water throughout the USRB, an answer would need to be found through negotiation, compromise, and cooperation, one "without recourse to expensive and drawn out litigation" (Fiege, 1999). In 1923, a meeting with representation of more than 60 canal companies came together and a special committee was appointed that would prepare a cooperative plan for distributing water. It was proposed that this special committee consist of two representatives from the North Fork of the Snake, four from the South Fork and main stem, and three from the Minidoka-Twin Falls area, all of which would work together to find compromise in the management of the basin's water.

In 1924, these nine representatives came to be known officially as the Committee of Nine and furnished the first of many compromise agreements that, although not solving all of the hydrological problems of the Snake River, did result in an annual compromise schedule that irrigators throughout the basin could agree on in terms of water distribution. Being the result of an annual compromise, the schedule of water would be decided on a year-by-year basis and would take into consideration factors including any shortcomings from previous years and future projections of seasonal water supply in the basin. These compromise schedules required not only basin representation offered by the nine committee members, but also required input from the many separate canal companies, the State Office of Engineer, and coordination with federal entities such as the USGS and Bureau of Reclamation (BOR), which succeeded the USRS in 1923. The institutionalization of the Committee of Nine and created the first of many water districts, helping to release tensions that had developed in the early years of irrigation development offering irrigators along the Snake River a platform for future compromise and conflict resolution.

Today, the Committee of Nine still exists and continues to meet annually to discuss the distribution of water along the Snake River between Jackson Lake Dam and Milner Dam. This length of the Snake River is referred to as Water District 01, and consists of the entire upstream portion referenced in the "two rivers" concept. A majority of irrigators along the Snake River rely on the annual management decisions of the Committee of Nine when making seasonal decisions in regard to water use and crops to plant, including some of the most senior surface water users residing in the Magic Valley region[2]. Although a critical player to the management of the river, Water District 01 is a water district like all others, and the Committee of Nine is overseen by the IDWR and the Director, which at the time was the Department of Reclamation for the state and the Commissioner of Reclamation.

Officially, the Committee of Nine was formed to figure out the proper distribution of water in such a complicated hydrological landscape, but the committee also represents the strong cooperative values shared among irrigators across the southern Idaho landscape. Implementing the prior appropriation doctrine was done in hopes of effectively distributing exact quantities of water based on priority rights, but the complexity of the basin made this system of water administration imprecise. The institutionalization of the Committee of Nine and other institutions throughout time are indicators of the desire of these irrigators to

[2] The Twin Falls Canal Company and North Side Canal Company are some of these most senior surface water users that reside within the Magic Valley.

cooperate and ensure a consistent and adequate supply of water to all users on the landscape regardless of seniority. These water institutions also offered a platform for water users to collectively adjust to changing seasonal conditions and helped to aid water transfers among users of different priority. Phenomena such as water transfers further represent the respect that irrigators had for one another in this growing agricultural region and the understanding that cooperative management was the most effective method for successful water management in the region.

The introduction of institutions and growing cooperative actions amongst irrigators to improve the region's water management allowed for the Snake River plain to flourish agriculturally in the beginning of the 20th century. With the construction of the many dams in the Snake River Plain helping to increase water storage and the completion of railroads connecting the region to growing regional and national markets, irrigators throughout the Snake Plain began to capitalize off the production of high demand crops including sugar beets, potatoes, alfalfa, and hay. Despite periodic fluctuations in the economy such as the recession following World War I, the region was able to take advantage of openings in the market where demand existed for high quality commodity crops, feed crops for cattle, and seeds. Other growing agricultural ventures included trout propagation in the Thousand Springs region, milk and cheese production, and various pre- and post-production industries that prepared products for market.

Having tapped the market and entered a more modern world of agriculture, the southern Idaho landscape began to be industrialized and organized into a more efficient and mass-producing region. The popularity of crops grown in Idaho resulted in many farms industrializing and introducing more mechanized ways of production rather than relying on labor from neighbors as had been the custom in the region's earlier days. Standards for crops began to be enforced through legislation such as the Pure Seed Act of 1911 and the creation of cooperatives that held their members to certain standards such as the South Idaho Potato Producers' Association and the Idaho Seed Growers' Association (Fiege, 1999).

By the 1920s, roughly two million acres throughout the Snake River plain were irrigated by water running through the Snake River system (Lindholm & Goodell, 1986), leading to steadily increasing levels in the ESPA, which is located beneath a majority of the agricultural lands. In 1902, the Snake Plain aquifer discharged about 3,800 cubic feet per second (cfs); in 1917, discharge from the aquifer had reached 5,000 cfs; by 1956 the level was at 6,000 cfs (Fiege, 1999). It was found that, as water was transported through poorly lined canal systems and made to flood fields for irrigation, the porosity of the volcanic landscape consumed a majority of the water, resulting in seepage into the aquifer far in excess of its natural recharge rate. Some estimates suggest that when water is diverted for surface water irrigation in this region, about 60% of it ends up as seepage into the ESPA (Fereday et al., 2018; IDOR, 1969). Through observation of the growing agricultural landscape and corresponding increase in aquifer discharge, it became clear that a positive correlation existed between the growth of surface water irrigation and the level of the aquifer's water table.

A major advantage to increasing flows out of the aquifer was the ability of hydropower production to grow due to the "two rivers" concept allowing for separate administration of Snake River water above and below Milner Dam. Above Milner Dam, water was primarily reserved for irrigation development while below Milner Dam the Idaho Power Company (IPC) took advantage of the increasing flows from the aquifer to provide reliable and relatively cheap electricity to residents of the state (Strong & Orr, 2016). As discharge from the aquifer increased, hydroelectric production provided cheap electricity to ratepayers, especially at the Swan Falls Dam, the first of many hydroelectric projects built on the Snake River by the IPC and completed in 1901. The “two rivers” concept allowed for both irrigation and hydropower development to flourish together in the first half of the 20th century.

By the late 1940s, the introduction of ground water pumping technology, paired with an increasingly cheaper price for electricity, allowed irrigators to begin taking advantage of the rise in the aquifer’s water level. High crop prices and technological advancements following World War II enabled rapid adoption of ground water pumping technology and the expansion of irrigation to lands that had previously been deemed economically inaccessible to irrigation due to their distance from surface water sources. The use of pumping technology established new irrigated lands that no longer required intricate networks of canals to provide water to farm plots, and sprinkler systems were introduced that began replacing older methods of flooding fields and allowed for more efficient water use. With a new source of water and more efficient irrigation technology, the region saw an increase of close to one million acres of new agricultural lands that had previously been left barren due to inaccessibility (Lindholm & Goodell, 1986).

Though additional acres of producing farmland resulted in further economic growth for the region, the existence of ground water pumping technology paired with cheap electricity began to reverse the increase in aquifer levels almost as they were introduced. The consequences of mass amounts of well drilling and ground water extraction was soon realized as the discharge of the aquifer began to slow down. This was paired with the adoption of more efficient irrigation practices, such as sprinkler systems, not only by ground water users but also surface water users, resulting in much less water being applied at the field level and a significant decrease in recharge to the aquifer. In Figure 4.5, this change in the level of the aquifer is evident around the year 1951 when the curve begins to decline.

Summary

This ends the background section related to the ‘Development Era’ that the Snake River plain experienced from the beginning of irrigation development in the 1880s to the introduction of ground water pumping in the late 1940s. The succeeding Table 6.1 will highlight the key occurrences that resulted in a growing complexity of the region and its panarchy, as well as the accompanying emergent and self-organizational qualities that developed and are characteristic of Complex Adaptive Systems, while Table 6.2 summarizes the phases of the adaptive cycle that the era goes through.

Complex Adaptive Systems Framework

When settlement began along the Snake River, the beginning of water administration consisted simply of surface water irrigators constructing their own personal irrigation networks and forming close-knit communities to administer water on a localized scale. As time passed, hierarchal organizations began to form as the landscape evolved, including federal level entities and state organizations to administer water rights. Eventually, water institutions formed not only to aid in water distribution but do so cooperatively to adapt to the changing nature of the resource as it interacted with the region’s growing society, its complicated geography, and periodic variations in weather.

At the end of the 1940s, the complexity of the Magic Valley region consisted not only of the individual water users on local scales, but also included the hierarchal organizations that have been introduced to administer water including both state and federal regulatory entities involved in water distribution and monitoring. This complexity also consists of various infrastructure across scales that linked these actors to the water within the basin. This panarchy of the region that existed at the end of the 1940s is shown in Figure 6.2. Although there are fewer institutional actors at this time than are represented in Figure 5.1, the mass presence of infrastructure, such as dams and canals, begins to closely link the social and ecological components on this irrigated landscape. At this time, it is probable that the status of water supply within the USRB and its availability to irrigators was just as dependent on the seasonal actions of irrigators and their use of infrastructure as it was on the complicated geography of the region and its variable precipitation, evidencing the rise of a social-ecological system.

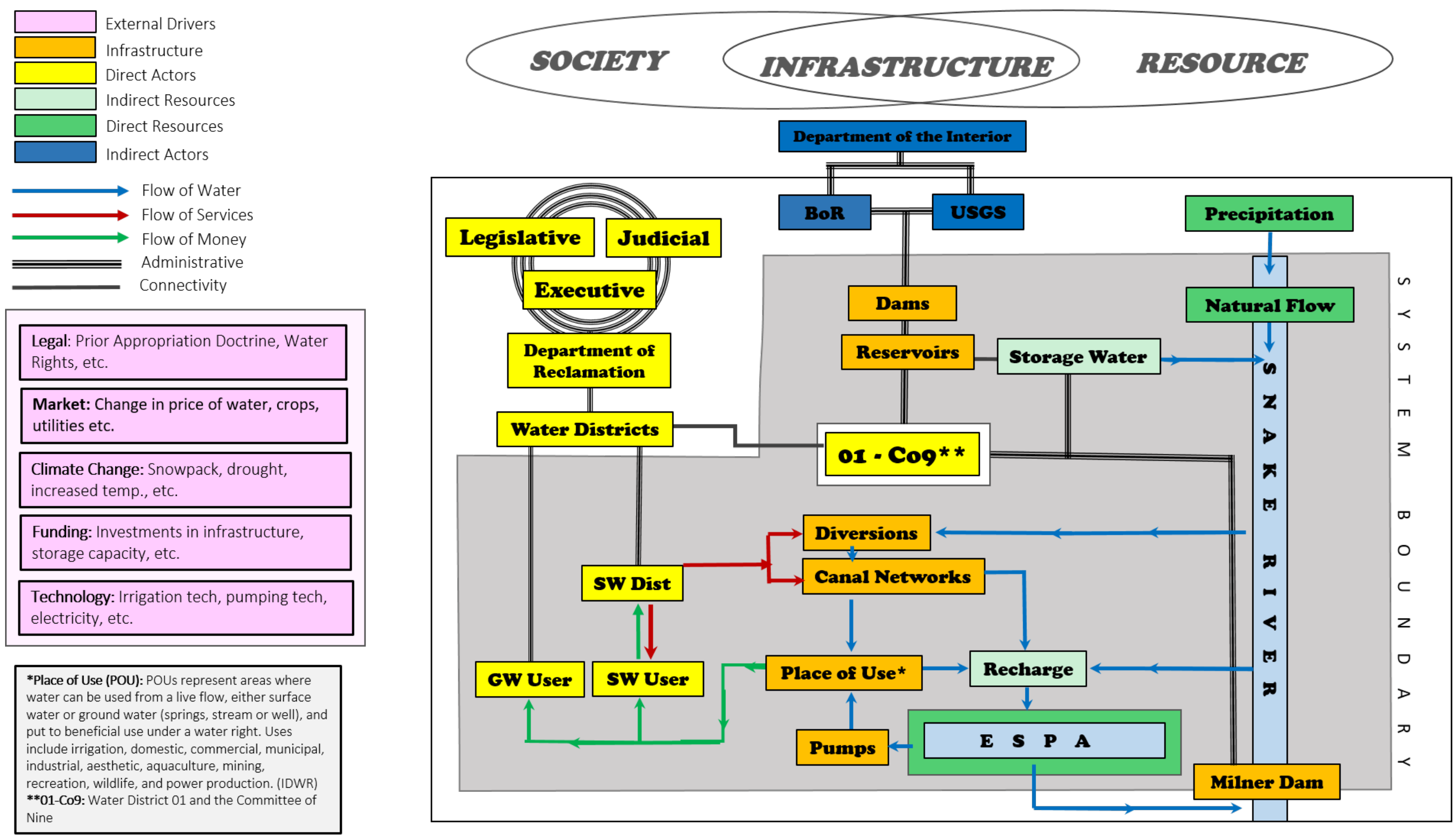

Figure 6.2: Revised conceptual map representing the interconnection between the social and ecological components of the Magic Valley as well as the infrastructure that connects them at the point that the Development Era ends (late 1940s). The hierarchal structure of the organizations represents the panarchy of the region.

