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Adapting to Socio-Environmental Change: Institutional Analysis of the Adaptive Capacity of Interacting Formal and Informal Cooperative Water Governance

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Abstract: Much of the world's agricultural lands are projected to face hydrologic and climatic changes that will lead to water scarcity and corresponding food insecurity. The emergent response of complex social-ecological systems to change requires rapid response and tailored solutions. Top-down responses without room for local self-organization may fail to implement effective solutions, yet self-organization alone may be too slow to respond in a period of rapid change and may lack the accountability necessary in the management of a public resource such as water. This research relies on concepts of governing complexity to assess the role of local self-organization nested within formal institutions in developing adaptive solutions to conflict involving irrigated agriculture in Idaho's Upper Snake River Basin. While formal institutions have provided a framework, steering, and resources for local action, the organization of water users dependent on the resource plays a large role in the ability of the region to adapt to water supply disturbances, highlighting the importance of local capacity within an umbrella of governmental steering to respond to rising water resources issues in semi-arid regions.

Keywords: food-energy-water systems; governing complexity; irrigation systems; social-ecological systems; water resource management

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1. Introduction: Governing Complexity

The complexity of social-ecological systems (SES) and the complexity of the systems that govern them require a greater understanding of the interaction between human-decision making and the biophysical, technological system [1]. Management decisions that fail to consider the emergent aspect of interconnections among the many subcomponents of SES, will make natural resource issues more problematic by failing to consider all facets at work within a system [2]. Top-down decisions that are not tailored to the specific SES tend to have narrowly defined goals, and although they may show signs of success in the short-term, tend to deplete the resource in question over the long term [3].

While Hardin called on regulation or property mechanisms to prevent the 'tragedy of the commons' [4], universal regulatory solutions to natural resource problems primarily consider issues present at one particular scale of interest and frequently do not take into account localized emergent properties or cross-scale interactions [2]. Property mechanisms allow the development of tailored solutions through markets [5], but often result in external consequences not captured within the market system [6]. At any given time, a multitude of interactions occur at multiple scales in time and space within an SES, defining the state of the system as a whole, but not accounted for in property and regulatory systems [5].

Ostrom brought a third approach to the dialogue surrounding the management of common pool resources through her empirical work observing long-enduring common-pool resource systems sustained by institutions put in place by the individuals interacting with the resource at local scales [6]. Case studies show that in these situations, actors dependent on a resource for their wellbeing will invest time and energy to avoid the tragedy of the commons and achieve the long-term viability of their resources [7,8]. Her work also documented that this local "self-organization" often emerged within institutions of governance that included both formal (i.e., governmental) and informal aspects, and that the characteristics of those institutions influenced the capacity of local actors to self-organize and to adapt as conditions changed [5,9,10]. Her dissertation looked at groundwater management in southern California nested within larger scales of formal and informal governance [11]. A decade later, she returned to the study of the commons with her Ph.D. student, William Bloomquist, who looked at the role of lawsuits and self-organized settlement in these groundwater basins to address problems with overuse of common pool resources [8,11,12]. She developed a framework for institutional analyses [7], and collaborated on its modification to focus on vulnerability and robustness within social-ecological systems [9,10]. Recent work by co-authors and others has returned to the framing of Bloomquist in considering settlement within formal institutions as an example of self-organization [8,13–15]. That work focuses on separating the role of formal institutions—i.e., law and government—from governance in the emergence of local self-organization to identify means to catalyze its emergence, address issues of accountability, and steer it toward the public good [13–15].

This article builds on these efforts by separating formal from informal institutions within a framework of institutional analysis to understand the interaction among local water resource users, government, and the hydrologic system on which the water users rely. This work returns to the topic of Ostrom's dissertation–interrelated water resources that are heavily relied on by humans. The case study setting for our modified institutional analysis is Idaho's Upper Snake River Basin (USRB), an SES that implements a state-level method of water administration, but is influenced by regional and local water institutions initially self-organized from the bottom-up that play a large role in tailoring management of the basin's water resources to the emergent properties of the setting [11,12]. This research identifies the many dynamic relationships among the system's hydrologic, formal, and informal institutional components to illustrate the important role that these relationships play in sustaining food-energy-water systems (FEWS) [13,14] and to increase our understanding of how we govern complexity [14,15].

The understanding of these dynamic relationships among hydrologic, formal, and informal institutional elements supports recent work recognizing the connections between structural, procedural, and relational changes in SES and potential levers of change necessary for transformative change [15]. This perspective views resilience in SES as a continuum of strategies from resistance to change to adaptive change to transformative change [16]. We posit that analysis of the connections among the biophysical system, formal and informal governance supports adaptive strategies in SES necessary for contending with multisystemic resilience in SES [17,18].

2. Methods

This research relies on two qualitative methods: (1) case study based on historic and legal document analysis; and (2) institutional analysis modified to separate formal and informal governance.

First, the case study method is a standard approach to understanding the detailed components of a system, how they interact, and their emergent properties [19–21]. It is limited by its transferability to other settings and the unreliability of drawing general principles from a single example [17,18]. Recent work, however, has called upon the need to consider the concept of transferability through time in a single setting if society is to manage the surprising, nonlinear, and emergent properties of SES facing rapid change [15]. Given the need for tailored response and adaptation within water-dependent SES as climate change proceeds, this research uses document analysis, common in historical research [19], and statutory and case analysis common in legal research [20], and relies on previous research on changes to the hydrology of the USRB to understand the interaction among the hydrologic, formal, and informal institutional components of the USRB SES [12].

Second, this research builds on prior work on institutional analysis [22,23]. When analyzing the relationships within SES and their subcomponents, applying a conceptual framework is useful to bridge differences between social and ecological realms and discover where institutional influence exists [13,24]. A basic framework can also guide interdisciplinary research in identifying the main components and common linkages at work within SES [25]. Various frameworks have been developed to identify overlaps between these two systems [7,26]. Through the application of a framework, relationships that contribute to the ability of systems to achieve sufficient long-term resource supplies can be uncovered.

