When the Canals Run Dry:
Collective Choice Arrangements, Monitoring, and Sanctions for the Maintenance of Tajikistan's Irrigation Infrastructures

Corrie Hannah*

Abstract
Agricultural productivity is greatly contingent on irrigation infrastructure conditions. In coupled infrastructure systems, physical infrastructures combine with public services to link social, natural, and economic processes. Scholars suggest these processes can be governed with similar institutions used for governing common pool resources. How might common pool resource institutions affect the management and conditions of public infrastructures? Using the case of Water User Associations (WUAs) in Tajikistan, I examine how collective choice arrangements, monitoring, and sanctions affect rule conformance, water user participation in maintenance activities, and conditions of irrigation infrastructures. Ordered logistic regression analysis was conducted using data from structured interviews with 160 WUA leaders across Tajikistan. Preliminary results show that collective choice arrangements, rather than monitoring and sanctions, were a positive predictor of water user compliance of WUA rules; water user compliance of rules specific to water use, rather than to maintenance participation, were positively associated with irrigation infrastructure conditions.

Keywords
irrigation systems, irrigation infrastructure, Water User Associations, food security, collective choice arrangements, monitoring, coupled infrastructure systems, Tajikistan, Central Asia

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*PhD Candidate, Nicholas School of the Environment, Duke University
Environment Hall, 9 Circuit Drive, Box 90328, Durham, NC 27708
Phone: +1-919-402-3427, Email: corrie.hannah@duke.edu

I. INTRODUCTION

Even though infrastructures are key to the appropriation of common pool resources, the role and function of infrastructures are not often fully considered in the analyses of common pool resource governance. The study of the commons often focuses on sets of institutions, or informal and formal rules, that govern the interdependencies between social, natural, and economic processes (Ostrom 2007, 1990). These social, natural, and economic processes are typically linked together by public infrastructures, which are the combined physical infrastructures and public services that are required for maintaining the use of shared natural resources (Anderies, Janssen, and Schlager 2016, Anderies, Janssen, and Ostrom 2004).

In order to discuss infrastructure maintenance and management, it is important to know the key criteria and characteristics of public infrastructures. Public infrastructures are defined as follows:

1. The infrastructure may be consumed nonrivalrously for some appreciable range of demand;
2. Social demand for the infrastructure is driven primarily by downstream productive activities that require the infrastructures as an input;
3. The resource may be used as an input into a wide range of goods and services, which may include private goods, public goods, and social goods (Frischmann 2012)

Additionally, public infrastructures can take many forms. Hard infrastructures refer to physical human-made infrastructures, such as roads and bridges; soft infrastructure are human-designed processes or institutional arrangements for using infrastructures; natural or environmental infrastructure describes the ecological processes or services that are important for society; human or intellectual infrastructure refers to human knowledge; and social infrastructure describes the relationships among individuals, such as social capital (Frischmann 2012). In irrigation systems, for example, hard infrastructure the physical irrigation infrastructures (i.e., canals, gates, drainages) and soft infrastructure is the governance system in places for managing a particular irrigation system (Anderies and Janssen 2013). Natural infrastructures describe the hydrological processes that allow water to be diverted from rivers to irrigate agricultural fields. Human infrastructure is the knowledge farmers have regarding their use of the irrigation system and social infrastructure describes their social interactions – and quite possibly the group characteristics that are described as preconditions for governing common pool resources (Ostrom 2000).

The conditions, maintenance, management, and use of public infrastructures allows for resource appropriation, which subsequently contributes to additional production activities in downstream market and nonmarket systems (Frischmann 2012). For example, consider the role of irrigation infrastructures in facilitating food production and food security. Higher yields are likely if irrigation infrastructures are maintained in good conditions to support the appropriation of water resources. Maintaining canal networks ensure that irrigation infrastructures retain their function of water appropriation for agricultural production. Cleaning irrigation drainage systems also reduces water logging and soil salinization, which can increase the biological productivity of soils (Merrett 2002). Downstream production systems use raw goods from these agricultural yields as inputs for further production activities, which can contribute to regional trade and food security. Water appropriation and subsequent economic markets and social benefits would not be possible without the maintenance or governance of irrigation infrastructures.