Table 6.1: Description of the CAS Framework characteristics that exist in the Development Era (1880s - 1950).

Time	Occurrence	Description
1880s	Surface water irrigation systems constructed in the Upper Snake River region utilizing gravity irrigation	The semi-arid character of the southern Idaho landscape and the immensity of the Snake River made irrigated croplands the preferable method of agricultural production. On a local scale, groups of farmers with similar interests and a knowledge of irrigation technology self-organize into irrigation cooperatives where they would each help one another build irrigation networks, maintain farm plots, and manage water distribution – all vital for their small-scale farms. The self-organization of these earliest farmers embodied the cooperative character of the future of irrigation, and their cooperation resulted in the emergence of small-scale, locally constructed, maintained and administered irrigation networks.
1890	Prior Appropriation	The motivation for prior appropriation in this region began with members of the LDS Church who brought the practice of 'first in time, first in right' and the 'beneficial use' requirement from settlements in Utah. This doctrine and its two main requirements will be defined as bedrock principles of water administration for the purposes of this analysis.
1900	Irrigation begins to develop in present-day Magic Valley	The availability of federal funding and outside investment allowed for the organization of water users into irrigation districts and canal companies in present-day Magic Valley. The passing of the Carey and Reclamation Act marked the beginning of the Magic Valley landscape becoming a complex network of water users and their institutions, infrastructure, and water. The ability of water users to organize into specific districts allowed for very local-scale emergence in the form of user-created bylaws and district rules.
1911	Rexburg decree adjudication	Water adjudications, of which the Rexburg was one of the first, allowed for the proper accounting of water rights and, although completed to help enforce prior appropriation, its completion allowed for better management of the system's complex nature. Having a legally established inventory of water rights (volumes/priority/spatial distribution in face of a hydraulically complicated landscape, etc.) helped to better manage the complexity of the landscape.
1913	First record of water transfers	The development of more official ways of obtaining water rights and better recording created security and accountability and enabled the emergence of water transfers between users in dryer years. These transfers were facilitated by the growing complexity between a maturing state government, especially of the state water resource board and the courts, water districts, and water users, and by the growing feedback loops between them. The BOR and USGS also aided the monitoring and control of the supply of water in the system.
1924	Creation of the Committee of Nine	The communication and feedback loops among actors across the landscape resulted in the self-organization of the Committee of Nine. Their organization led to stronger adaptive cycles of communication and feedback among regional actors about better ways to manage water distribution in the basin in lieu of the strict enforcement of the prior appropriation doctrine.
1924	Annual compromise agreements determined by the Committee of Nine	The adaptive cycles of communication and feedback occurring with the Committee of Nine's organization led to compromises in regard to the annual distribution of water within District 01. The annual nature of these compromises results in constantly adapting management schemes that helped to increase the adaptive capacity of the water system. The Committee's role in managing water supply and distribution becomes more important as the basin continues to mature.

Phases of the Adaptive Cycle

The Development Era of the Magic Valley and the Snake River plain region went through a full rotation of the adaptive cycle, in contrast to the latter half of the 20th century and the beginning of the 21st century. The first phase of growth and development was experienced as settlement in the region increased and irrigation allowed agricultural enterprises to expand. By the 1900s, most of the surface water resources were appropriated and were being put to a beneficial use, which was aided by the construction of dams that helped to capture water and increase the supply. It is during this time that the region enters a phase of maximum productivity where it can no longer expand to other arable lands due to the inability for surface water resources to extend such distances. This phase of maximum productivity is assisted by an improved documentation of water resources and increases in water transfers between water users. The region began to enter a period of economic hardship as periods of drought highlighted the mismanagement of the basin and the enforcement of the prior appropriation could not satisfy all water users, especially those junior to others. Water scarcity sparked discussions regarding how to better manage the basin's water uses, and in 1924 the region officially entered the institutionalization phase when it created the Committee of Nine and began to create annual compromises for better management. After institutionalizing, the region entered a new growth and development phase where it was managing water more effectively, increasing transfers, and working to satisfy the needs of all irrigators in the basin despite hydrologic complications and variable weather conditions. The region continued to experience this growth and development until the 1940s when ground water pumping was introduced and it entered a new phase of rapid growth and development. These phases of the adaptive are explained in Table 6.2.

Table 6.2: Identification and description of the various adaptive cycles as they exist in the Development Era (1880s – 1945).

Period of Time	Phase of the Adaptive Cycle	Description
1880s – 1900	Growth and Development	In the 1880s, as the agricultural potential of the region was increasing realized and settlers rushed to the region, the water that was available was used in quantities that were excessive and the resources were exploited. This was due in part to the assumption that the Snake River and its tributaries were expansive and that the volume of water was infinite. The growth of the region was rapid and soon the USRB was populated with irrigation communities.
1900 – 1910s	Maximum Productivity	More irrigators began to populate the USRB and the federal government steps in to facilitate the growth of population by offering funding for the construction of dams and irrigation systems. The construction of dams and resulting reservoirs allows for the capture of water resources throughout the season and the optimal use of available water.
1910s – 1923	Economic Hardship	The rapid expansion of irrigated acres due to the construction of intensive water infrastructure leads to the over-allocation of water throughout the basin. This over-allocation is realized in times of drought when the water supply dwindles, resulting in conflict among water users in regard to who has priority and what water belongs to who, especially when water users begin to have their diversion gates closed. Overshadowing all of this is the complication that the region still has in figuring out the hydraulic connection of surface water resources to those underground.
1924	Institutionalization	A general commonality among irrigators across this basin was their cooperative values and the inability to watch other irrigators fail due to the lack of water. As economic hardship became more frequent, especially during the years of 1915 and 1919 when droughts overwhelmed the region, discussion began to emerge amongst farmers in regard to how to better manage the river system. It was accepted that the hydraulic connection between surface and ground water was far from being understood and that a new management scheme was needed that did not strictly enforce prior appropriation to satisfy all water users regardless of location within the basin. The organization of the Committee of Nine was the result of conversation amongst irrigators from all reaches of the basin and was one of the first institutions for water management that emerged from this region. This committee comes up with annual compromises for water distribution that are the result of constant feedback regarding previous years of water use and projections of future water supply throughout Water District 01.
1925 – 1945	Growth and Development	After the institutionalization of the Committee of Nine, the entire Snake River plain and USRB began to more effectively manage their water and distribute it based on timing and location of water users rather than following distribution based on priority. The resulting management scheme allowed for the consistent use of water across the basin to the lands already developed. The agricultural economy was able to grow and the region became a leader in the growth of notable products. This growth and development stage is steady until around 1945 when ground water pumping technology is introduced to the region and it enters a new, more rapid phase of growth and development.

Ground Water Era (1951 – 1987)

This section includes relevant information about the incorporation of ground water pumping into the Magic Valley and the surrounding Snake River plain region as it began in the late 1940s and began to grow throughout the latter half of the 20^{th} century. This section will end in 1987 when the Swan Falls Agreement was put into effect due to the massive depletion of ESPA water levels and the resulting decrease in discharge from the Thousand Springs area. This section correlates with the declining portion of the hydrograph depicted in Figure 4.5.

Background

As discussed in the previous section, ground water pumping began to pick up in the late 1940s as the technology was introduced, increased discharge from the ESPA enabled for cheap hydroelectric power, and irrigators were eager to tap the water below the surface in the Snake River plain to expand irrigated acreage. Although legislation existed validating the appropriation of underground water sources, a general disagreement existed as to whether ground water was subject to prior appropriation the same as surface water bodies were. Disputes grew in reference to specific language in Idaho's Constitution stating that 'the right to divert and appropriate the unappropriated waters of any *natural stream* to beneficial uses, shall never be denied…(I.D. Const. Art. 15 Sec. 3) ' with the definition of 'natural stream' often assumed to mean strictly surface waters (Fereday et al., 2018).

In 1931, the Idaho Supreme Court officially recognized the appropriation of ground water and determined that these subterranean waters could be appropriated through their diversion and application to a beneficial use, or the statutory method of appropriation. With the introduction of pumping technology towards the end of the 1940s and the use of ground water rising significantly, the appropriation of ground water was given legal status in 1951 through the passage of the Ground Water Act. This legislation verified the appropriation of ground water resources, reified their subsequent administration and protection and validated all existing appropriations of ground water that had been established before the act (Fereday et al., 2018).

In 1953, amendments to the Ground Water Act (Id. Code § 42-226 – 42-239) were passed in an effort to protect the future of ground water development, and included three key aspects: 1) that the prior appropriation doctrine could be applied to ground water; 2) that management should not block full economic development of the resource; 3) that prior appropriations of ground water, or senior water users, are to be protected as long as they maintain reasonable ground water pumping levels; and 4) that the Director of the state water resource agency, which at this time was the State Reclamation Engineer of the Idaho Department of Reclamation, had the authority to protect ground water from. These amendments were significant because they were instruments for appealing to the language of the prior appropriation doctrine and respecting senior appropriators, while also protecting underground water resources for future development. The appropriation of ground water resources was further officiated in 1963 when the statutory method for applying for and obtaining a permit for ground water use was developed, replacing the constitutional method of appropriation (Id. Code § 42-229).

In addition to irrigation interests advocating for an increased use of the aquifer's water, hydropower producers also had their eye on securing further access to the Snake River's flow, a majority of which came from the aquifer. As the "two rivers" system works, water from the aquifer replenishes the Snake River downstream of Milner Dam, and with increased aquifer discharge came an increasingly recharged river. In addition, the "two rivers" concept allowed for the waters downstream of Milner Dam to be used primarily for hydropower considering the difficulty that irrigation interests had in diverting water out of the deep canyon for irrigation purposes. In the late 1940s and early 1950s, IPC fought to gain federal approval to build more hydropower dams on the Snake River downstream of Milner Dam, especially in the Hells Canyon area. In order to do so, IPC had to gain support of the state and irrigation interests, both of which favored the use of water primarily for irrigation purposes. To appease these interests, IPC included a subordination clause in their federal license that guaranteed that the hydropower project would be "operated in such manner as will not conflict with future depletion in flow of the waters of Snake River and its tributaries…for the irrigation of lands and other beneficial consumptive uses in the Snake River [watershed]…" (14 F.P.C. 55, 1955). To support this subordination, C.J. Strike, the president of IPC at the time, testified to the fact that water downstream of Milner Dam was deemed unavailable for irrigation purposes, and that the discharge from the aquifer back into the river was sufficient to supply hydropower operations past that point. The company was given approval to build additional hydropower facilities on the assumption that all future hydropower purposes were to be absolutely subordinate to all future water uses for irrigation.

With legislation in place to officiate the appropriation of ground water and cheap electricity offered by new hydropower sources, the region saw an increase of nearly a million acres in irrigated lands. The new agricultural lands put into production were those that were previously deemed arable yet unfeasible for surface water irrigation due to their distance from surface water sources. In addition to expanding acreage, the ability to appropriate ground water benefitted surface water users as well by providing an additional source of water that could be used when their primary source of water was not available, thus increasing water security in times of need, such as droughts.

With the expansion of irrigated acres across the plain came a boom in the agricultural economy, but the consequences were observed through the latter half of the 20th century as the volume of water in the ESPA slowly declined (Fiege, 1999). In contrast to surface water irrigation systems, a landscape of ground water irrigation systems was less strewn with canals and laterals and more organized into plots of land irrigated with sprinkler systems, such as the center pivot, that pumped water straight from underground and connected it directly at the field scale. These sprinkler systems were much more efficient, were easy to utilize with cheap electricity provided by hydropower, and appealed to surface water users as well, who saw them as an instrument to conserve their own water. This new irrigation technology, although conservative in its water use, decreased the amount of water that had previously infiltrated into the aquifer as farmers abandoned old practices such as flooding fields. The implementation of this efficient technology, paired with increased ground water pumping across the region, led to a significant drop in the volume of the ESPA in the coming decades. Slowly, as seen in Figure 4.5, the water discharging at the Thousand Springs area began to decrease, providing a strong indication that the aquifer was being depleted over time as the region's irrigation techniques continued to evolve.

Although not directly related to the depletion of the aquifer, the state took early action on the mismanagement of the state's water resources by amending the state constitution in 1965 to create the Idaho Water Resource Board (IWRB). The IWRB was given the ultimate responsibility to promote the economic development of water through implementing water conservation activities and ensuring a sustainable supply of water for current and future uses in promotion of the public interest. These duties were separate from those of the Idaho Department of Reclamation which remained in charge of the administration of the state's water rights. To achieve these goals, the IWRB was responsible to 'formulate and implement a state water plan for optimum development of water resources in the public interest' (Id. Const. Art. 15 Sec. 7). Although it has jurisdiction extending to the entire state, the IWRB plays a critical role in the management of the ESPA and in efforts to reverse its declining water levels in the future.