This research draws from previous applications of conceptual frameworks to systems, and establishes a purpose-specific SES model that is applicable to the irrigation-based landscape of the Upper Snake River Basin (USRB). Specifically, this research relies on the framework developed within Ostrom's workshop [7,27,28] and its modification in application to resource system vulnerability [9], to develop a framework that treats formal and informal governance separately (Table 1). The SES framework provided by Anderies et al. (2004) that focuses on vulnerability is primarily composed of four main system subcomponents–the resource, resource users, public infrastructure providers, and public infrastructure–and includes the critical relationships that exist between these four components [26]. We have modified this framework by dividing "public infrastructure providers" into formal and informal/local institutions for the provision, regulation, and management of public infrastructure. Note that informal and local are used interchangeably in this analysis. The local institutions in the case study began through self-organization. While formal legal mechanisms were used to institutionalize the resulting entities, they retain the local character, decision-making, flexibility, and adaptability associated with informal institutions. Through applying this framework, system components and linkages can be identified to analyze the facets contributing to the USRB system's ability to ensure long-term irrigation water supplies, and particularly the role of interaction among local self-organized water users and government, as well as how these components interact with the hydrologic system. Using this framework three different periods of agricultural growth in the USRB are identified and examined, and have been identified as indicative of the multi-scale interactions between various system subcomponents. Each of these time periods is influenced by particular social decisions that have altered the state of the basin's water supplies (Table 2). By assessing these time periods and the evolution of the agricultural landscape over time, the effects of social and ecological interactions can be seen, and the importance of assessing resource issues through the lens of SES science can be highlighted.

Table 1. Summary of the important linkages that exist within the USRB system to facilitate the successful management of water resources. This table and its numbers correspond to the numbers linking the major SES system components (from Anderies et al. (2004) [9]) modified to reflect linkages between local resource users, formal government, and changes in hydrology.

#	Interaction	Example
1	Between resource and resource users	Diversion or pumping of water by water users
2a	Between resource users and formal institutions	Voting; assessment fees to users for the distribution of water; water user participation in the development of rules and use of the judicial system; state and federal subsidy for the development of water infrastructure
2b	Between resource users and local informal institutions	The use of legal mechanisms to form irrigation districts and canal companies; the assessment of fees
3a	Between formal institutions and public infrastructure	Funding and scientific expertise for the development of dams and large-scale water distribution systems; rules requiring the adoption of new technology for efficiency for enforcement of water right
3b	Between local informal institutions 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 groundwater resources; recharge dependent on irrigation method; 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	External forces on resources and infrastructure	Disturbances including climate change, drought, flooding; lack of funding; policy incentives driving cropping patterns, therefore altering irrigation demands
7	External forces on social actors	Disturbances, including: rising populations, and suburban development of former farmland

Table 2. Three time periods have been deemed as important by the research are described below. These time periods begin with European settlement in the area and have been split up to reflect periods of time that have each implemented different methods of irrigation and water administration.

Time Period	Description
Development Era 1860–1950	Period beginning with the development of the earliest water rights in the Snake River Plain and the development of surface water irrigation, including major federal reservoirs, and ending with the introduction of groundwater pumping technology and the beginning of the ESPA's water level decline.
Groundwater Era 1951–1987	Period beginning with the passing of groundwater legislation and the growth of groundwater pumping and usage throughout the USRB until 1987 when the state and the Idaho Power Company enter into the Swan Falls Agreement.
Governing Complexity 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 2015 Settlement Agreement entered into between surface and groundwater users.

3. Results: Case Study, Upper Snake River Basin

The Upper Snake River Basin was chosen for the case study due to its economic dependence on irrigated agriculture and long history of interaction among formal and informal institutions to develop and manage water [12]. The following subsections will begin with the hydrologic and social setting, followed by a narrative description of the interaction among local self-organized water interests, formal institutions, and the hydrology of the water resource.

3.1. Hydrologic Setting of the Upper Snake River Basin

The headwaters of the Upper Snake River Basin (USRB) begin in Wyoming, with the Snake River extending in a southwestern direction through south-central Idaho (Figure 1). The Snake River runs almost directly through the center of the basin, with the majority of its natural flow composed of snowmelt carried by tributary rivers from surrounding mountain ranges at the edges of the basin. Where these mountain ranges end, the landscape transitions into the Snake River Plain, a distinctively flat area extending in a crescent shape across southern Idaho with an annual precipitation of 20–36 cm [29]. The Plain is underlain by volcanic and porous basalt features that result in a significantly high infiltration of water into the region's many underground aquifers [30], including the Eastern Snake Plain Aquifer (ESPA) that extends for 27,971 km^2 below the Snake River Plain, underlying the largest irrigated agricultural area in the Pacific Northwest [31]. The ESPA flows underground in a southwestern direction [32], and influences both gains and losses to the river depending on its hydraulic connectivity to the ESPA influenced by the height of the water table.

The ESPA ultimately discharges back into the Snake River in the form of springs found along the north walls of the Snake River canyon in the Hagerman area of Idaho [30]. As the region has grown into an agricultural leader over the last century, these discharge points have become the main indicator of the relationship between regional irrigation practices and the aquifer's volume. The change in discharge over time has shown an overall positive correlation between the increasing agricultural activity on the landscape and the fluctuating discharge from these springs [33]. For this reason, a basic understanding of the regional hydrology and the effects that irrigation practices have on the ESPA's discharge is critical to understanding how basin water supplies are influenced by the decisions of actors.