When there are multiple individuals and markets that benefit a particular public infrastructure, the question of governance becomes an inherent challenge. Open access to a resource that is appropriated by a particular infrastructure leads to scale returns, resulting in greater social value with greater use of the resource. Productive use of infrastructures (i.e., roads) leads to positive externalities and social surplus, including private and social value Open, nondiscriminatory management increases participation in the use of the resource, but not necessarily in the management of infrastructures. (Rose 1986). In other words, a number of individuals do not contribute to the infrastructure maintenance and management, even if they obtain benefits from the infrastructure's operations in downstream markets. Individuals closest to the infrastructures, such as the farmers in irrigation systems, are often faced with the task of maintaining and managing irrigation infrastructures

The impact of public infrastructures on economic productivity depends on how well the infrastructure is managed and maintained. The maintenance of public infrastructure depends on the contextual details of the relevant community, including its' political economy, existing infrastructures, available technologies, societal needs, etc. (Frischmann 2012). As such, there are a multitude of economic and political approaches for managing and maintaining public infrastructures (i.e., subsidies, government provisioning, paying taxes according to an individual or group's marginal benefits). Frischmann (2012) proposes that infrastructures should be managed as a commons resource, because of the scale returns and downstream increases in individuals' participation in markets that directly or indirectly benefits from the public infrastructure (Frischmann 2012). What considerations should then be made if public infrastructures could be managed as commons resources are?

It would make sense to look towards literature on the commons, to examine the proposition that public infrastructures can be managed as commons resources. Concerning irrigation systems, on the one end, some scholars have based their analyses on collective action and the appropriation rules across networks of irrigation infrastructures (Cox 2014, Tang 1992), but less so on the outcomes of these rules on physical infrastructure conditions. Other scholars have examined the downfalls of managing irrigation infrastructures using only a technical approach (i.e., repairing and maintaining irrigation infrastructures without providing and training or guidance to local infrastructure users) rather than a combined institutional and technical approach (Lam 1998, Shivakoti et al. 2005). Further studies have provided modeling approaches to examine the responses of overall irrigation system robustness or resilience to external disturbances, such as climate change, drought, urbanization and globalization (Cox and Ross 2011, Yu et al. 2014). While these studies have offered some insights infrastructure management in the context of common pool resource management, the functions and conditions of the irrigation infrastructures remain in the background, especially since the focus of these analyses are on the resource conditions and participation of resource users in governance processes.

In this manuscript, I examine currently overlooked institutional drivers and actor activities that may directly affect infrastructure maintenance and management using the case of irrigation infrastructure management in Tajikistan. Since the late 1990's, the primary governing model for managing and maintaining irrigation infrastructures have been through Water User Associations (WUAs). WUAs are non-governmental organizations composed of groups of water users, namely farmers, who are now responsible for maintaining secondary and tertiary irrigation infrastructures in Tajikistan. WUAs use a number of institutions derived from the study of the commons to manage not only water resources, but also irrigation infrastructures. In order to afford the cost of irrigation infrastructure maintenance and repair, WUAs in Tajikistan depend on farmers' payments of irrigation service fees. In addition farmers, engage with a number of formal and informal institutions to manage irrigation systems (i.e., voting for WUA leaders, participating in discussions on issues that affect the WUA, contributing labor to repair infrastructures).

The paper begins with an overview of key concepts and irrigation infrastructures in Tajikistan. I then introduce the research questions and theoretical frameworks. I draw from two theoretical frameworks to set up my inquiry – the Coupled Infrastructure Systems (CIS) framework and Institutional Analysis and Development (IAD) framework. I then follow with my hypotheses, research methods, and results. Since this is a working paper, the results are preliminary and further analyses will be conducted. As such, the discussion is also preliminary and will evolve over the course of subsequent analyses.