The first state water plan was accepted by the legislature in 1976 and included recognition of the complexities inherent to the ESPA and Snake River system. The plan briefly touches on concerns that the supply of water in the basin was over-allocated and that there was a general need for more storage capacity and recharge efforts (Streiff et al., 1976). Although the plan only mentioned hypothetical recharge locations, the Idaho legislature passed the first statute regarding recharge efforts to the ESPA in 1978, codified in I.C. § 42-234. This legislation encouraged a "pilot project to recharge ground water basins in the vicinity of St. Anthony and Rexburg," both located in the northeastern portion of the ESPA (Figure 6.1). This legislation also determined that 'recharge' was to be officially considered a beneficial use when it came to appropriating water (I.C. § 42-234), a significant change to what had been considered a beneficial use historically.

Further steps were taken by the Idaho legislature and the IWRB in regard to water conservation measures with the creation of a state 'water bank' in 1979 that allowed water users with excess water to provide it to other water users in need. This legislation added 'water transfers' to the growing list of water uses that the state recognized as beneficial. This legislative move also involved the appointment of the Committee of Nine to administer the Water District 01 Rental Pool, which is rental water held in reservoirs, to users in need located upstream of Milner Dam on the Snake River. The creation of this rental pool has played a significant role in the ability of the IPC to produce electricity by providing upstream river resources to power plants downstream of Milner Dam (IWRB, n.d.).

In 1973, the court's decision in *Baker v. Ore-Idaho Foods, Inc.* marked the beginning of the state interpreting language in the Ground Water Act to favor public interests over private interests in ground water disputes. This case involved senior water users seeking to enjoin junior water users from pumping out of a common aquifer. The district court decided, and the Idaho Supreme Court confirmed, that all water users in question were collectively pumping from their shared local aquifer in an amount that exceeded the rate of natural recharge, or were 'mining' the aquifer contradictory to language in the Ground Water Act prohibiting this type of pumping. The language of interest is reads that, "Water in a well shall not be deemed available to fill a water right therein if withdrawal therefrom of the amount called for by such a right would…result in the withdrawing of the ground water supply at a rate beyond the reasonably anticipated average rate of future natural recharge" (Id. Code § 42-237a). This court case confirmed that senior appropriators would only be protected in their maintenance of reasonable pumping levels, and in this case, their pumping was exceeding the rate of natural recharge, which was not reasonable nor in the public interest (*Baker v. Ore-Idaho*, 1973).

In the end, the district court found that the aquifer of interest was recharging at a rate of 5,500 acre-feet a year, and therefore determined that all water users who were party to the action would be limited to a portion of that 5,500 acre-feet that collectively would ensure the aquifer was not being mined. In addition, the district court denied pumping from the aquifer by water users who had not been a party to the action (*Baker v. Ore-Ida*, 1973). Rather than enjoining the junior water users who were party to the action from pumping further and allowing the senior water users to continue pumping at their historic rates, the court effectively altered the historic levels of seniors and juniors alike to ensure economic development and longevity of the collective ground water source. This decision took into consideration the important ruling in *Schodde v. Twin Falls Land & Water Co.* that no appropriator was absolutely protected in their means of diversion in order to preserve the policy of the state ensuring water resources for the benefit of the public. This decision was a further evolution of the administration of water in Idaho from the strict enforcement of ‘first in time, first in right’ towards one that values the economic development of water and its values of ensuring that the appropriation of water is in the interest of the public.

Depletions of the ESPA water levels began to affect water users in the latter half of the 1970s as high-lift pumping technology enabled irrigators to begin taking advantage of Snake River water below Milner Dam that had previously been unavailable for irrigation use due to the height of canyon walls (Strong & Orr, 2009). The momentum that this new pumping method gained led to an increased need for electricity to run the technology while also reducing the water available in the river for hydropower production. In time, IPC ratepayers took action by filing a petition with the Idaho Public Utilities Commission regarding the fact that IPC was failing to enforce their senior water rights at Swan Falls Dam, which was in turn increasing the price they were paying for utilities. One of the most important responses by the IPC was their filing of a declaratory judgment with the district court to determine whether their water rights at Swan Falls were ultimately subordinate to irrigation uses as was determined in the early 1950s when applying for additional hydropower facilities. This issue went as far as Idaho's Supreme Court, which in 1983 ultimately decided that IPC's water rights at the Swan Falls Dam, which had been built in 1901 long before the Hell's Canyon project, were not subordinate to irrigation water rights the same as the more junior project dams downstream were. With this decision, the IPC now had the authority to make water calls against those junior water users both junior and senior that were thought to be reducing the flows required for the operation of the Swan Falls Dam, the majority of which were using ground water for irrigation purposes.

In 1984, the State, the Governor, and the Attorney General came to a settlement with the IPC, denoted the Swan Falls Agreement. Under this agreement, the state determined that a minimum flow of 3,900 cfs would be required to supply the dam at Swan Falls during the irrigation season, while a minimum flow of 5,600 cfs would be required during the non-irrigation season in order for IPC to supply sufficient power to their customers (IWRB, 1986). This amount was agreed on in order to appease ratepayers, and to avoid any legal conflicts regarding whether the IPC, having waited for some time to enforce their water rights at Swan Falls Dam, had inadvertently forfeited these water rights which could have initiated a lengthy law suit between the company and their rate payers.

This requirement brought attention to the important connection between the Snake River and the ESPA and the importance of properly managing both water sources together considering their hydraulic connectivity and the high demand for ground water to supply irrigation and other uses downstream from Milner Dam. With a majority of water rights having been created through the constitutional method of appropriation, or simply diverting water and applying it to a beneficial use, the ability of IPC to make any sort of water call against juniors would be close to impossible. Considering this, an additional facet to the Swan Falls Agreement was the support by all parties for legislation to commence a general adjudication of the Snake River basin. Such an adjudication would determine all water rights within the basin, including their priority, beneficial use, amount of water appropriated, and spatial location within the basin, helping to significantly improve management of water rights within the drainage. The legal process for this adjudication began in 1987 and comes to define the final era of interest – the Modern Water Management Era: Adjudication and Conjunctive Management.

Summary

This concludes the background section related to the 'Ground Water Era' that the Snake River plain experienced from the introduction of ground water technology and pumping to the development of the Swan Falls Agreement and the commencement of the SRBA as an incident of drastic depletion to the ESPA. Throughout this time period, the interconnection between society and the environment becomes increasingly complex, especially with the introduction of new ground water infrastructure that complicates the relationship of surface water resources and the ESPA. The decline of the aquifer becomes a direct consequence of the actions of the water users on the landscape as irrigation technology and methods evolve. Contrary to the first half of the 20th century, the introduction of ground water pumping technology effectively reversed the water level of the ESPA, ironically decreasing the resource fueling the region's agricultural and economic growth.

The succeeding sections will highlight the key occurrences that resulted in a growing complexity of the region and its panarchy, the accompanying emergent and self-organization qualities that are characteristic of Complex Adaptive Systems, and the phases of the adaptive cycle that are present in this time period.

Complex Adaptive Systems Framework

The introduction of ground water pumping technology, cheap hydro-electricity offered by abundant water in the Snake River, and the passing of the Ground Water Act that officiated the appropriation of ground water all contributed to an increasingly more complex landscape in the Snake River plain. This complexity is seen by the addition of nearly a million more acres of crop land, new water users, and the incorporation of different irrigation systems and technology than was typical of surface water systems. This growth introduced an entirely new level of complexity to an already complex system. Aside from complexity existing in the form of new water users on the landscape, the complexity of the hydraulic connection between the Snake River and the ESPA was confirmed as the aquifer almost immediately reversed its course and in time is unable to continue meeting the demand of water users as its supply decreases.

The resulting decisions of society showed an effort to prolong the growth and development of the region to ensure the optimum use of state water resources for the good of the public. These decisions included further interpretations of the Ground Water Act emerging that altered the bedrock principles of the prior appropriation doctrine, such as what constitutes a beneficial use, and the subordination of irrigation water rights to hydropower water needs downriver. In addition, concerns regarding unsustainable water use resulted in the institutionalization of the IWRB with the duty to increase efficient water use and conserve diminishing supplies. Figure 6.3 represents the panarchy of the region as it existed at the end of this era in 1987.

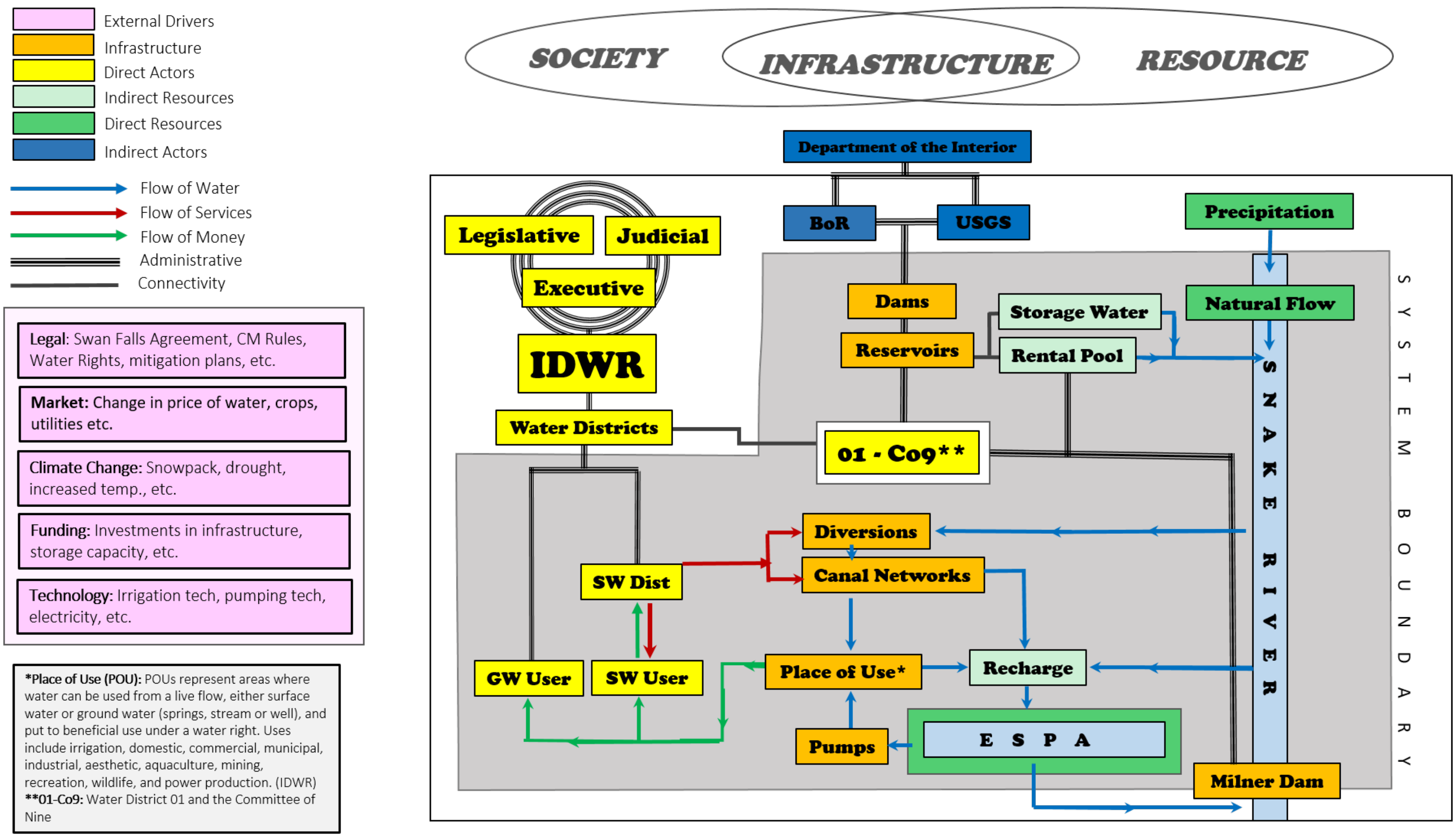

Figure 6.3: Revised conceptual map representing the interconnection between the social and ecological components of the Magic Valley as well as the infrastructure that connects them at the point that the Ground Water Era ends (1987). The hierarchal structure of the organizations represents the increasing complexity of the region's panarchy.

Table 6.3: Description of the CAS Framework characteristics that exist in the Ground Water Era (1951-1987).