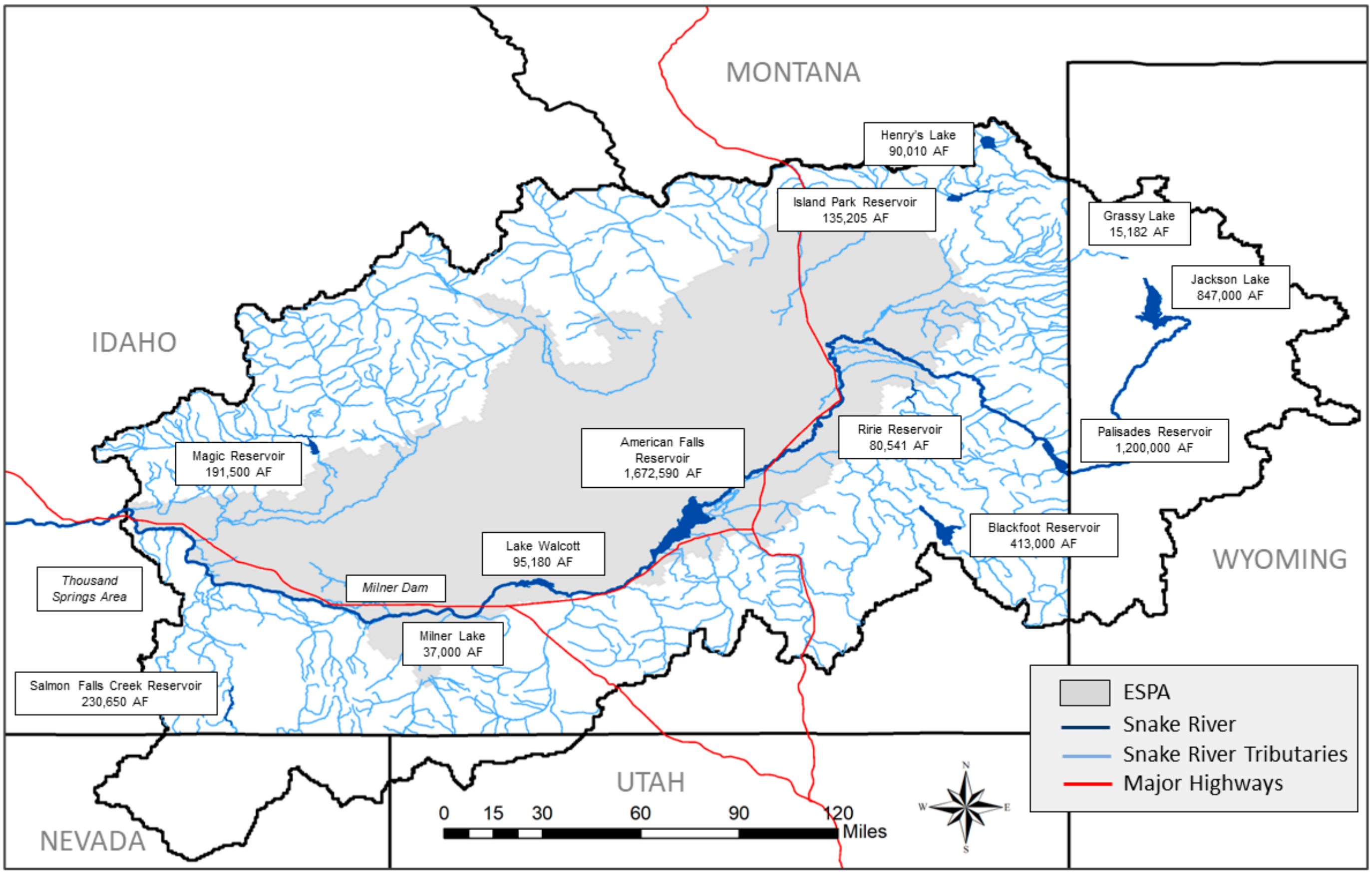

Figure 1. Spatial representation of the Upper Snake River Basin (light grey), the underlying Eastern Snake Plain Aquifer (dark grey), and the dam and reservoir system within the southern portion of Idaho.

3.2. Social Setting of the Upper Snake River Basin

Prior to Euro-American settlement and the implementation of westernized irrigation techniques around 1860, the USRB was known as the Snake Country by members of the Shoshone-Bannock tribe, who had resided for centuries along the Snake River and its tributaries. This culture continued until the expansion of Euro-American travel and commerce increased to the point that native subsistence methods and social organization were no longer possible in lieu of western settlement and economic values [34].

Euro-American settlement of the Snake River Plain for irrigation was by members of the Church of Jesus Christ of the Latter-Day Saints (LDS), who migrated north from the Salt Lake Valley region in Utah [25]. Roughly two million acres throughout the Snake River Plain were irrigated by surface water by the 1920s [35]. By the late 1940s, the introduction of groundwater pumping, paired with the provision of cheap electricity, allowed irrigators to take advantage of the aquifer's rising water levels. High crop prices and technological advancements following WWII enabled rapid adoption of groundwater pumping technology and expansion to lands that had previously been deemed economically inaccessible to irrigation due to their distance from surface water sources. These newly irrigated lands no longer required intricate networks of canals to provide water to farm plots, and sprinkler systems were introduced that began replacing flood irrigation practices, allowing for more efficient water use [36]. With a new, less variable, source of water and more efficient irrigation technology, the region saw an increase of close to one million acres of new agricultural lands [35].

Other water uses require instream flows, including hydropower production, recreational use, endangered species protection, aesthetics, and spiritual values. Various dams along the Snake River system require specific volumes of water for hydropower production to meet electrical demands [37]. These dams also create reservoirs providing recreational opportunities and requiring a delicate balance between the release and storage of water for activities such as flood control and flow augmentation (Olmstead, 2018). The Snake River system is also required to meet certain instream-flow levels to meet Endangered Species Act requirements for listed species [38]. Nevertheless, today the basin remains dependent on irrigated agriculture.

3.3. Multi-Scale Interaction of Formal Governance, Informal Governance, and the Hydrologic System in the Upper Snake River Basin

Relying on the framework set forth in Table 1, this section identifies three different eras of agricultural and institutional growth that have shaped the USRB (Table 2), and examines the multi-scale interactions among SES components. Each of these time periods was selected to reflect the influence that various irrigation methods and related decisions have on the ESPA's water levels and the resulting water administration and management decisions made by water users and coordinated formal water institutions. Formal and local institutional components are summarized in Table 3 at the end of this section. A strong correlation between agricultural practices and water supply has previously been identified [33], giving weight to the importance of assessing the multi-scalar interaction in this SES to identify both formal and informal institutions that have played a role in ensuring irrigation water supply through adjusting to fluctuations in aquifer levels and seasonal variations in water availability. The following paragraphs assess this interaction.

Table 3. Summary of the collaborative initiatives and adaptations that have materialized over time as a result of the interaction of formal and informal institutions facilitating water resource management and allocation in the Upper Snake River Basin system.

Year	Initiative	Formal and Informal Institutional Actions and Interactions	Summary
1924	Committee of Nine	Informal self-organization by basin water users Formal legislation to institutionalize the management committee	The cooperation among early irrigators across the basin resulted in the organization of the Committee of Nine. Their initial organization created a platform for communication and conflict resolution for the proceeding years, and today's role in the coordination with federal entities in the operation of dams.
1924	Annual compromise agreements determined by the Committee of Nine	Committee, now recognized as a formal institution facilitates informal collaboration	The communication platform offered by the Committee of Nine led to annual compromises in regard to the seasonal distribution of water within District 01, or the Snake River system above of Milner Dam. These annual compromises are altered each irrigation season to suit the fluxing irrigation demand and water supplies to ensure water allocation.
1965	Idaho Water Resource Board (IWRB)	Informal self-organization develops political support for a formal institution Establishment of the formal statewide institution	With growing realization that basin water is over-allocated and susceptible during drought, the IWRB is created by statute to, and adjacent to the IDWR, with the principal responsibility of engaging in conservation initiatives, including creating a state water plan and funding state water projects.
1978	Recharge Statutes	Cooperation between locally self-organized water users water districts and canal companies and scientific agency identifies problem and a solution of recharge Formal legislation to allow implementation of the solution within the legal system of prior appropriation	Aquifer statutes allowed for recharge initiatives to be implemented across the ESPA through adding 'recharge' as a recognized beneficial use.