II. LITERATURE

I provide an overview of three key institutions from the commons literature that may contribute to the maintenance, management, and subsequent conditions of irrigation infrastructure conditions. These institutions are collective choice arrangements, monitoring, and sanctions. These institutions are also three of the eight design principles for governing common pool resource systems. A design principle is a condition that accounts for the enduring success of institutions in maintaining a given resource system and ensuring compliance of resource users over an extended amount of time (Ostrom 1990).

Collective choice arrangements

Collective choice arrangements allow water users to establish and modify the rules for irrigation infrastructure maintenance, including the procedures through which public irrigation infrastructure maintenance activities are accomplished (Ostrom 1990). Participation in the development of rule enforcement procedures often leads to greater compliance of rules (Olson 1971). Communication, such as discussion of rules and irrigation maintenance and management affairs, may facilitate cooperation on rule compliance by eliciting preferences of group members, enhancing trust among members, activating social values and responsibility, and facilitating the creation of group identity (Ben-Ner and Putterman 2009, Messick and Brewer 1983). There is also some evidence that democratic participation of local resource users in rule making leads to rule compliance in some (Rausser and Antinori 2007, Özerol 2013), but not in all cases (Vollan, Prediger, and Frolich 2013).

For irrigation systems, water users also are more likely to comply with WUA institutions and participate in maintenance activities, if they are involved in the creation of the collective choice arrangements of the WUA (Tang 1991). As such, the WUA models across the globe are designed to strengthen the engagement of local water users in the relevant governance and decision-making processes for managing irrigation systems (Vermillion and Sagardoy 1999, Salman 1997).

According WUA legislation in Tajikistan, water users are in charge of collective choice arrangements. For this study, operationalized variables for collective choice arrangements include electing leaders, and discussing and voting on issues pertaining to management of the irrigation system, such as budgets, maintenance, sanctions, and resolution of disputes. Compared to Soviet-era natural resource governance, collective choice arrangements allow for greater participation of local water users to make decisions regarding irrigation management that is most suitable to local conditions (Ostrom 1990, Agrawal and Gibson 1999, Baland and Platteau 2000). However, in post-Soviet communities, water users may not often participate in the creation and compliance of rules associated with collective choice arrangements. Lack of participation in WUA activities and compliance of WUA rules is typically attributed to legacies of top-down natural resource governance and power dynamics as result of institutional change (Dukhovny, Sorokin, and Stulina 2008, Moss and Hamidov 2016, Sehring 2009a, Theesfeld 2011). If the institutional changes have indeed contributed to limited water user engagement in collective choice arrangements, then irrigation infrastructure conditions would be adversely affected.

Monitoring

Monitoring occurs when monitors, who actively audit common pool resource conditions and appropriator behavior, are accountable to the appropriators, or are the appropriators(Ostrom 1990). Two main aspects of monitoring are considered in the commons literature[1]: 1) monitoring other resource users' behaviors in the appropriation of the resource and 2) monitoring the resource (Tomás, Arnold, and Cox 2010).

Yet, in consideration of monitoring the resource, no distinction has yet been made between the monitoring of the common pool resource (i.e., water) and the public infrastructure (i.e., irrigation infrastructures). The conditions of both are critical to the productivity of the common pool resource system. For this paper, I focus solely on the monitoring rules for irrigation infrastructure. The two operationalized variables for monitoring irrigation infrastructures include the payment of irrigation service fees and voluntary labor contributions to irrigation infrastructure maintenance.