1951	Ground Water Act (I.C. § 42-226)	The introduction of pumping technology resulted in legislation that officiated the appropriation of ground water. Rapid expansion across the landscape resulted in the integration of a new level of complexity – new irrigators who utilized new methods of irrigation. The result was a drastic reversal in the trajectory of ESPA water levels as it began to diminish. This increase in complexity lays the ground for future emergence and self-organization in response to the consequences.
1953	Ground Water Act amendments	Amendments to the Ground Water Act established that a reasonable exercise of 'first in time, first in right' shall not block full economic development of underground resources, which replaced the former standard of historic pumping levels. These amendments determined that senior appropriators of ground water would be protected as long as they maintained reasonable pumping levels. These amendments emerged as instruments that appealed to the language of the prior appropriation doctrine while reaching to encourage economic develop in the public interest.
1963	Ground Water Permit System	The statutory method of appropriating ground water was used until the development of a permit system that helped to keep better track of ground water use. Although the appropriation of ground water added additional complexity to the water use landscape, the introduction of an official permit system helped to create a more structured record and accounting of water rights that in the future allowed more emergent phenomenon such as water transfers and ground water tracking to occur.
1965	Idaho Water Resource Board created	The IWRB was created with the duty to create a state water plan, implement management activities, and support the sustainable use of state water resources. The institutionalization of an organization to oversee conservation of water in the state created an additional link to the panarchy of the system that was less involved in the administration of water rights and the prior appropriation doctrine and interested in more nuanced activities promoting the conservation of water and the goal of optimal use of state water resources. Having a separate role from that of IDWR allowed for the IWRB to prioritize conservation efforts without overlapping with IDWR's responsibilities. The existence of this individual board allows for the implementation of future emergence and self-organization while IDWR is chiefly responsible for the administration of water rights.
1973	*Baker v. Ore-Ida Inc.*	The ultimate finding in this case was that no senior appropriator is absolutely protected in either their historic water level or historic means of diversion, and in some cases, senior appropriators may have to accept some modification of their rights to achieve the state's overall goal of full economic development. This was emergent because it altered the common law application of 'first in time, first in right' and historic diversions in order to provide for full economic development and reasonable water use.
1978	Recharge Statutes	Although recognized as a valuable management activity in the 1976 State Water Plan, aquifer recharge was not fully implemented until 1978 after recharge statutes were passed. This legislation allowed for recharge initiatives to be implemented across the ESPA with pilot projects in the upper reaches of the aquifer and the development of an official recharge district in the far western portion of the ESPA. To support recharge efforts, 'recharge' was added as an official beneficial use of water, an emergent characteristic altering the historical definition of the term.
1979	Creation of State Water Bank and Water District 01 Rental Pool	The legislature created a state water bank and instituted local rental pools from which water could be transferred or rented by water users in need. The Committee of Nine was appointed by the IWRB to govern water transfers in the upper reaches of the Snake River. This was made possible by the complexity that already existed between the Committee and their multiple constituent irrigators that had been growing since their instatement in 1924. The initial emergence and self-organization of the Committee had aided in a successful growing complexity of the region and its ability to effectively manage water, which involves the effective transfer of water to those in need. A further emergent characteristic was the decision to recognize 'water transfer' as a beneficial use.
1984	Swan Falls Agreement	In order to ensure hydropower to rate payers, the state of Idaho and the IPC entered into a settlement that guarantees IPC water rights at Swan Falls Dam. The Idaho Supreme Court ruled that the subordination of water did not extend upstream to the Swan Falls Dam, altering the historic preference of water for irrigation use over that of hydropower. This was an emergent event that altered the preference of water use and acknowledged the troubling relationship between ground water pumping in the ESPA and decreasing discharge to the Snake River.

Phases of the Adaptive Cycle

After the introduction of the ground water pumping technology and the passing of the Ground Water Act, the region entered a new period of rapid growth and development as it implemented ground water technology and managed to expand agricultural production by nearly 1 million acres. Although the level of the ESPA almost immediately began to drop, the region effectively continued to pump and use ground water for the majority of the latter half of the century. This is aided by the passing of new and amended legislation that affected the administration and protection of ground water resources, including the development of a permit system and rules regarding reasonable pumping levels and methods. Although the principles of prior appropriation still stand as the bedrock of water administration, the state makes this administration more flexible to ensure the use of water is consistently in the public interest and is optimally used. The region remained in the growth and development phase through the second half of the 20th century, but was affected by a steady introduction of micro adaptive cycles that slowed down the growth and development phase until the region reached maximum productivity. These micro-adaptive cycles included the various legislation and court decisions that allowed the appropriation of ground water to continue to develop while also addressing issues of ground water conservation and a decreasing aquifer. A summary of the events occurring in the Ground Water Era and how they fall into the phases of the adaptive cycle are seen in Table 6.4.

Table 6.4: Identification and description of the various adaptive cycles as they exist in the Ground Water Era (1945-1987)

Period of Time	Phase of the Adaptive Cycle	Description
1945	*Rapid* Growth and Development	The introduction of ground water pumping allowed the region to expand to those lands that were previously deemed unavailable due to their distance and inaccessibility to surface water resources. With a new source of water, the region added nearly 1 million acres to its agricultural production.
1951	*Rapid* Growth and Development	**Ground Water Act:** The passing of the Ground Water Act officiated the appropriation of ground water and allowed for its subsequent administration and protection.
1953	*Rapid* Growth and Development	**Amendments to the Ground Water Act:** New amendments to the Ground Water Act stated that a senior appropriation would only be protected if it was maintaining reasonable pumping levels. This meant that in some cases, senior water rights could be altered and the curtailment of junior water users could be denied if senior water users were not using their water optimally.
1963	Growth and Development	**Ground Water Permit System Developed:** A permit system for the appropriation of ground water was developed and replaced the statutory method that had been used before. This allowed for more effective accounting of ground water rights helping to protect and conserve these resources.
1965	Growth and Development	**Idaho Water Resource Board:** The IWRB is created with the main responsibility of writing a state water plan and implementing conservation activities to ensure there is water available for both present and future uses.
1973	Growth and Development	***Baker v. Ore-Ida Inc.*****:** In this court case, it is determined that the mining of aquifers is not allowed. This case altered the water rights for both the senior and junior water users involved, replacing the strict enforcement of the prior appropriation doctrine and allowing for the optimal use of the resource.
1978	Growth and Development	**Recharge Legislation:** Legislation was passed to enhance recharge efforts in the upper reaches of the Snake River Plain. This represented the mounting concern regarding the state of the aquifer and its depletion, and added 'recharge' as an acceptable beneficial use demonstrating the flexibility of the legislature in adjusting the constitutional requirements of water use in the state.
1979	Growth and Development	**Water Banking:** A state water bank was created by the Idaho legislature that made it possible for water transfers to happen between water users where possible. This added 'water transfers' as an additional water use that was considered beneficial. This allowed for the transfer of water from more senior water users to more junior water users providing security in times of scarcity.
1984	Growth and Development	**Swan Falls Agreement:** Although the constitution states that the use of water for irrigation shall be preferred to water use for power generation, the conflict among IPC utility customers, IPC, and the state resulted in an adjustment to this preference. Rather than subordinating its water rights, IPC was given authority to enforce their water rights to the level of their hydropower capacity, altering the historical preference of irrigation water use.

Modern Water Management Era: Adjudication and Conjunctive Management (1987 – 2015)

This section includes information in regard to the evolution that water administration in Idaho experiences after the legal process to adjudicate the Snake River basin begins and the benefit this adjudication offers to the management of the basin and the administration of hydraulically connected surface and ground water rights. Although a moratorium was placed on further ground water permits, this does not stop the ESPA water levels from continuing to drop, reinforcing the need for more elaborate efforts to approach the decreasing ground water supply that fuels a significant amount of the income for the state. The focus of this section is on the evolution that Idaho's water institutions undergo in advancing Idaho's water management through the commencement of an adjudication of water rights in the Snake River basin and the completion of Conjunctive Management Rules for determining the process for responding to water calls of senior surface water users against junior ground water pumpers, as well as the major implications that this has for water users in the region. Various law suits will be discussed that illustrate the rising conflicts between senior water users and junior ground water users throughout the era and the effects of the conjunctive administration of water rights. This era, defined by the implementation of rules defining the process for conjunctive management, ends with a historic settlement agreement between both senior and junior water users that serves as a modern and progressive approach to managing the Upper Snake River system and a leading example of effective water management for other irrigated communities throughout the western United States.

Background

This period of time began with the state of Idaho and the IPC entering into the Swan Falls Agreement, a critical outcome of which was the state's commitment to provide funding for the general adjudication of the water rights throughout the entire Snake River basin in 1987, or the Snake River Basin Adjudication (SRBA). It was determined by the state that the Snake River basin could not effectively be managed in the public interest without a "comprehensive determination of the nature, extent and priority of the rights of all users of surface and ground water from that system" (Swan Falls Agreement, 1984). Funding for the SRBA was provided to fund hydrologic and economic studies to determine the connection of surface and ground water, and a SRBA court was created specifically for the adjudication. In 1987, the Director of the IDWR filed a petition to commence the SRBA, and an official commencement order from the presiding judge followed to initiate the adjudication. Initial proceedings in the adjudication followed guidelines laid out by adjudication statutes developed in 1987.

In addition to the initiation of the SRBA, the IDWR, which was created in 1974 when the IWRB and the Idaho Department of Water Administration merged, imposed a moratorium on any further ground water permits in the ESPA in 1992 as an immediate effort to halt further ground water. This moratorium took effect in 1993 and still remains in effect today. This moratorium was imposed to deny future permits primarily for irrigation purposes in an effort to combat the decreasing levels of the ESPA that affected both ground water pumpers as well as those water users downstream of Milner Dam that relied on the discharges of the ESPA back into the Snake River.

Included in the Swan Falls Agreement was a statement that a general adjudication of the Snake River basin would result in "the quantification of federal and Indian water rights," which until that point had been unresolved (Framework for Final Resolution of Snake River Water Rights Controversy, 1984). As a condition to the SRBA, the legislature called for the state to engage in negotiations with federally recognized tribes that had water rights reserved under the Winters Doctrine. As a result of *Winters v. United States* (1908), the Winters Doctrine required that when Congress reserved land for an Indian reservation, it also reserves water sufficient to fulfill the purposes of the reservation. In regard to the water within the Snake River basin and those waters flowing out of the basin and affecting downstream water users, both the Shoshone-Bannock tribe and the Nez Perce tribe were in effect legal parties to the SRBA and proceeded with efforts to reserve water on each reservation.

In 1990, the state was directed by the legislature to engage in negotiations with the Shoshone-Bannock tribe, which resulted in the 1990 Fort Hall Indian Water Rights Agreement that secured the tribe's water rights, as established through treaties with the federal government, in the amounts set forth in the Michaud Contract of 1957 (The 1990 Fort Hall Indian Water Rights Agreement, 1990). This contract was a result of the construction of the Michaud Flats project that serviced a significant portion of land on the Fort Hall reservation, and reserved storage water rights for the tribes in the amounts of 46,931 acre-feet from American Falls Reservoir, and 83,900 acre-feet of water from Palisades Reservoir. The tribes also secured a significant amount of water for use sourced primarily from the Snake River, the Blackfoot River, and Grays Lake. As a condition of the 1990 agreement, the tribes were provided the right to create a Tribal Water Bank similar to the rental pool system operated by the Committee of Nine in Water District 01. As a result of this agreement, the tribe secured valuable water rights in the SRBA for current and future water uses that are protected from the penalties associated with other water rights, such as losses through forfeiture or non-use. In addition, the excess water that is not used by the tribe for water use on the reservation can be rented for use to off-reservation and non-Indian parties, which has provided roughly $15 million in income to the Tribes since its initiation in 1998 (Teton, 2017).

While the Shoshone-Bannock tribes made claims to water sufficient for irrigation, the Nez Perce in northern Idaho made claims within the SRBA court to in-stream water flows sufficient to sustain their native fishery. Rather than enforcing these water rights stemming from their 1855 treaty with the federal government, the tribe conceded these rights in exchange for a settlement that included a significant volume of water to be left in-stream in the portion of the Snake River traveling through the USRB. This portion of the settlement was termed the Snake River Flow Component and was a flow augmentation program designed to provide water for fish downstream of the IPC's Hell's Canyon Dam. Of this flow augmentation water, 427,000 acre-feet would be rented and delivered downstream from the portion of the Snake River above Milner Dam for an agreed upon period of thirty years (Nez Perce Agreement 2004).

The SRBA Final Unified Decree was signed on August 25, 2014 putting to rest many conflicts over the use of water in Idaho among the various existing water interests. Issues in regard to the Swan Fall Settlement were resolved within the SRBA as well as the long-unresolved quantification of federally reserved water rights for tribes within the Snake River basin. In addition, requirements set forth in the Endangered Species Act regarding water flows have also been resolved by the federal government. Although a long and expensive process, the SRBA is a huge endeavor that Idaho has undergone in an effort to properly manage surface and ground water resources.