Table 3. *Cont.*

Year	Initiative	Formal and Informal Institutional Actions and Interactions	Summary
1979	Create of State Water Bank and Water District 01 Rental Pool	Informal self-organization to move water around within districts requires formal legislation to expand Formal legislation to create water bank and facilitation through the provision of state and federal technology. Use of formal institution originally designed through local self-organization with local representation	Additional statutes created a State Water Bank and institutionalized local rental pools to be operated by the Committee of Nine. The success of the water bank and rental pool operation is facilitated by the many links connecting water users all the way up to federal entities, such as the Bureau of Reclamation operating dams and the U.S. Geological Society monitoring water flows throughout the basin.
1987	Snake River Basin Adjudication (SRBA)	Formal institution requiring legislation and designation of a water court within the judicial system	The commencement of the SRBA was critical to developing a comprehensive determination of the extent of all water rights within the Snake River basin to provide information to improve the management of water rights and to support conjunctive administration of surface and ESPA groundwater rights.
1995	Conjunctive Management (CM) Rules	Use of the formal judicial system to force priority enforcement between surface and groundwater users Formal development of administrative rules Use of the formal judicial system to challenge the administrative rules	The CM Rules determined that the administration of water rights 'first in time, first right' was also subject to evolving interpretations of what was a beneficial use and how to determine the optimum use of the state's water resources. This offered a process for surface water usersto initiate water calls against groundwater users.
1995	Idaho Ground Water Appropriators (IGWA)	Self-organization of groundwater users.	To specifically represent those ESPA groundwater users subject to delivery calls by surface water users, IGWA organized to help represent these users and share the cost of litigation and mitigation plans.
2005	Surface Water Coalition (SWC)	Self-organization of surface water users	Similar to the organization of IGWA, SWC organized to represent surface water users with higher seniority in litigation against ESPA groundwater pumpers.
2005	Mitigation Plans	Formal administrative rules provided an alternative. While self-organization to settle conflict could arrive at the same solution, the rules allowed the administrative agency to determine the adequacy of a plan even if the parties are not in agreement Self-organization to develop mitigation plans	Without the intricate links connecting social and ecological subcomponents from the local to federal levels, mitigation plans that avoid curtailment of groundwater use would not have been possible. System capacity supported by the many dams and reservoirs throughout the basin played a large role in their success.
2015	Settlement Agreement between IGWA and SWC	Self-organization to develop a longer-term solution than possible with yearly mitigation plans Formal legislation and funding facilitate implementation	When mitigation plans could no longer compensate SWC members due to a period of drought and decreasing water supply in the system, the settlement agreement offered a new pathway for avoiding curtailment and increasing management initiatives in the basin. All previous evolutions of the system came to support the success of this agreement, which to this day has been markedly successful in stabilizing the aquifer and reducing reliance on storage volumes upriver.

3.3.1. Development Era (1860–1950)

Idaho was a territory at the time of the initial development of irrigation in the USRB. The Territorial courts departed from the use of the riparian doctrine, adopted in eastern states from the common law of England, as the body of law to govern the administration of water. The riparian doctrine allows water to be used only by those who own property upon which the water source exists, or is adjacent to, and shortage is shared among riparian water users [39]. In the water-scarce landscape of the western United States, prior appropriation was more effective in administering water by enabling settlers to establish a water right through diverting water and applying it to a beneficial use regardless of property location [40].

Prior appropriation was thought to encourage investment in an arid region because it ensured that a water right was valid against those developed later, creating a distribution system based on priority in times of scarcity (*Drake v Earhart*, 2 Idaho 750; 23 Pacific Reporter 541 (Idaho Territorial Supreme Court, 1890)). The water right created under the doctrine of prior appropriation is a property right of sorts, but only a use right ("usufruct")—i.e., the right to use of something owned by another. In this case, the owner of water is the state as memorialized in Idaho's constitution, adopted on statehood in 1890, and early statutes (Idaho Constitution, Article XV, Section 1; Idaho Code, Title 42, Chapter 1). Thus, the state has substantial authority to regulate the distribution of water provided it does not violate the principle of priority.

Allocation of the natural flow of variable surface water resources tested the sustainability of irrigation in this arid landscape, and distribution in order of priority quickly reached its economic limit. In this early era, water users and states seeking increased agricultural development turned to water storage as the answer [24]. The U.S. Congress, thus, sought to encourage homesteading and support irrigation efforts through the Carey Act of 1894 (28 U.S. Statutes at Large 422 (1894), as amended 43 U.S.C. 641) and the Reclamation Act of 1902 (32 U.S. Statutes at Large 388 (1902)) [36]. Federal assistance allowed for the construction of large infrastructure projects such as dams and irrigation networks, which serviced the majority of arable land at this time (Figure 1) [29]. 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 investors and construct irrigation projects [41].

Of all the US western states, Idaho has been the most successful in taking advantage of the opportunities provided by the Carey Act [41,42]. One irrigation project of 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 [41]. One factor of the TFSSP's success was the construction of Milner Dam in 1905, built to divert the Snake River from its natural course to irrigate lands to the south and north of the river. Downstream from Milner Dam, the Snake River enters a deep canyon, which at the time made the use of the river's water beyond this point unfeasible due to the lack of pumping technology [43].

From this point of diversion, the majority of water transported for irrigation was lost as seepage due to the volcanic geology of the landscape and would find its way underground [30]. Surface water irrigation in these early years of development was a significant source of recharge, especially for the ESPA (Figure 2), due to the infiltration that resulted from poorly lined canals and the practice of flood irrigation [32]. Water lost to seepage that found its way to the ESPA would follow the southwest flow of the aquifer until reaching the Thousand Springs area where it would discharge back into the river [44]. Understanding this path that water from Milner Dam takes–across the plain through irrigation networks to agricultural fields, with a majority seeping into the ESPA and discharging back into the river downstream from Milner Dam–is essential to understanding the complex hydraulic makeup of the Snake River Plain and how irrigation decisions alter water supplies.

The Reclamation Act further supported the provision of water to settlers by providing for the federal development of dams and large-scale irrigation infrastructure and a fund for that purpose [45]. One of the earliest reclamation projects in Idaho was the Minidoka Project which helped bring irrigation water and hydropower to the region. Over time, this project brought to the region five reservoirs including American Falls in Idaho, and Jackson Lake in Wyoming, diversion dams, hydropower facilities, and hundreds of miles of canals that significantly increased the irrigation capacity of southern Idaho [46]. As diversions and canals were constructed to transport water to irrigable agricultural lands, an agricultural landscape began to emerge across the basin [36].