New WUA development initiatives promote monitoring rules in order to coordinate water user participation in the maintenance of irrigation infrastructures (Tang 1991). According to the WUA model in Tajikistan, groups of water users are charged with monitoring the conditions of water resource and irrigation infrastructures. These groups of water users determine who is responsible for irrigation infrastructure maintenance, as well as how and when maintenance activities should occur. Tajikistan's WUAs currently promote two specific monitoring mechanisms: 1) costly enforcement mechanisms through the payment of irrigation service fees, and 2) conditional cooperation through the voluntary labor contributions in irrigation infrastructure maintenance activities.

Sanctions

Sanctions, and preferably graduated sanctions, can be used for resource users who violate the rules of appropriating a particular common pool resource. Other resource users or officials may use sanctions on violators (Ostrom 1990). Sanctions designed to encourage rule compliance among actors and scholars have noted that compliance is attainable when resource users believe the collective goal can be achieved and when they know that other will also comply (Levi 1989).

Sanctioning activities provide a system of checks and balances through costly enforcement mechanisms and conditional cooperation of local resource users (Rustagi, Engel, and Kosfeld 2010, Vollan and Ostrom 2010). Resource users bear a personal, sometimes financial, cost when they monitor other resource users, public infrastructure providers and pubic infrastructures. Payment of irrigation service fees is an example of a costly enforcement mechanism that financially contributes to the maintenance of irrigation infrastructures. New water reforms in Tajikistan require farmers to pay irrigation service fees to cover the cost of operating and

[1] In the original design principles, monitoring only considered the monitoring of resource users to hold them accountable to the resource appropriators (Ostrom 1990). The concept of monitoring was later expanded to include monitoring the resource conditions (Tomás, Arnold, and Cox 2010).

maintaining irrigation canals (Wouters, Dukhovny, and Allan 2007, Sokolov 2006). Empirical evidence suggests that from irrigation service fees enable public infrastructure providers to provide better services (Small and Carruthers 1991, Svendsen 1993).

Conditional cooperation is a social norm, where the cooperation of an individual resource user is conditional on the participation of other resource users (Rustagi, Engel, and Kosfeld 2010). In Central Asia, conditional cooperation of water users to monitor and maintain irrigation infrastructures has been practiced through the use of *hashar*, which is the collective mobilization of community members to contribute voluntary labor to the maintenance of irrigation systems (Thurman 1999). Today, WUAs in Tajikistan may also employ some elements of graduated sanctions through the using of warning, fines, not allowing violators to appropriate water, or appealing to economic courts or other external authority. These costly enforcement mechanisms through payment of fees and conditional cooperation activities through contributions of voluntary labor prevent appropriators from exploiting irrigation water resources and irrigation systems from falling into disrepair.

III. IRRIGATION INFRASTRUCTURES IN TAJIKISTAN

The study area for this paper is situated in post-Soviet Tajikistan[2], located in Central Asia. Before Russian colonization of the Central Asia in the late 19th century, water users in Tajikistan collectively contributed to the financial and voluntary labor processes for maintaining irrigation infrastructures (Gunchinmaa and Yakubov 2010, Moss and Hamidov 2016). Until the early 20th century, monitors, called *mirobs*, were in charge of overseeing the appropriation of water resources and conditions of irrigation infrastructures. In addition, communities participated in collective labor processes, called *hashar,* to maintain and repair irrigation infrastructures. However, under Soviet communist rule, from 1917 to 1991, increasing centralized state control over natural resource management and development severely weakened the role of the traditional *mirob* and nearly eliminated collective contributions to irrigation infrastructure maintenance activities (Thurman 1999).

Since the centralized state oversaw all aspects of irrigation management, including the appropriation of water resources and provisioning of irrigation infrastructures, *mirobs* and water users had no benefit or incentive[3] to organize or contribute to irrigation infrastructure maintenance activities. As a result, water users began to engage in free riding and shirking behaviors that are common to state-driven collective management models (North 1990, Moe 1984, Wade 1987). With such strong state oversight by the middle of the 20th century, *mirobs* could not implement sanctions to account for water users' free riding on water appropriation or shirking on labor contributions if many other individuals are already supplying labor. Scholars posit that these behaviors continue to exist in the post-Soviet context and remain a challenge to the process of decentralizing natural resource management (Kovács 1994, Sehring 2009b, Theesfeld 2004). In

[2] As of June 1, 2017, cases from the Former Soviet Union (n=113 of 7233) only represent 1.6% of the compiled literature on the commons (Digital Library of the Commons). For the irrigation sector in 2013, roughly 6 percent of the world's area equipped for irrigation is in the Former Soviet Union (FAO AQUASTAT).