Although the SRBA was a step toward having a conclusive record of water rights for the Snake River Basin to improve management, its development did little to offer a method for conjunctively managing surface and ground water rights. In 1994, the Director of IDWR came under fire for neglecting to develop a process for responding to water calls by senior water users against junior ground water pumpers in an area having a common ground water supply. In the case of *Musser v. Higginson*, the Mussers were senior water users who requested to have their decreed water rights delivered, the source of which was a spring. The call involved the curtailment of junior water users who were pumping from the ESPA. The Mussers sent this complaint to their local water master, who sent the complaint to the Director who rejected the request and argued that they were "not authorized to direct the watermaster to conjunctively administer ground and surface water…short of a formal hydrological determination that such conjunctive management is appropriate" (*Musser v. Higginson*, 1994). The trial court in this case decided that the Director had a "clear legal duty to distribute water under the prior appropriation doctrine," and that the Director's failure to have a method in place for responding to the Musser's call was a breach of his duties.

This conflict brought attention to the fact that hydrological studies in support of conjunctive management, although imperative to the management of the Snake River and the ESPA, were not being engaged in as needed. The ruling in *Musser v. Higgins* served as a catalyst to the adoption of the Conjunctive Management Rules (CM Rules) by the IDWR, although the Department claimed that there had been previous intention to do so. The CM Rules adopted by the agency included criteria for determining whether a junior water user pumping from the ESPA was materially injuring a senior water user, how to determine this injury, and the validity of a water call on a case by case basis. These CM Rules were approved by the Idaho Legislature in 1995, introducing a new standard for determining water calls by senior water users against junior water users. Their integration into the IDWR's method for water administration began a new era of water management by requiring that the historic concept of "first in time, first in right" be subject to the many policies of reasonable use.

Musser v. Higginson also brought to light the legal conflicts that would continue to develop between the senior and junior water users sourcing water from the ESPA. Recognizing the rise of litigation between ground water users and surface water users, the Idaho Legislature passed statutes to officiate the organization of ground water districts. Contrary to irrigation districts and canal companies that were primarily organized to distribute water, ground water districts were developed to help share the cost of monitoring water use and, most importantly, share the cost of litigation and resulting mitigation. In direct response to rising conflicts on the Snake River plain, the Idaho Ground Water Appropriators (IGWA) formed to represent those ground water users pumping from the ESPA and affecting the flow of water to senior water users. IGWA is comprised of nine ground water districts positioned throughout the ESPA (Figure 6.4), as well as various industrial parties and municipalities (Idaho Water Policy Group), and comes to play a critical role in mitigation for senior water users and in the development of modern management of the aquifer for those senior surface water users located in the Magic Valley region.

After the case of *Musser v. Higginson*, the IDWR and water users did not encounter any serious conflicts that required use of the CM Rules or that threatened the curtailment of junior water users until the early 2000s. At the turn of the century, two ground water management areas (GWMAs) were created – the American Falls GWMA and the Thousand Springs GWMA - both areas of the Snake River that had higher hydrologic connection with the aquifer than other reaches (Fereday et al., 2018). After a period of prolonged drought conditions, the Director requested mitigation plans by those ground water pumpers who were identified as affecting these reaches of the river. Five of the IGWA districts responded to the Director's order by developing mitigation plans to last for a period of two years to compensate surface water users for lost water from the aquifer (Fereday et al., 2018) An additional conflict arose in 2003 when Rangen Inc. (Rangen), a company receiving water from the same tunnel as the Mussers, filed a water call alleging that ground water users were compromising their flows. A settlement was reached in 2004 involving Magic Valley GWD and the North Snake GWD that developed a mitigation plan to compensate Rangen.

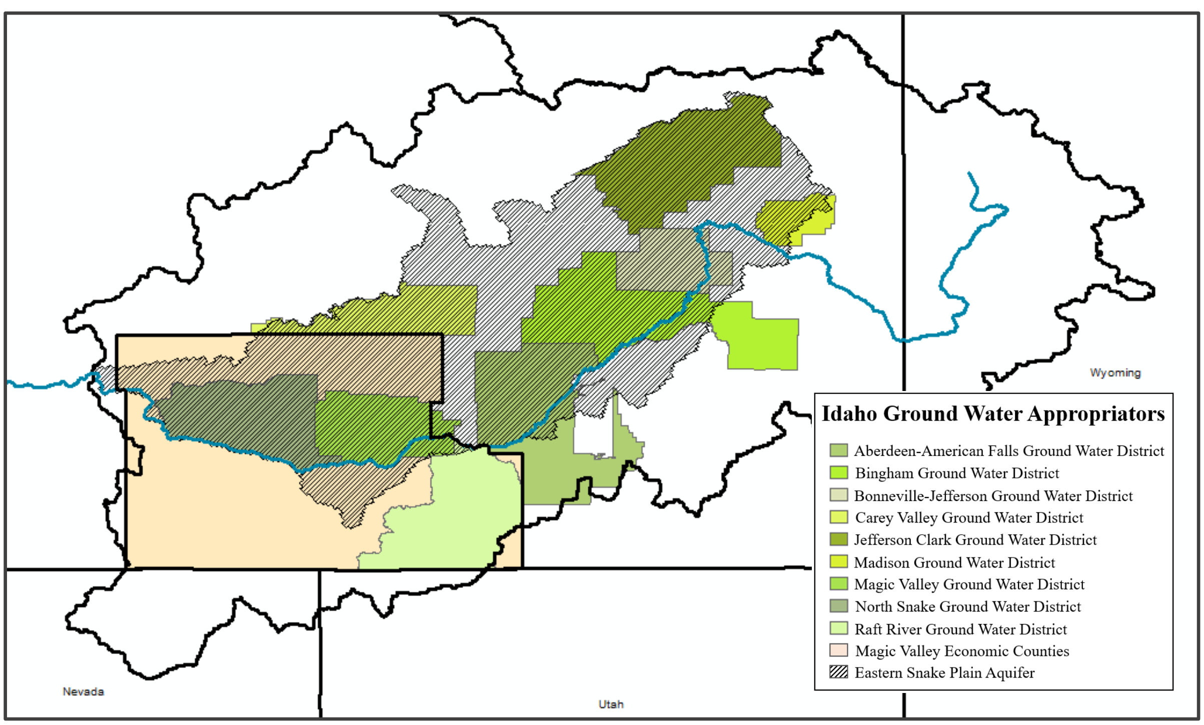

Figure 6.4: Spatial representation of the individual ground water districts that make up the Idaho Ground Water Appropriators and their location relative to the economic counties of the Magic Valley and the USRB as a whole.

These mitigation plans created by GWDs to compensate surface water users are a requirement of the CM Rules under Rule 43 and come to play a large role in the ability of the region to remain functional even with decreasing ground water supplies. As seen in Figure 6.1, the layout of the USRB and the storage capacity of the system created by dams and reservoirs inform the success of mitigation plans to those senior water users in the Magic Valley region. It is this design of the USRB and its ability to store so much water that plays a significant role in the ability of the region to adapt to the drastic declines in aquifer levels throughout the beginning of the 21st century.

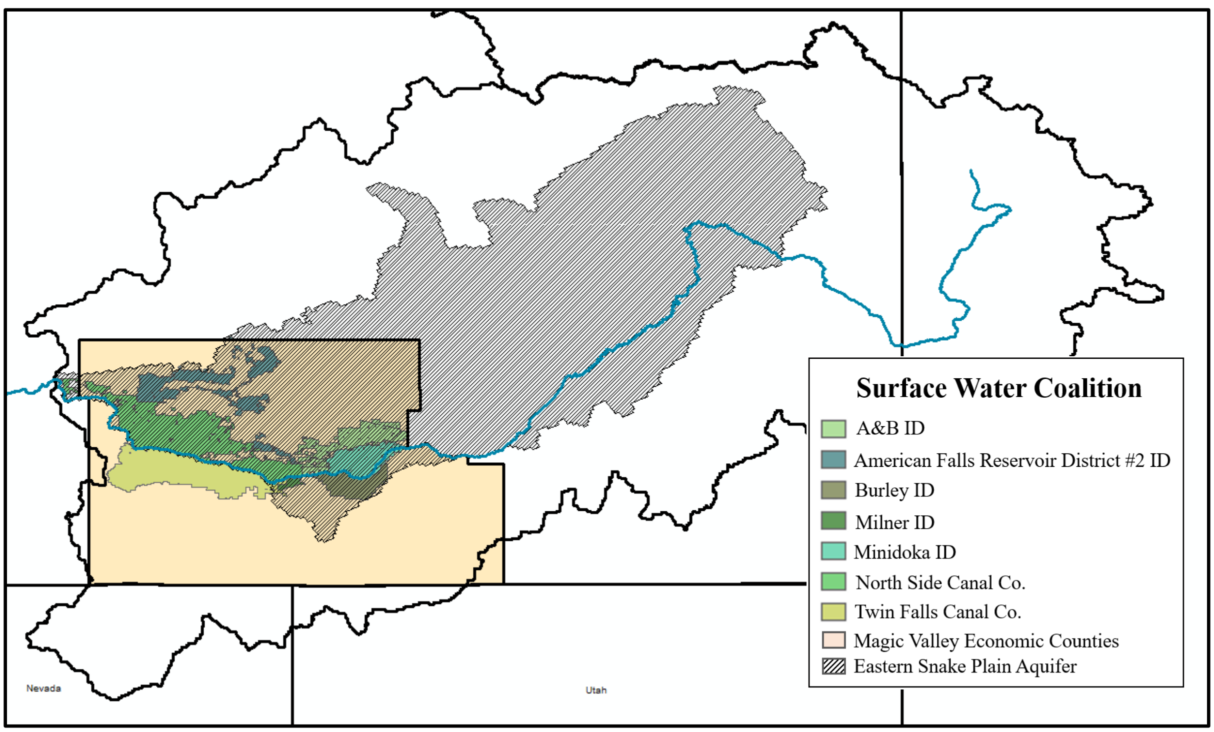

Figure 6.5: Spatial representation of the individual surface water districts that make up the Surface Water Coalition and their location relative to the economic counties of the Magic Valley and the USRB as a whole.

In 2005, the increasing water calls made by surface water users against those pumping from the aquifer led to the development of the Surface Water Coalition (SWC), a group of seven irrigation districts and canal companies, all positioned within the Magic

Valley and therefore the most affected by aquifer depletions (Figure 6.5). The main purpose of the SWC was to represent senior surface water users in litigation and one of their first actions was filing a delivery call for their decreed water rights held in American Falls Reservoir. Similar to the Thousand Springs area, a significant amount of aquifer discharge reaches the Snake River in this area in the form of springs, but due to over-pumping, the water that they relied on to refill the river system was insufficient. With some of the oldest water rights downstream of American Falls, the SWC followed the CM Rule process to request a delivery call from the IGWA. In addition to this water call, the SWC also initiated a court challenge to the CM Rules claiming that they were unconstitutional and violated the principles of prior appropriation and the strict enforcement of seniority in water rights.

In 2007, a significant ruling was made by the Idaho Supreme Court in this case that has come to be known as *American Falls District No. 2 v. IDWR.* The court ruled that the CM Rules uphold the foundational values of prior appropriation by ensuring that the decisions in regard to delivery calls not only consider priority, but also consider whether a water use is meeting the standards of optimum and beneficial use and is not hindering the full economic development of water in the state. This ruling effectively legitimized the use of the CM Rules as the process for making water calls within the ESPA while revolutionizing the standards by which water is administered. In addition to the priority that senior water users have in water conflicts, the court ruled that the ultimate administration and distribution of water would be decided on a suite of important factors in addition to this priority, including whether a diversion is reasonable, whether water use is wasteful, and whether there will be sufficient water in the future to satisfy a water right, which in this case includes carry-over storage in reservoirs upstream of where the SWC diverts from American Falls reservoir.

Although the SWC had qualms with the validity of the CM Rules in light of the constitution, the outcome of the case favored the SWC's water call and required that future injury to the SWC be determined on an annual basis. Essentially, if their projected water demand was higher than the projected water supply, the IGWA would be required to mitigate them up to that amount (Harris, 2015). This water call has been revisited annually since 2005 to determine yearly whether mitigation is necessary, with the majority of mitigation water being rented from Palisades reservoir upstream of American Falls.

Also in 2005, a similar water call was made by senior water users in the Thousand Springs area who, like the SWC in the previous case, were not getting water sufficient for their operations. These senior water users happened to be fish producers whose primary use of spring water was to raise trout. An official evidentiary hearing was commenced in 2007, with a final decision in 2011 that further upheld the CM Rules, although there were multiple arguments by the ground water users against them. One of these arguments was that the surface water user's water diversion was not reasonable, and that they had the ability to install an alternative diversion method for fish production and should do so. The court determined that due to the nature of their fish propagation operations, there was no other reasonable way for them to divert water because the springs provided water at the quality they required. Therefore, it was determined that the spring users had in fact been materially injured as defined by the CM Rules, so the depletion of their water by ground water pumpers was evidence enough to support material injury. In addition, the outcome of the case supported the IDWR's use of the Eastern Snake Plains Aquifer Model as a means for evaluating water calls that determines the timing of water and hydrologic connection between the aquifer and the Snake River. Although speculation exists as to the validity of the model and its use, it was determined to be the best available science and a model that would be use in concert with the implementation of the CM Rules in determining water calls between senior surface water users and junior ground water pumpers in the ESPA.