The expansion of irrigated acreage across the Snake River Plain, paired with shifts to more water-thirsty crops, posed issues in years that the Snake River system experienced drought. Conflict among irrigators in various reaches of the river rose as water demand increased and over-allocation became apparent in drier years. Over-allocation of water was paired with a limited understanding of the exact hydrology of the basin and a lack of official water right records that made the enforcement of prior appropriation tedious [36].

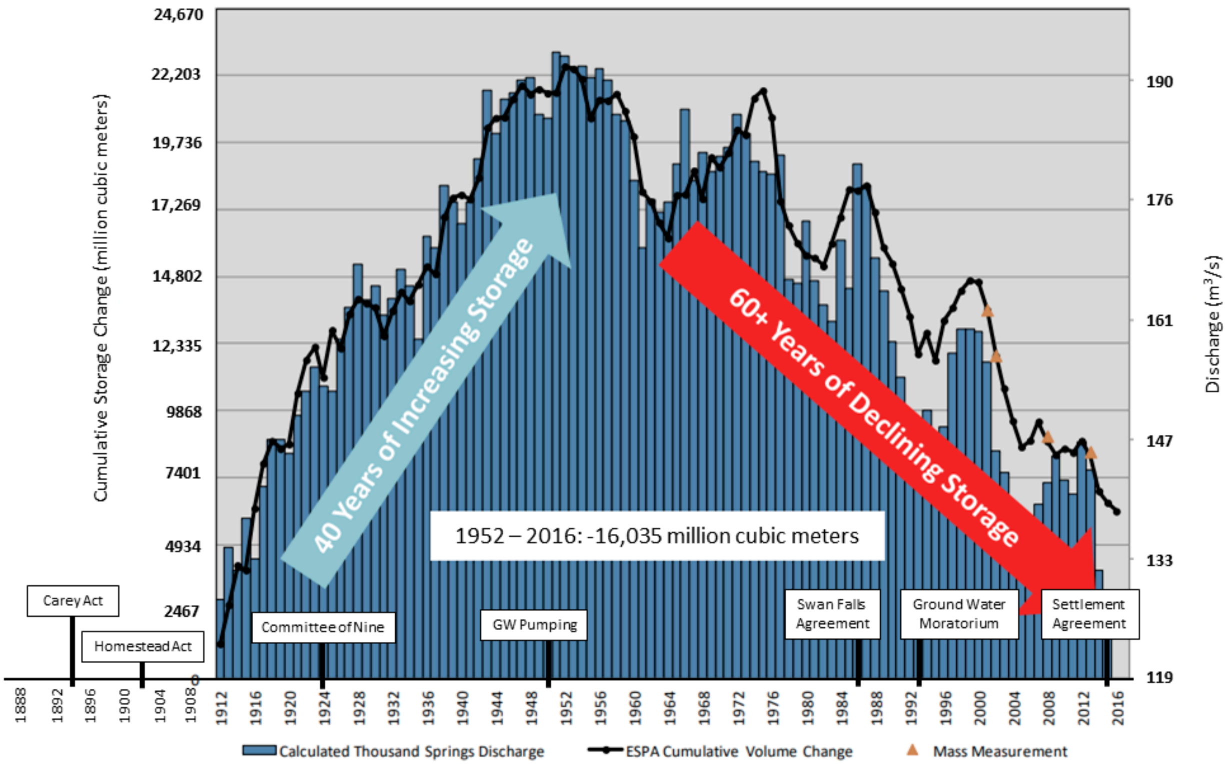

Figure 2. Visual representation of the volume of water discharging from the Eastern Snake Plain Aquifer at the Thousand Springs area of Idaho. Significant events that have impacted irrigation practices are indicated by white boxes at the time that they occurred. This graph has been edited from its original form using units in the imperial system to those in the metric system, with values rounded to the nearest decimal (Updated by Idaho Department of Water Resources from Kjelstrom (1995)).

In 1923, a committee was established under state law composed of representatives from each section of the river above Milner Dam. This committee was tasked with preparing an annual cooperative plan for distributing water. In 1924, this committee was ratified as the Committee of Nine and it furnished the first of many annual compromises that would determine water distribution on a schedule that all irrigators could agree on. These compromises also involved input from the many separate irrigation districts and canal companies, the Idaho Department of Reclamation (SDOR) (predecessor to IDWR), and coordination with federal entities. The institutionalization of the Committee of Nine helped release tensions that had developed in the early years of irrigation development, and offered irrigators along the Snake River a platform for future compromise and conflict resolution [36]. The collaboration of water users represents self-organization, however, its facilitation and legitimacy within the state legal system were made possible by the formal legal structure establishing the committee.

As irrigation expanded to roughly two million acres in the Snake River Plain by the 1920s [35], aquifer levels in the ESPA increased (Figure 2) due to flood-irrigation water infiltration far in excess of the aquifer's natural recharge rate. Some estimates suggest that about 60% of water diverted for surface water irrigation ends up as seepage into the ESPA [47]. Increasing aquifer levels and discharge rates in the Thousand Springs area greatly benefitted hydropower production downstream of Milner, with increasing discharges to the river allowing for cheaper and more reliable power production, especially at the Swan Falls Dam, the first of many hydroelectric projects built by the private Idaho Power Company (IPC). The divide offered by Milner Dam led to the "two rivers" concept, with water rights and distribution upstream of Milner treated separately from those downstream [48]. This allowed for both irrigation and hydropower development to flourish together in the first half of the 20th century [49].

At the peak of the ESPA's discharge around the 1940s (Figure 2), hydropower producers also sought to take advantage of increasing flows to the Snake River. Idaho Power Company (IPC) gained federal approval to build more hydropower projects on the Snake River downstream of Milner Dam, with the condition that a subordination clause be included stating the operation of the project would not interfere with "future depletion of the Snake River and its tributaries, or . . . future upstream diversion and use of such waters, for the irrigation of lands and other beneficial consumptive uses in the Snake River watershed" (14 F.P.C. 55, 1955).

3.3.2. Groundwater Era (1950–1987)

Cheap electricity and the introduction of groundwater pumping technology in the late 1940s allowed for groundwater sources in the USRB to be tapped [36]. For the second half of the 20th century, groundwater development saw massive expansion as additional arable lands, previously unserviceable by surface water infrastructure, could be irrigated [47]. Though additional acres of productive farmland resulted in further economic growth for the region, ESPA groundwater pumping began to reverse the increase in aquifer levels almost as soon as it was introduced. The consequences of massive amounts of groundwater extraction were soon realized as the volume of aquifer discharge to the Snake River began to decrease (Figure 2). This was intensified by the adoption of more efficient irrigation technology by both groundwater users and surface water users alike, resulting in much less water at the field level recharging the aquifer through infiltration.