[3] The challenge for managing common pool resource systems is to ensure a net benefit for the cost of appropriating and providing irrigation services (Coase 1937, Olson 1971, Krutilla 2011, Eggertsson 1990). The lack of benefits or incentives, to participate in collective choice arrangements and monitoring activities can lead to free riding or shirking behaviors.

other words, post-Soviet communities are less likely to collectively partake in the management of public infrastructures and common pool resources.

With the disintegration of the Soviet Union in the early 1990's until today, post-Soviet countries, including Tajikistan, have restructured their political economies through an ongoing decentralizing process, especially in the agricultural sector. In particular, effective maintenance and management of irrigation infrastructures is crucial for addressing food security concerns among the regions' agricultural populations. In order to maintain and manage irrigation infrastructures, the country has devolved responsibilities for managing water resources from the state to non-governmental organizations, called Water User Associations (WUAs). WUAs are non-governmental organizations composed of groups of water users, who are now responsible for maintaining secondary and tertiary irrigation infrastructures. It is widely believed that the establishment of WUAs can increase the participation of water users in irrigation infrastructure maintenance and management, and in doing so, restore deteriorating infrastructures to restore agricultural productivity (Vermillion and Sagardoy 1999). From a theoretical standpoint, this would also mean restoring the weakened key linkages between water users and irrigation infrastructure monitors, such as *mirobs*, in order to improve irrigation system robustness (Anderies, Janssen, and Ostrom 2004).

Since the late 1990's the government of Tajikistan and international organizations have created over 400 WUAs. WUAs are in charge of secondary and tertiary irrigation systems, whereas the national irrigation agency oversees primary irrigation systems. In this devolution process, there has been discord between WUAs and the government over irrigation infrastructure maintenance responsibilities, as well as the access to financial and technical resources to maintain infrastructures. In the meantime, irrigation infrastructures are in disrepair or deteriorating, which continues to limit water user access to water resources.

In order to respond to these irrigation infrastructure maintenance challenges, WUAs in Tajikistan are currently striving to employ new sets of recommended institutions (i.e. formal and informal rules) for maintaining and managing irrigation infrastructures. These institutions include water user engagement in collective choice arrangements and promoting monitoring and sanctioning rules that encourage water users to comply with WUA rules and participate in maintenance activities. However, scholars have questioned whether this is possible for the irrigation sector in the post-Soviet context, due to Soviet-era habits of power asymmetries, rent-seeking, shirking, and free riding (Theesfeld 2004, 2011, Sehring 2009b). The case of WUA development in Tajikistan and uneven adoption of new WUA institutions across the country provide an interesting opportunity to examine how irrigation infrastructures can be governed using principles from the management of common pool resources and through the lens of a coupled infrastructure system.

IV. RESEARCH QUESTIONS

I address the following overarching research questions regarding the maintenance of irrigation infrastructures in Tajikistan:

1. *How does water user engagement in collective choice arrangements of the WUA (i.e., electing leaders and voting on WUA rules) affect the monitoring and sanction rules that are associated with irrigation infrastructure maintenance fees (i.e., paying fees and contributing voluntary labor)?*

2. *How do monitoring and sanction rules affect water user compliance and participation in irrigation infrastructure maintenance activities?*
3. *How water user compliance and participation in irrigation infrastructure maintenance activities affect the conditions of irrigation infrastructures?*

V. THEORETICAL FRAMEWORKS

To address the research questions, I draw from two frameworks: the Coupled Infrastructure Systems (CIS) framework and the Institutional Analysis and Development (IAD) framework. I use the CIS framework to systematically identify the key linkages and interactions among the hard and soft infrastructures within Tajikistan's irrigation systems. I then use the IAD framework to characterize the action situations (i.e., key interactions among individuals in a resources system that produces a given set of outcomes). These action situations form the basis my hypotheses. In this section, I provide an overview of the CIS and IAD frameworks and then introduce my hypotheses.