A similar determination as to the reasonableness of a diversion was questioned in *A&B Irrigation District v. IDWR,* when the A&B Irrigation District, a member of the SWC, made a delivery call seeking to curtail ESPA ground water pumpers in 2008. A&B Irrigation District is made up of an 'A' portion of irrigation water that comes from diversions on the Snake River, and a 'B' portion that obtains water from ground water wells that pump from the ESPA. Although they receive their water in the same nature as other ground water users in the ESPA, they alleged that due to additional pumping after their priority date of 1948, they have not had as much water available to them as they had historically. Their request was denied by the Director in 2008 and upheld by the Idaho Supreme Court in 2012 after the Director determined the district had not been materially injured, applying the standards outlined in the CM Rules. Although the district was not receiving the water it had historically received, the Director determined that it still had sufficient water for its irrigation operations and therefore upheld the CM Rules' principle denying wasteful water use. In addition, the Idaho Supreme Court ruled that the district's diversion and use of water was unreasonable and that it needed to take steps to maximize its ability to move water within the system before it could seek curtailment or compensation. This decision once again emphasized the importance of efficient and non-wasteful water use rather than the strict enforcement of prior appropriation.

Throughout the course of the early 2000s, the Idaho Supreme Court was met with many conflicting water use cases where the validity, constitutionality, and the application of the CM Rules are challenged. Ultimately, the court upheld their progressive values and introduced a more modern process for administering water rights that emphasized the state's ultimate values of the public interest, the optimum development of water, and its beneficial use. Although constantly threatened with curtailment, various agreements between the IGWA and the SWC consistently avoid it. This success in avoiding curtailment is buoyed by the immensity of the river system as a whole and its storage capacity that allows for mitigation plans developed by the IGWA to appease the SWC. Although the river system administration has grown more complex, the institutions developed to represent water users and resolve water conflicts have successfully avoided any serious economic hardship for irrigation entities.

While the IDWR played a main role in determining the outcome of delivery calls and water rights conflicts throughout the beginning of the century, the IWRB continues to play a major role in developing initiatives to support the conservation of water and prolonged management of the ESPA. In 2007, pursuant to their initial duties to manage the state's water resources, the board was directed by the state legislature to develop a Comprehensive Aquifer Management Plan (CAMP) for the ESPA which was adopted and submitted in full to the legislature in 2009. The purpose of the plan was to incrementally implement management initiatives in the ESPA in an effort to increase its storage for the purposes of sustaining it as a water source, with a main goal to "[s]ustain the economic viability and social and environmental health of the [ESPA] by adaptively managing a balance between water use and supplies" (IWRB, 2009). Action items included various management strategies such as ground to surface water conversions, reductions in overall ground water pumping, and an overarching goal of recharging the aquifer at designated sites in the amount of 250,000 acre-feet a year.

Although the CAMP was comprised of many proactive management strategies, it did little to actively achieve its overarching goal of recharging 250,000 acre-feet a year until the system as a whole, the aquifer and reservoirs together, reached an alarming state and both members of the SWC and the IGWA began to take serious action. Although ground water pumpers coexisted with surface water users for a while through the implementation of mitigation plans to avoid curtailment, the system eventually reached a point where the constant transfer of water to mitigate senior water users was no longer feasible due both to periodic droughts and short water supply as well as the mounting costs of constant litigation. This reality was litigated in the long drawn out case of *Rangen Inc. v. IDWR* (2016), which began with a second delivery call filed by Rangen. in 2011 against junior ground water pumpers whom they alleged were affecting their spring flows. It was determined that the ground water pumpers were in fact materially injuring Rangen's water right and an impending curtailment threatened to shut off water use for multiple ground water users, including many industrial and municipal ground water pumpers. The required mitigation plans developed by the IGWA included actions such as buying and leasing water rights to compensate the lost flows and constructing pipelines to carry water to Rangen.

Although mitigation plans served as temporary solutions to both the Rangen water conflict and the annual response to the SWC's 2005 water call, which is still ongoing, the IGWA realized that they could not continue to remain in litigation with surface water users and constantly expend money on both legal fees and the cost of implementing mitigation plans. Although the IGWA constructed a pipeline to successfully transfer water to Rangen, the expense of operating and maintaining the pipeline for years to come did not appeal to the organization. This expense was piled on top of the constant mitigation plans that were imposed yearly in response to the SWC's 2005 water call and the price that was required to deliver water successfully to American Falls.

It is clear that constant mitigation was not the best solution for the water conflicts that continued to worsen, but actions to fully engage in more robust and effective management did not come into conversation until 2015 when unusually warm weather conditions early in the season resulted in the highest demand for water ever seen in District 01. The effects of the warm weather on the system were instantly seen at Murphy Gage, the site of the Swan Falls Dam, when the river flow was below the minimum flow requirement in March for the first time ever, and threatens to dip below the summer minimum flow requirement later in the season (IDWR, 2017). In light of the injury determination that had persisted since 2005 in response to the SWC's water call, the system was in serious trouble considering the fact that Palisades is the primary source of mitigation water for the IGWA. As seen in Figure 6.1, Palisades Reservoir is tributary to American Falls, which means that Palisades reservoir cannot fill unless American Falls is full. With such unusually warm weather and a major stress on the storage of the system, the threat of continuing to simply mitigate through transferring water to American Falls was not a realistic solution for the IGWA. Should more severe and long-term periods of drought affect the basin, Palisades could run the risk of drying up completely if the IGWA continued to be required to compensate for the depletion of water in American Falls reservoir (P. Arrington, personal communication, May 22, 2018).

To avoid the inability of the system to continue to provide current and future water supplies, as well as the imminent curtailment of ground water pumpers that could ensue, the

IGWA and SWC entered into an unprecedented Settlement Agreement on June 30, 2015 that outlined a suite of robust long-term management activities that would actively work to recharge the aquifer, decrease ground water pumping, and sustain the functionality of the system as a whole. Although the 2009 CAMP included recommendations for improving the state of the aquifer, its legitimate enforcement lacked funding adequate for its application due to the economic recessions, while funding for the implementation of the Settlement Agreement was given in concert with its approval by the legislature. The implementation of the Settlement Agreement was also made possible by the multitude of motivated actors who understood that without its immediate implementation, the future of the USRB was severely threatened. The primary goals of the Settlement Agreement were to ultimately reverse the declining trend of the aquifer's water level and to return them back to the average of the 1991-2001 levels. To reach this goal, actions to be taken included: 1) reduction of ground water diversions by 240,000 acre-feet a year to be shared proportionately by each ground water district; 2) a delivery of 50,000 acre-feet of water to the SWC to meet irrigation needs; 3) a restricted irrigation season to start no earlier than April 1 and to end no later than October 31; 4) required installation of measurement devices for wells without them; and 5) state-sponsored recharge of 250,000 acre-feet of water to the aquifer (IDWR, 2015b). As long as the IGWA was meeting these requirements and fulfilling their part of the deal, they were provided safe harbor from curtailment or any further legal action by the SWC.

Such a specific and tailored Settlement Agreement has major benefits for the water system and irrigators who rely on reliable supplies of both storage and ground water for present and future irrigation seasons, as well as huge implications for the continued economic prosperity of the state as an agricultural leader. For this reason, the Settlement Agreement has seen prodigious support from the IDWR and IWRB in the form of allowing this alternative agreement to take place of any strict curtailments or legal actions, and support from the state in the form of funding for managed aquifer recharge initiatives. In addition, both surface and ground water irrigators agree that the implementation of the agreement's action items have huge benefits for both parties to ensure long-term sustainable water supplies.

Since its initiation, the Settlement Agreement has seen huge success in directing the region towards a sustainable USRB. The period of October 2016 to July 2017 saw an estimated total of 317,714 acre-feet of recharge, with certain sensitive areas of the aquifer witnessing a rise of nearly 20 feet in water levels (Weaver, 2017). So far, the basin has experienced good water years in terms of high precipitation rates that have allowed recharge efforts to surpass the 2020 goal for water levels in the aquifer presenting IGWA in a positive light so far in their efforts to hold up their end of the Settlement Agreement. If their efforts and the efforts of the region continue to benefit the aquifer this way, the outlook for the goals to ensure a sustainable and healthy aquifer and the economic and social vitality of the region is within reach.

Summary

This concludes the portion of this analysis covering the development and implementation of the CM Rules during a time when the system's water supply was growing increasingly more vulnerable. A significant theme of this section was the evolution of the state's overall interpretation of what water uses constitute as optimum and beneficial uses and what use is ultimately in the public interest in addition to priority in right. The succeeding sub-sections will discuss how this era experienced increasing complexity, emergence, and self-organization, and will identify the phases of the adaptive cycle it is in.

Complex Adaptive Systems Framework

The beginning of this era was marked by the outcomes of the Swan Falls Agreement and the state's moratorium on ground water permits that brings serious attention to the hydraulic connectivity between surface water and the ESPA and the need for a more modern form of management. Throughout the early 21st century, the complexity of the USRB (Figure 6.6) began to play a large role in the ability of the system to adapt to rising system constraints. With the implementation of the CM Rules, the mitigation plans required of the IGWA were made possible by the constructed network of dams, reservoirs, and canals throughout the USRB that created an increasingly integrated river and aquifer system. This system, although subject to the uncertainties of nature, could be manipulated through controls such as flow augmentation from dams, the opening and closing of diversions, and managed recharge efforts to the ESPA. In the presence of seasonal fluctuations in the system's water supply, system actors consistently responded by controlling the storage and delivery of water to meet seasonal demands. Although some actions negatively affected the system, such as pumping ground water, other controls were instituted that helped to counteract this, such as delivering water from upriver to compensate water users downriver. These controls are possible due to the infrastructure that facilitated a unique connection between social and ecological system components

Just as infrastructure had been constructed through time to control the availability of water in the system, the development of water institutions also facilitated this control. As disturbances to the system arose, connections between water users and their respective water institutions strengthened the administration of water and made the implementation of water conservation practices possible. The early 21st century saw a strong relationship between water users, their local water representatives in the form of various districts, the IDWR and IWRB, and the state through its various government branches (Figure 6.6). System function in the USRB was especially aided by the existence of the Committee of Nine and Water District 01 that constantly monitored the system's water storage and release, made possible through relationships with the BOR and the USGS.

On a more local level, the Magic Valley saw the development of the IGWA emerge as a form of self-organization to represent ESPA ground water pumpers as the ruling of *Musser v. Higginson* presages the litigation that began to affect this group of water users. As conflicts among surface and ground water users became more frequent, the SWC subsequently self-organized to represent affected senior surface water users. These two organizations worked to effectively make use of the system's infrastructure networks to ensure water delivery and mitigation.

Although rising conflict was alleviated by the creation of mitigation plans and use of extra storage in the system, the two organizations were no longer able to rely on this in 2015 as system constraints and weather conditions diminished the water available for further mitigation. With impending curtailment to ESPA ground water pumpers and an ensuing reduction of the economic base of the Magic Valley, both organizations came together to create a vigorous plan for recharging the aquifer and achieving water levels sufficient for supplying water to all irrigators. This collaborative effort, the 2015 Settlement Agreement, was the ultimate emergent property that today represents the region's ability to adapt to system disturbances – an effort that would not have been possible without the complexity between the region's valuable ecological resource, its infrastructure, and motivated water actors.