In 1951, groundwater pumping was brought under the umbrella of state regulatory authority through the passage of the Ground Water Act, which verified the appropriation of groundwater resources, reified their subsequent administration and protection, and validated all existing appropriations of groundwater that had been established before the act (Id. Code § 42-226–42-239). The appropriation of groundwater resources was further officiated in 1963 when a statutory permit system administered by what is now the Idaho Department of Water Resources for obtaining a right to develop large groundwater wells was enacted (codified as amended at Id. Code § 42-229).

With legislation in place to officiate the appropriation of groundwater and cheap electricity offered by new hydropower sources, the region saw a significant increase in irrigated acreage. The consequences of this expansion were soon seen throughout the latter half of the 20th century as the volume of water in the ESPA slowly declined [33]. The nature of groundwater pumping created a landscape less strewn with canals and more populated with groundwater pumps that were connected at the field level to irrigation systems [36]. Installment of efficient sprinkler systems as well as increased efficiency in surface water systems played a role in the aquifer's depletion by phasing out flood irrigation methods that had been a significant recharge source for the ESPA [29]. As seen in Figure 2, the level of the aquifer slowly began to decline throughout the latter half of the century as agricultural methods evolved [33].

Recognizing the absence of planning in its management of its water resources, the state amended the constitution in 1965 to create the Idaho Water Resource Board (IWRB) consisting of eight members appointed by the Governor. The IWRB was given the responsibility of promoting economic development through implementing water conservation and management activities, and 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). The IWRB and the SDOR were combined in 1974 to create the present-day IDWR, with their individual responsibilities of water conservation versus administration remaining separate, but both staffed by agency scientists.

The first state water plan was approved by the legislature in 1976 and recognized the complexity of the ESPA and Snake River's hydraulic connection. It expressed that basin water supplies were over-allocated and that there was a general need for more recharge efforts and storage capacity [48]. In 1978, legislation was passed that deemed recharge a new beneficial use to encourage recharge initiatives in the basin (I.C. § 42-234), a significant change to what was traditionally considered beneficial use. In 1980, additional legislation created the state Water Supply Bank and designated the IWRB to facilitate water transfers between water users (Id. Code § 42-1762) to encourage the highest beneficial use of water and provide a source of water for new and supplemental water uses (IDAPA 37.02.03–Water Supply Bank Rules). The IWRB also appointed the Committee of Nine to officially administer the Water District 01 Rental Pool (Id. Code § 42-1765). This made the committee an important player in the operation of the USRB reservoir system above Milner Dam as a rental pool system, and an important link between local, state, and federal water actors.

Even with increased conservation activities, pumping from the ESPA continued to draw the aquifer's levels down, further reducing flows available for hydropower production downstream of Milner Dam. IPC filed a declaratory judgment in 1983 with the district court to determine whether their water rights at Swan Falls (a hydropower facility built in 1901) with priority dates ranging from 1900-1919 (*Idaho Power Co. v. State*, 104 Idaho 575, 661 P.2d 741 (1983)) were subordinate to irrigation uses above Milner Dam as determined in their 1950s federal licenses for the downstream Hells Canyon complex [49]. The Idaho Supreme Court ultimately ruled that Swan Falls' water rights were not included in the subordination to irrigation uses above Milner Dam, setting the stage for IPC to make water calls against those junior water users upriver, including ESPA groundwater users (*Idaho Power Co. v. State*, 104 Idaho 575, 661 P.2d 741 (1983)). This conflict resulted in the Swan Falls Agreement, under which a minimum flow of 3900 cfs would be required to pass through the Swan Falls complex during the irrigation season, and 5600 cfs during the non-irrigation season, introducing a new stringent management objective for the basin.

3.3.3. Modern Water Management Era (1987–2015)

The new flow requirements in the Swan Falls Agreement highlighted the importance of properly managing the ESPA and Snake River's hydraulic connection to ensure optimal use of both in light of the "two rivers" concept. It was determined that the Snake River 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 [groundwater] from that system" (Swan Falls Agreement, 1984). To achieve this, funding was provided to commence the Snake River Basin Adjudication (SRBA). To avoid any further appropriation of ESPA resources, the IDWR imposed a moratorium on further groundwater permits in 1992 (IDWR Moratorium Order, 15 May 1992), which took effect in 1993 and is still in effect today.

In 1994, the first of many requests for water calls against junior groundwater pumpers was filed with IDWR (the enforcing agency) by the Mussers–senior surface water users who claimed that ESPA pumping was reducing their flows. The Director of IDWR denied their call arguing 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". The Idaho Supreme Court overruled this decision, holding that the Director had a clear and legal duty to administer water rights, and that denying the Musser's water call was a breach of his duties (*Musser v. Higginson*, 1994). The problem then became: how to administer surface and ground water as one resource, despite the differences in behavior of groundwater systems?

To address this, Conjunctive Management Rules (CMRs) were adopted by the IDWR to provide a process for determining injury when delivery calls were made by senior users against juniors (IDAPA 37.03.11–Rules for Conjunctive Management of Surface and Ground Water Resources). These CMRs provided guidelines for determining injury and the validity of a water call on a case-by-case basis. While the CMRs did not attempt to change the underlying rule of priority, they did take a much more rigorous view of the concept of "reasonable use" as the means to define the volume of a water right. They did so by listing a number of factors, including efficiency improvements, and changes in diversion infrastructure, that must be shown by the senior water user to demonstrate material injury (Rule 42), before the Director will place a call on the junior water users. The CMRs also allowed junior water users to be protected from a delivery call if they developed a mitigation plan (Rule 43) that would eliminate the material injury suffered by the senior water user. The CMRs were upheld against a challenge to their constitutionality in 2007 (*American Falls Reservoir Dist. v. IDWR*, 154 P.3.d 433 (Idaho 2007).

Surface water calls rely on the ability to measure water flow in the source and determine if a specific junior upstream diversion is actually injuring any downstream senior diversion. Recognizing that requiring this type of determination with a surface-to-ground water call would mean that whoever had the burden of proof, the senior or junior, would lose, IDWR worked with basin water interests to develop a hydrologic model to be used to determine which wells to curtail in the event of a delivery call. The model was found to be the best available science and therefore adequate in the first major delivery call (*Clear Springs Foods*, *Inc. v. Spackman*, 252 P.3d 71 (Idaho 2011). These rulings and several others set the legal bounds for the water conflicts in the basin. The encouragement of mitigation plans provided the nudge to self-organize to develop solutions.