Coupled Infrastructure Systems (CIS) Framework

Anderies, Janssen, and Schlager (2016) developed the CIS framework to emphasize the importance of infrastructures in common pool resource systems (Anderies, Janssen, and Schlager 2016). The CIS framework is useful for systematically identifying the key interactions and functions of the components within an irrigation system. The framework was derived[4] from the Robustness Framework that elucidated linkages between resource users, resources, infrastructure providers, and physical (i.e., hard) and social (i.e., soft) infrastructures (Anderies, Janssen, and Ostrom 2004). More theoretically, the CIS framework characterizes the coupled nature of how infrastructures affect human interactions with one another and their surroundings (Anderies, Janssen, and Schlager 2016). These interactions can include developing rules for maintaining and managing infrastructures, as well as participating in irrigation infrastructure maintenance activities.

The CIS framework contains, at minimum four components: A) the resource, B) the resource users, C) the public infrastructure providers, and D) the public infrastructure (Figure 1). The links between the four components determines the relationships between resource users and public infrastructure providers, and their use and management of the resources and public infrastructure Each link characterizes an action situation, which refers to the same action situation from the IAD framework (Anderies, Janssen, and Schlager 2016, Anderies, Janssen, and Ostrom 2004). In recognition of the various forms that infrastructures can take, natural, social, human, soft human-made and hard human-made infrastructures are distributed across the system (Anderies, Janssen, and Schlager 2016). Hard infrastructure refers to the maintenance of the physical system, such as irrigation canals, and soft infrastructure as the governance system in places for managing a particular irrigation system (Anderies and Janssen 2013).

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[4] The origins of this Coupled Infrastructure Systems (CIS) framework has evolved from the Institutional Analysis and Development (IAD) (Kiser and Ostrom 2000), Robustness Framework (Anderies, Janssen, and Ostrom 2004), and the Framework for Analyzing Sustainability (i.e., the Social-Ecological Systems Framework) (Ostrom 2009, 2007). I abstain from delving too much into the theoretical evolution of these frameworks for studying the governance of common pool resources for this conference paper, especially since several scholars have already done so elsewhere (McGinnis 2011, Anderies, Janssen, and Schlager 2016, Ostrom 2011, McGinnis and Ostrom 2014, Anderies and Janssen 2013, Janssen and Anderies 2013).

For this paper, I have identified the configurations of the WUA governance mechanisms (i.e., soft infrastructure) within Tajikistan's irrigation systems. These mechanisms include collective choice arrangements, monitoring, and sanctions rules that characterize the interactions of water users with infrastructure providers, as well as with the physical irrigation infrastructure (Figure 1). In this model, water users are the farmers that appropriate water resources for agricultural production[5]. Irrigation infrastructure providers are the leaders of the WUAs, who work independently, as well as with the government of Tajikistan and international organizations, to maintain irrigation infrastructures. Irrigation infrastructures are the physical structures that allow for the appropriation of water resources.