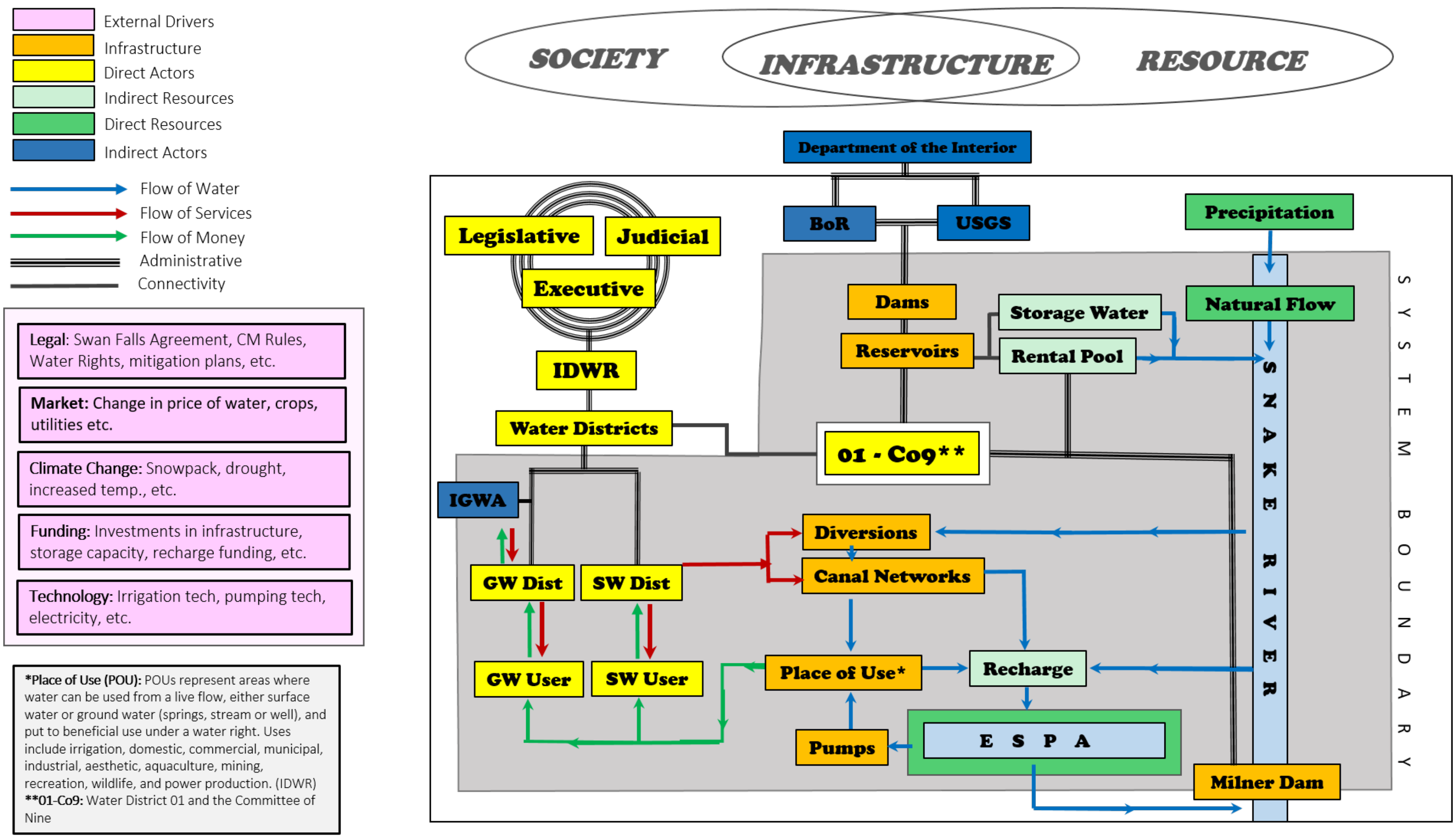

Figure 6.6: Conceptual map representing the final complexity of the Magic Valley at the end of the Modern Water Management Era in 2015. The ability of the region to continue water administration and conservation is a result of the interconnection between the many water actors and the system's water availability that is heavily facilitated by the infrastructure throughout the USRB.

Table 6.5: Description of the CAS Framework characteristics that exist in the Modern Water Management Era: Adjudication and Conjunctive Management (1987-2004).

1987	Snake River Basin Adjudication	The commencement of the SRBA was important in developing a comprehensive determination to the extent of all water rights within the Snake River basin. This was significant in that it contributed vital information to improve the management of water rights and to the conjunctive administration of the hydraulically connected water rights of the Snake River and the ESPA. This information sharing comes to play a significant role in increasing the adaptive capacity of the region through providing a critical first step for conjunctive management.
1993	Moratorium	The moratorium placed on ESPA ground water permits led the region into an era where decisions in regard to water administration began to consider the nature of water rights and whether they were optimum and beneficial uses, non-wasteful, and in the public interest.
1994	Ground Water Districts	*Musser v. Higginson* brought to light the seriousness of water conflicts between surface and ground water pumpers that was likely to get worse, and new legislation allowed for the organization of ground water users into districts for legal representation and to provide a collective source of funding for other activities. Similar to irrigation districts and canal companies, these districts provided a body of representation for individual ground water users and a platform for making decisions. This additional link in the panarchy increased the complexity without overstepping other actors.
1994	IGWA	To specifically represent those ESPA ground water pumpers subject to delivery calls by senior surface water, the IGWA emerged as a form of self-organization. This additional node to the web of complexity facilitated future litigation and required mitigation plans.
1995	CM Rules Adopted	The CM Rules determined that administration of water rights 'first in time, first in right' was subject to the beneficial use doctrine and a determination of what water use was in the public interest. These rules emerged to address the water issues specific to the water users sharing the aquifer as a common source in the USRB.
2005	SWC	Similar to the IGWA, the SWC emerged as a form of self-organization to represent surface water users who were affected by the ground water pumping in the ESPA.
2005	Mitigation Plans	The outcome of the SWC's water call against the IGWA introduced the important role that mitigation plans would play in conserving the system's water supply. These mitigation plans were not possible without the complex interactions existing between water actors, infrastructure, and water supplies on various scales from small (water users and their ground water pumps) to large (BOR and water control from dams).
2007	*American Falls District No. 2 v. IDWR*	The court's decision in this case determined that although the CM Rules did not strictly enforce the prior appropriation's principle of 'first in time, first in right' they did align with the constitution by upholding principles that are in the public interest. This decision supported the CM Rules as a more emergent method for administering water that balanced priority with values of conservation.
2012	*A&B Irrigation District v. IDWR*	Although a court ruling in regard to spring users' water diversions determined that they were protected in their diversion due to the specific nature of their operations, an additional ruling regarding A&B Irrigation District determined that their water diversion and overall use of water was not efficient and gave them no grounds to make a water call. This decision further enforced the CM Rules and their use of more progressive standards in administering water, an emergent property resulting from the specific nature of the USRB system.
2015	Settlement Agreement	Unfavorable weather conditions resulted in a period of drought that made the continuation of mitigation plans and the transfer of water to those in need no longer possible. Both ground water pumpers and senior surface water users recognize that the complexity of the system they operated within would detrimentally affect their region if more comprehensive management decisions were not implemented. Using their representative platforms, the SWC and the IGWA, these water users came together and collaborated to develop an emergent plan for reversing the state of the aquifer and getting it back to levels that are sustainable. Although the Settlement Agreement used management recommendations and goals similar to previous plans such as the CAMP, their efforts were more serious due to this ultimate disturbance to their ecological base, and were possible due to the complexity that exists among present-day system components.

Phases of the Adaptive Cycle

During the Modern Water Management Era, the region struggled to remain in the maximum productivity phase of the adaptive cycle and was slowly moving towards a period of economic hardship. With the moratorium on ground water, the region was no longer able to grow and expand and instead made the most of the water that was already appropriated. Adopting rules for conjunctive management was a prime example of the state trying to keep the region within the maximum productivity phase by requiring that water calls be determined not by priority in right, but by determination of beneficial use, optimum use, and economic development. The region stayed within the maximum productivity phase for the better part of this era due to the success of mitigation plans that were contributed to by the storage capacity of the system, even though the IGWA are constantly challenged in court.

In 2014, the region entered a period of economic hardship where ground water users found that they could no longer engage in litigation because of the rising expense and could no longer simply transfer water to compensate surface water users because the storage capacity of the system was decreasing. This was exacerbated by a period of drought during this timeframe. With the realization that a more cooperative and effective management scheme needed to be implemented, the SWC and IGWA came together and agreed on the 2015 Settlement Agreement, effectively entering a phase of institutionalization where their emergent representative groups began to play a more active role in conservation and management of the aquifer.

Table 6.6: Summary of the events that keep the region in the adaptive cycle phase of Maximum Productivity throughout the Modern Water Management Era (1987 – 2004)

Period of Time	Phase of the Adaptive Cycle	Description
1987	Maximum Productivity	**Snake River Basin Adjudication:** The Swan Falls conflict brings to light to immediacy of management the water resources of the Snake River basin, leading to a state-supported adjudication of all water rights. It is clear that the water rights in the basin are over-allocated, especially the water rights of the ESPA, leading the region from a phase of growth and development into one of maximum productivity.
1993	Maximum Productivity	**Ground Water Moratorium:** With a moratorium on ground water permits, the region was no longer able to expand their water use and instead focused on meeting demand with the supply of water provided by the present system. This event led the region into a phase of maximum productivity where it stretched its supply.
1994	Maximum Productivity	***Musser v. Higginson:*** The case of *Musser v. Higginson* brought to light the stress that litigation would bring to the region and the conflict that would continue to rise between senior surface water users and ground water pumpers. In response to a changing resource, the state adjusted some of the strategies for administration by adopting the CM Rules. Ground water districts were also established and IGWA formed as a means to represent ground water pumpers in litigation.
1995	Maximum Productivity	**Conjunctive Management Rules Adopted:** CM Rules were developed to provide a method for determining water calls by seniors against junior water pumpers sharing a common aquifer. The development of these rules introduced an adaptive approach to determining water calls that was specific to the nature of the water users sharing the ESPA and was not determined strictly by priority. These new rules introduced a modern approach to administering water that favored optimum development of the resource in the public interest.
2001	Maximum Productivity	**Mitigation Plans:** Rangen's 1st water call incentivized the development of a mitigation plan to compensate lost flows, illustrating the advantage mitigation plans offer to help keep the region in the maximum productivity and avoid curtailment.
2005	Maximum Productivity	**CM Rules Deemed Constitutional:** A major outcome of the SWC Call was the ruling that the CM Rules were constitutional. This solidified their use in water calls and the validity of prioritizing optimum development of water over enforcing priority of right.
2012	Maximum Productivity	**Reasonable Diversions:** The Idaho Supreme Court ruled that A&B Irrigation District's diversion and irrigation network were not efficient and that ensuring non-wasteful water use was to be prioritized before a water call could be made.
2014	Economic Hardship	**Costly Litigation/Mitigation:** Although the IGWA survived two decades of litigation since the adoption of the CM Rules, the mounting cost of legal fees and mitigation activities started to put a strain on their ability to continue, threatening curtailment. These costs were the combination of conflict with both Rangen and the SWC, a conflict that was revisited for a decade.
2015	Economic Hardship	**Insufficient Water Supply:** The expense of litigation was met with an unusually warm spring that resulted in the highest demand for water that District 01 had ever seen, as well as the first time that the minimum stream flows for the Swan Falls Dam were not met. The IGWA and SWC realized that rather than continuing litigation and pursuing mitigation efforts that were increasingly less possible, a more robust management plan must be found to ensure the sustainability of the USRB and the Magic Valley region.
2015	Institutionalization	**Settlement Agreement:** In a serious effort to sustain the water supply, the IGWA and the SWC come to the table and develop a plan for immediate implementation to improve the entire supply within the USRB. While the IGWA and SWC as organizations once played separate roles with the sole purpose of representing districts and canal companies in litigation, the Settlement Agreement allows them to merge into a cooperative team working together to co-manage and improve the state of the aquifer. This institutionalization was an immediate response to the system as it dipped below minimum flows and threatened the water availability for seasons to come.

7. DISCUSSION: ADAPTIVE CAPACITY OF THE MAGIC VALLEY

As discussed when introducing the CAS framework, complex systems are composed of many adaptive cycles connected across both social and ecological components at multiple scales, with emphasis on the incorporation of local knowledge. The multi-scale adaptive cycles and the communication networks that comprise CASs increase the adaptive capacity of these systems by constantly allowing them to learn and respond to system disturbances. As these many adaptive cycles ebb and flow to absorb disturbance, the system as a whole is kept within its preferable stable state – a state within which the system continues to provide its full range of ecosystem services in the face of changes. The ability of a system to do this, much of which is due to its complexity, adaptive cycles, and emergence, allows the system to achieve resilience, or in the case of the Magic Valley, the continued supply of water to irrigators in the face of various ecological changes to the system.

Throughout the previous analysis, the Magic Valley and the USRB were discussed at length to give a background on their defining characteristics and the evolution of these characteristics as irrigation has advanced and the basin's resources have gone through different phases of change and perturbations. This background information was given to analyze how the complexity of the region has grown throughout time, how this complexity has informed the region's ability to emerge and self-organize in the face of disturbances, and how this complexity has allowed the region to successfully navigate through phases of the adaptive cycle without collapsing. Descriptions of how each era fit within the CAS framework and of what phase each era resided in within the adaptive cycle followed each era's analysis. The ability of this system to navigate the adaptive cycle without collapsing (Figure 7.1) and to increase its adaptive capacity through emergence and self-organization is primarily a factor of its inherent complexity – it has never been too complex or not complex enough to continuously make water available to meet demand.