Legislation in 1995 gave groundwater users the ability to officially organize groundwater districts (Id. Code. § 42-5200). Contrary to irrigation districts and canal companies primarily organized to distribute water, groundwater districts developed to share the cost of monitoring water use and litigation, implement mitigation measures, and other duties (Id. Code § 42-5224). Groundwater pumpers across the ESPA formed districts, and in further response to the conflicts rising between groundwater pumpers and surface water uses, the self-organized Idaho Ground Water Appropriators (IGWA) was formed to represent the nine groundwater districts pumping from the ESPA [50]. In a similar effort, seven surface water irrigation districts and canal companies organized to form the Surface Water Coalition (SWC) in 2005. Similar to IGWA, their main purpose was to represent senior surface water users in litigation, however, both entities would become instrumental in developing a long-term plan.

From 2005 forward, the IDWR determined on a yearly basis whether the same injury would occur, to what degree, and whether or not IGWA would need to mitigate (Final Order Regarding Methodology for Determining Material to Reasonable In-Season Demand and Reasonable Carryover, 2010). Although IGWA mitigation plans served to satisfy senior water users for the first two decades of CM Rules' implementation, a loss in system water supply in 2015 due to drought conditions diminished their success. That year brought unusually warm weather early in the season, resulting in the highest demand for water ever seen in District 01. For the first time since the Swan Falls Agreement, the flow of the river at Swan Falls Dam was below the minimum flow requirement and threatened to dip below the summer minimum flow requirement later in the season [51]. IGWA members faced strict curtailment which had been avoided up to that point.

To avoid further expensive litigation and curtailment, the IGWA and SWC entered into a Settlement Agreement in 2015 that outlined a suite of robust long-term management activities that would actively work to stabilize the basin's water supplies. With a goal of reaching the average level of the aquifer that had been seen between the years 1991–2001, this settlement agreement was composed of an annual pump-reduction target of 240,000 acre-feet to be shared by IGWA members, which was equivalent to 13% of their usual pumping levels, and an annual goal of recharging the aquifer by 250,000 acre-feet in coordination with the IWRB. State-facilitated cooperation between the SWC and IGWA has resulted in modern solutions to a problem that would have resulted in considerable economic harm had litigation been the only path. As the USRB's agricultural landscape has grown and evolved, actors have responded to fluctuations in water supply through developing initiatives for managing strained irrigation resources among water users. This collaboration has culminated in a modern era of water administration and management that respects the priority inherent to water rights yet ensures long-term water supplies for present and future beneficial uses.

4. Discussion: Governing the Complex Social-Ecological System of the Upper Snake River Basin

Throughout the three eras identified, the growth of the agricultural landscape in southern Idaho has heavily influenced the stability of the ESPA and the availability of water in the basin system. The effects of modernizing irrigation methods have affected water supplies and the water users relying on them, leading to conflicts between irrigators of varying priorities. The threat of mass curtailment of junior water users has consistently loomed over irrigators in a basin where water availability fuels landscape productivity and a majority of the state's net income [52]. As illustrated in the previous section, decisions of actors in response to fluctuations in basin water supplies have adapted throughout time to tailor a water management and allocation scheme that is specific to the nature of the USRB and informed by bottom-up design (Tables 1–3 [23]).

As a means to resolve conflict surrounding the administration of water in times of scarcity, Idaho has followed prior appropriation since its territorial status to allocate water based on 'first in time, first in right', yet water users within the USRB have consistently worked to avoid its strict implementation. Thus, the clear legal rule has provided a catalyst for cooperation [23,53]. The constitutional requirement of just compensation for the taking of private property only applies to governments, thus, the law does not prevent private water users from voluntarily agreeing to a distribution system that ignores priority. Throughout the growth of the agricultural landscape in the USRB, water users have been able to work cooperatively and through the use of technology to avoid the harsh consequences of the prior appropriation doctrine and seasonal curtailment of water users in times of water shortage (Tables 1 and 3). The Idaho Department of Water Resources (IDWR) and the Idaho Water Resource Board (IWRB) work closely with water users and other institutions to achieve this. Across various scales, actors work to effectively manage the basin's water to ensure sufficient water supplies for all water uses, while also respecting the priority that senior water right holders have in water distribution. Rather than subject irrigators to curtailment and a possible economic downturn, state legal systems have provided irrigators with resources and processes to cooperate since the early 20th century to properly manage the basin's water supply (Table 1). Irrigators have used the power of their organized voice to work with and within federal and state systems for water development and management, to adapt to the variability of the basin's hydrology and climate. In turn, the federal and state systems have provided legal mechanisms to institutionalize and fund solutions, increasing the likelihood they will withstand the test of time (Table 1 [53]).

The successful efforts of irrigators in managing basin resources began with water users constructing small-scale ditches and canals for transporting irrigation water and forming irrigation entities through the Snake River Plain and has grown to include regional actors distributing water to diversions and head gates, state-level agencies and guidance from legislative and judicial bodies, and coordination with federal agencies (Tables 1 and 3). These social connections have grown in stride with changes to basin water supplies, from periodic drought conditions to over-allocation of water, and fluctuations in the aquifer's storage. Before agricultural development, the hydrology of the Snake River and the ESPA was fueled primarily by variations in annual precipitation but has since seen influence from surface water irrigation networks and infrastructure, the construction of Milner Dam, the introduction of groundwater pumping, and alterations to irrigation methods affecting infiltration rates and spring discharge (Figure 2). Figure 3 provides a conceptual model illustrating the interaction of system components based on Tables 1 and 3 [50].

The ability of social actors within the USRB to manage their water resources would not be possible without the nested scales of governance and the various linkages connecting formal and informal governance actors (Figure 3). The linked social-ecological overlap is most apparent when considering the effects of massive infrastructure constructed to manipulate and transport water supplies (Figure 3 [12,23]). The location, scale, and timing of irrigation projects each play a role in the nature of the basin's hydrology due to its hydraulic complexity while also having a large influence on the ability of irrigators and institutions to effectively allocate water. All of these efforts are informed by strong communication among institutions, and the provision of modeling and data by state and federal agencies (Table 1, Figure 3), with the key federal and state actors in formal governance shown above the shaded box. Figure 3 also illustrates that while the larger-scale infrastructure is, for the time being, locked in, local actors have considerable room to adjust the use of water on the ground, its management, and even its recharge. This supports resilience approaches for SES that are positioned as adaptive strategies on the continuum from resistance to transformative strategies [16] and help elucidate the role of social structures in managing significant change in SES [15]. In the context of water security in multisystemic resilience (e.g., FEWS) the conceptual model (Figure 3) represents a scaled strategy, where the levels at which actors have influence and in which action takes place are contested and negotiated, and in which institutional interplay, where rules and norms in different sectors influence each other at different levels, are integral to adaptive capacity [54,55].