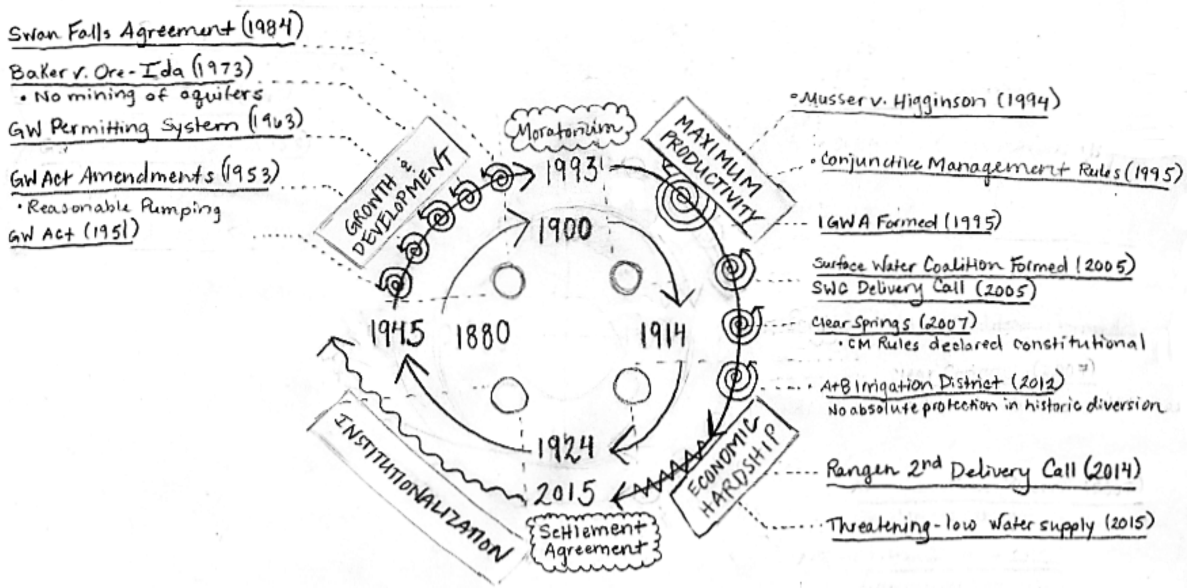

Figure 7.1: Graphic representation of the phases of the adaptive cycle that the Magic Valley and the encompassing USRB have gone through over time, with significant events and micro-adaptive cycles included.

During the Development Era, the system was characterized first by early farmers who formed small irrigation communities that were cooperatively operated. The first methods of irrigation used by these communities were small scale diversion and canal systems, and the primary method of watering crops was through flood irrigation. With the passing of the Carey Act and Reclamation Act, larger scale irrigation systems were constructed in the lower reaches of the USRB which still practiced flood irrigation but on a much larger scale. Many miles of poorly-lined canals paired with flood irrigation resulted in large amounts of water infiltrating into the aquifer, and the region witnessed higher water tables and noticeably higher rates of discharge from the aquifer into the Snake River, especially in the Thousand Springs region. After multiple periods of drought and a misunderstanding of the exact hydrologic connection between the Snake River and the ESPA, the Committee of Nine was created to help determine an annual water distribution schedule for water users in the basin. Their role became more important as additional dams and reservoirs were constructed to increase the water available for irrigation. The agency overseeing the complete administration of water within the basin and the entire state was the IDWR, and acting above them was the state legislature and court system who had a conclusive say in decisions and conflicts related to water administration.

Although a simple story line, the very beginnings of development throughout the USRB, which came to seriously affect the Magic Valley, were imperative to the success of the region when responding to system disturbances. The social system came to have an immediate impact on the water in the system through the construction of irrigation systems and the practice of flood irrigation. This was intensified when the state began to make use of federal funding and support for larger irrigation projects, which also helped to create a controllable storage water system through a network of dams and reservoirs that end at one point – Milner Dam. Through institutionalizing the Committee of Nine, the region effectively gave power over this system to one centralized power, but one that still directly and cooperatively represents the water users both up and down the Snake River. The end of this era saw a prosperous agricultural landscape that, although periodically affected by droughts and various seasonal weather conditions, was in the control of the water users themselves. The complexity that had evolved enabled irrigators to play a role in the state of their system.

The beginning of the Ground Water Era is marked by the introduction of ground water pumping technology into the region which allowed for the expansion of irrigation to those lands that had previously been unserviceable by surface water sources, which unsurprisingly presented a whole new layer of complexity. With the aquifer at its highest levels on record and the price of electricity very low, ground water pumping took off and a new variety of water users populated the landscape. Again, the social system through this new form of irrigator had an almost immediate impact on the water by beginning to reverse the aquifer water level that had been steadily rising for the first half of the century. This was accentuated with the implementation of more efficient irrigation technology that, although it had helped to consume less water at the field scale, it in turn harmed other water users downstream of Milner Dam and other water users benefitting from discharge of the aquifer into the Snake River. Efforts were made by the state to introduce conservation efforts to ensure a sustainable water supply including the instatement of the IWRB, but water levels continued to decline throughout this era, which ended with the Swan Falls conflict and a moratorium on further ground water appropriations.

The introduction of ground water pumping and the effects it had on the aquifer came to define the relationship between surface and ground water users during the Modern Water Management Era. This era began with a moratorium of additional ground water permits that served as an acknowledgement of the complicated hydraulic connection between the ESPA and the Snake River and the need for more serious action to conserve the aquifer. *Musser v. Higginson* supported this need by requiring the development of the CM Rules, and the legislature officiated the creation of ground water districts to help represent ground water users, which prompted the self-organization of the IGWA for specific representation of those water users in the ESPA region. In 2005, surface water users in the Magic Valley self-organized to create the SWC and filed a delivery call against ground water pumpers to help restore their right to water in American Falls reservoir, which started a decade of litigation between the two parties.

With litigation came the threat of curtailment, but with the organization of IGWA acting to represent ground water users and the implementation of the CM Rules, mitigation plans became the primary outcome of litigation between the two parties. This primarily took the form of leasing or buying volumes of water from other sources in the USRB and transporting it in some manner to compensate surface water users. Mitigation was highly successful when enough water was in the system, and would not be possible without the complexity of the USRB dam and reservoir system created in the early 20th century. Mitigation plans would also not be possible without the oversight of reservoir systems by the BOR and the USGS, or the Committee of Nine acting to communicate the state of the system to water users, or the IDWR determining the validity of mitigation plans. It would further not be possible without the existence of the IGWA and the SWC representing their respective water users. Had the system been composed of individual water users who acted in their own self-interest and who did not belong to collectives such as their individual irrigation districts and canal companies, or the IGWA and SWC, the administration of water may have followed the strict implementation of the prior appropriation doctrine. The complexity of the system and the interwoven relationships between water users, infrastructure, and water give the CM Rules value and make mitigation plans possible, allowing the system to remain within a state of maximum productivity, avoiding 'first in time, first in right' enforcement and retaining the economic growth of the Magic Valley.

When consistent drought conditions made it impossible for mitigation plans to continue, the same complexity between system components made new management actions in regard to the state of the aquifer possible. Surface and ground water users alike could agree that recharging the aquifer was in the interest of all water users, and using the platforms provided to them by the IGWA and SWC, more comprehensive management decisions were agreed upon in the 2015 Settlement Agreement. Rather than transporting water, serious efforts ensued to return water levels in the aquifer to what is assumed to be close to its original capacity. Efforts were made by both groups of water users, with ground water users making a collective effort to reduce pumping and monitor their water use, and certain surface water users engaging in aquifer recharge during the winter months.

The incorporation of the many small-scale surface water irrigation entities into management decisions and actions has been a key factor to the system's ability to increase its adaptive capacity and achieve resilience. This has been seen since the beginning of irrigation development when they played a part in organizing the Committee of Nine, and in the present day with their collaboration with ground water users and participation in management actions such as aquifer recharge. Within the Magic Valley, these small-scale surface water irrigation entities consist of the seven irrigation districts and canal companies that make up the SWC whose introduction to the landscape in the Development Era has allowed them to mature throughout time into knowledgeable bodies of water users. Unbeknownst to them at this time, their design incorporated much of the principles identified by Ostrom (1990) as characteristic of successful long-enduring CPR systems, which has no doubt contributed to their ability to ebb and flow with changes in the system. Table 7.1 revisits the principles identified by Ostrom (1990) and includes how each principle is, or is not, encompassed in the general design of the irrigation districts and canal companies in the SWC. Most of the principles can clearly be seen in the design of these irrigation entities, except for principle 5 and 6 that do not have a significant role in their success.

Table 7.1: The following table revisits the 8 design principles identified by Ostrom (1990) as characteristic of long-enduring CPR systems, and includes information regarding whether or not the irrigation entities found within the Magic Valley incorporate these principles or not. It is important to note that not all rules are ubiquitous, but are tailored specific to the nature of each irrigation entity (Burley Irrigation District, 2013; Fereday et al., 2018).

1	**The common-pool resource system has a clearly defined boundary and the individual appropriators have a clearly defined right to use of the resource.**
Irrigation Districts within the Magic Valley are each drawn with a specific geographic boundary, within which water is deliver pursuant to need and levies, and outside of which water is not able to be used with the exception of special circumstances determined by the entity.	
2	**Rules related to resource appropriation are related to local conditions and to provisioning rules.**
Internal rules and regulations controlling the distribution of water is specific to the nature of the districts, its members and their water use, and to the source (ex. Which reservoir water is taken from). There may be rules regarding what happens in times of drought or other variable weather events.	
3	**The individuals who are affected by the rules of the CPR system are involved in the development of the system's operational rules.**
The operational rules of an irrigation entity are often created by a board of directors or overarching governing body that is elected to represent district members. Those that have a say in the election of said official must reside and own land within the district, excluding non-members.	
4	**The parties involved in the monitoring of the CPR conditions are either the appropriators themselves or are held accountable in some way to the appropriators.**
Within irrigation entities, the governing body as well as the individual equivalent to a 'Director' or 'Manager' of a district is required to live and own irrigated lands within the district, excluding any non-appropriators of water to have a say in the entity's internal workings. The same is true for electors.	
5	**Graduated sanctions are imposed on those individual appropriators who do not comply with the operational rules either by other appropriators, by officials that are held accountable by the appropriators, or by both.**
Graduated sanctions exist that are imposed on irrigators who take water in excess of what they are allotted per season. Sanctions are often imposed based on the amount of excess water that was used in some variation of an acre-foot per acre basis.	
6	**In times of conflict, the appropriators and relevant system administrators and operators have a low-cost and easy-to-access venue available for conflict resolution.**
For irrigators, the most common source of conflict is among ground water pumpers and surface water users. Litigation is the most common way to solve this conflict, which is seldom cheap and easy to access, although the region is moving towards and cheaper and easier way to solve conflict through creating organizations such as the SWC and IGWA and through the settlement agreement.	
7	**Individual appropriators are given the right to form their own institutions without challenge from external government authorities.**
Individual appropriators are, by law, able to form their own institutions. There are statutes regarding 'irrigation districts' that allow for this formation. In addition, irrigation districts themselves are able to form their own institutions, as has been seen with the organization of the SWC.	
8	**Governance activities across the CPR system are organized into nested enterprises. This design principle is relevant to CPRs that are a part of larger systems.**
Within a typical irrigation entity, there is a Director or Manager who oversees a Board of Director and all other employees within the entity, such as ditchriders. All of these individuals respond to and oversee the needs of the water users themselves. This hierarchy allows for the incorporation of water users concerns into the working of the District. As seen in Figure 6.6, these districts are delivered water by the Committee of Nine, which is overseen by the IDWR, which is then overseen by the state legislature and court system.	

With a majority of these design principles informing the operation of irrigation entities from their initial creation, collective action decision-making and localized governance have been defining characteristics of the Magic Valley's agricultural landscape since the Development Era. The fact that entity rules and policies are created with heavy involvement of members has resulted in a system that, by nature, is a bottom-up approach to management and water allocation. Throughout time, this bottom-up strategy has continued to grow as irrigation entities have formed relationships incorporating adaptive cycles and feedback loops with other actors at multiple scales throughout the system.

Although control over major system components, such as the operation of reservoirs or decisions regarding the administration of water, has lain in the hands of more centralized powers, institutions such as the Committee of Nine have led the system to incorporate local level knowledge and resource-related concerns on a frequent basis. These adaptive cycles have been seen in the form of informative decisions in response to communication among system components, such as mitigation plans developed on a seasonal basis to keep the system in a stable and productive state. The success of these adaptive cycles has been heavily informed by the sharing of information among system components, including adjudications that record the specificity of water rights and the consistent monitoring of the system's water supply. The system's complexity and the development of its many micro adaptive cycles have made it resilient in the past and have given it the adaptive capacity to maintain a stable state of the system – a strong indicator that the region will remain resilient in the face of any future disturbances.

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