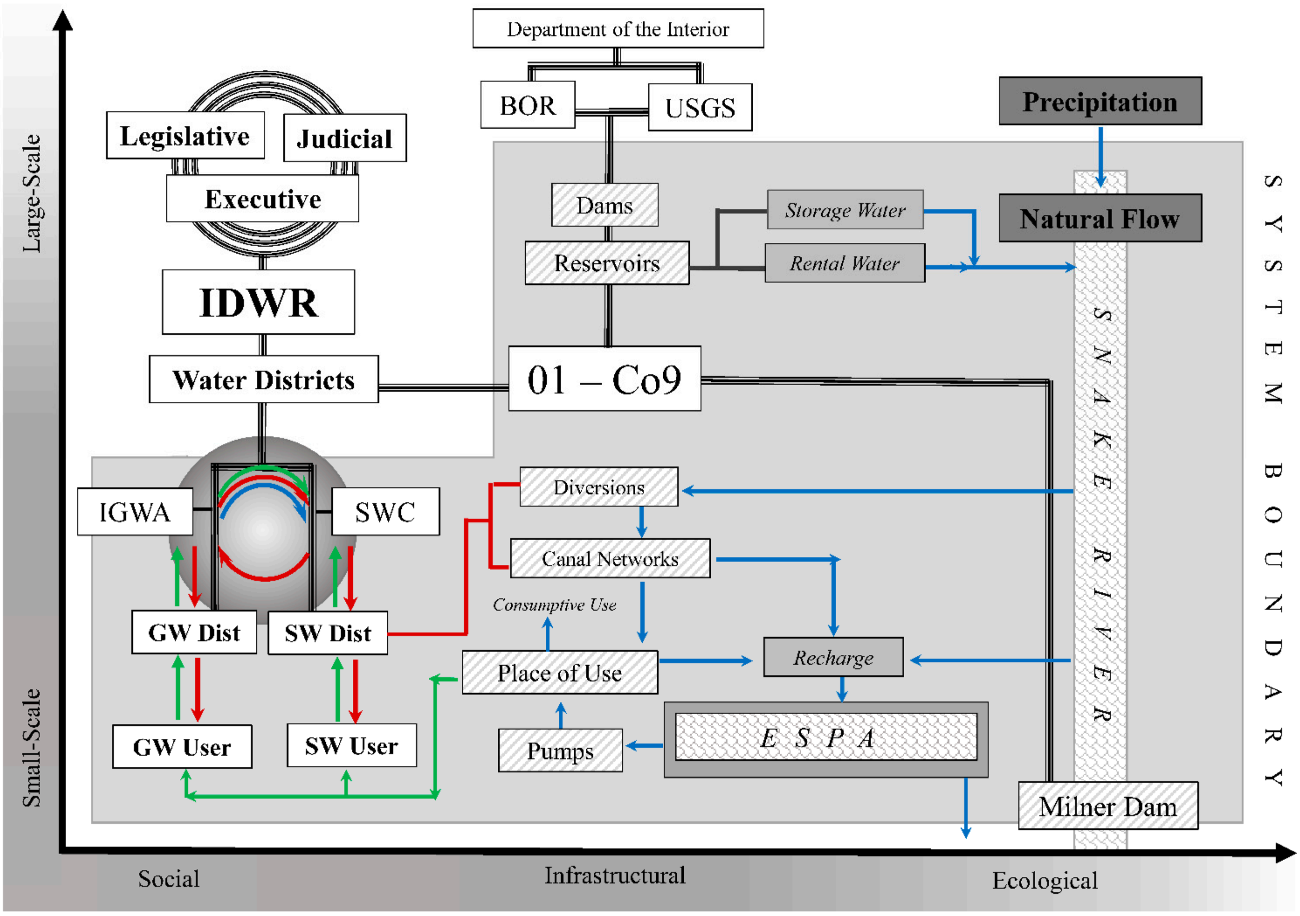

Figure 3. Conceptual model of the social (including governance), physical (including infrastructure), and ecological (including climate) subcomponents of the Upper Snake River Basin and their spatial, multi-temporal, and scalar linkages that combine to create a process-specific social-ecological system (Updated from [56]). IDWR: Idaho Department of Water Resources; IGWA: Idaho Ground Water Association; SWC: Surface Water Coalition; GW: Ground Water; SW: Surface Water; BOR: Bureau of Reclamation (U.S.); USGS: U.S. Geological Survey; Co9: Committee of Nine; ESPA: Eastern Snake Plain Aquifer.

5. Conclusions

The study illustrates that the slow process of local self-organization, its tendency to define narrow goals that may serve only those with the capacity to participate, and its lack of resources to follow through on creative solutions, can be addressed by clear, enforced goals, provision of judicial forums, institutionalization and funding of solutions by formal governance (i.e., government). It also illustrates that by mandating goals rather than the means to achieve them and by providing resources, the government may provide sufficient space for local, adaptive innovation. While specific conclusions from a case study may not be transferrable, the analysis of interaction among formal and informal governance suggests that any effort to implement a top-down solution to water allocation that is not tailored to the specific social and hydrologic setting, such as the implementation of the prior appropriation doctrine without means to self-organize around creative solutions, could cause drastic economic, ecological, and social consequences due to the reliance that the region has on sufficient irrigation water supplies [12]. The result of bottom-up management practices nested within formal governance has resulted in a purpose-specific SES that meets local and regional annual water allocations and management goals through constant adaptation and the implementation of collaborative initiatives assisted by place-based institutions. This should inform other efforts to adapt water dependent communities to climate change by highlighting the role of government as one of steering, resource provision, and checks on accountability, while leaving room for local innovation, tailoring, and flexibility and resources to continually adapt.

Finally, while the case study paints a positive picture of the collaboration of water users with shared histories and shared interest in irrigated agriculture, and of their productive interaction with state government, it does not explore the adaptability of local governance structures (such as the Committee of Nine) created in the last century, to new values and marginalized groups just beginning to build the capacity to participate. Future research should include recent efforts to obtain instream flows and improve water quality for listed species, as well as the capacity for the participation of the Shoshone-Bannock Tribes and the Nez Perce Tribe, located respectively in the USRB and downstream of the USRB.

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