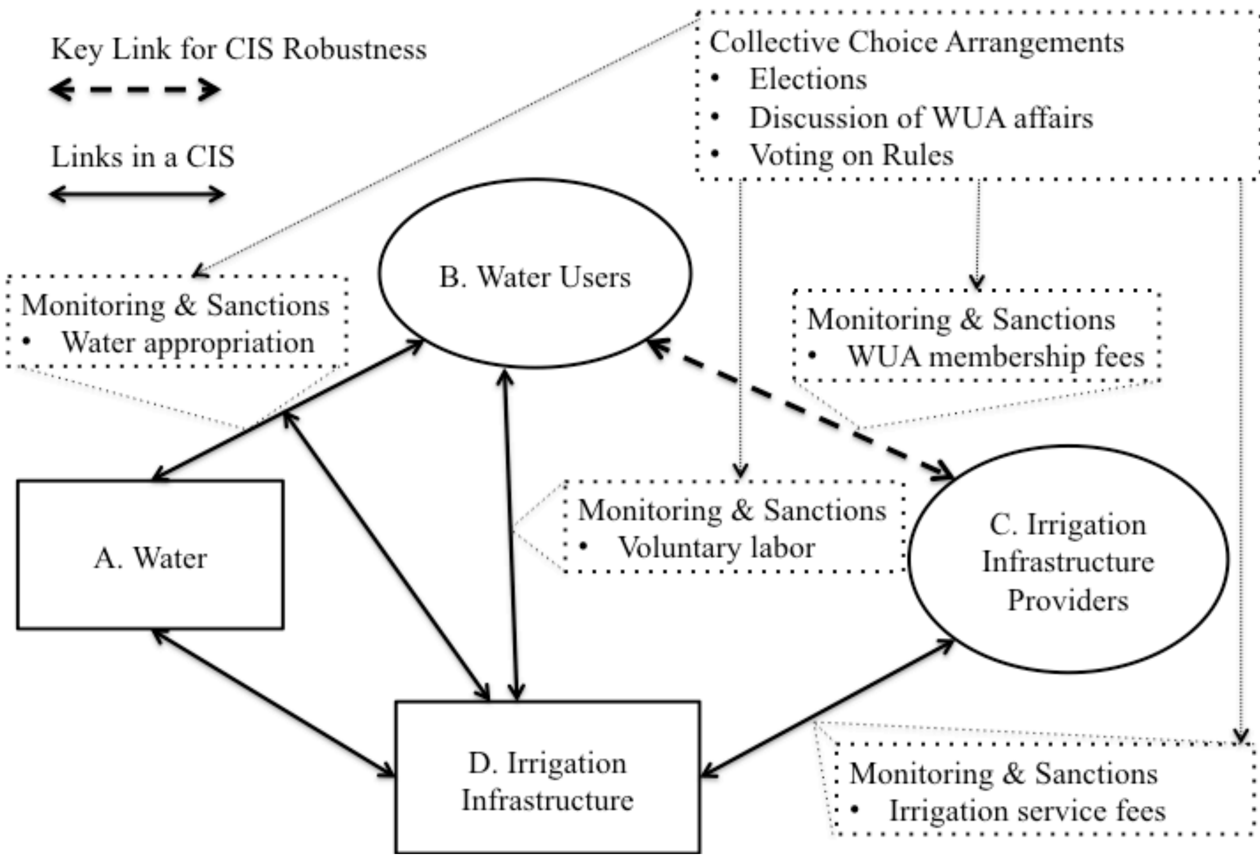

Figure 1. Conceptual framework of irrigation systems in Tajikistan, with a focus on water user engagement in collective choice arrangements, monitoring activities, and sanctions (i.e., referring to the dotted figures). This conceptual framework is modified from Anderies et al.'s framework for analyzing the robustness of common pool resource systems and the CIS Framework (Anderies, Janssen, and Ostrom 2004, Anderies and Janssen 2013, Anderies, Janssen, and Schlager 2016).

[5] For the purposes of this study, I do not consider users of domestic or drinking water. However, in several villages of Tajikistan, domestic and drinking water resources depend on the same public infrastructures that appropriate irrigation water. Additional WUAs have also been set up specifically for the management of domestic and drinking water. Further research on the governance of water-related infrastructures should examine the interrelationships between irrigation and domestic infrastructures.

Institutional Analysis and Development (IAD) Framework

Developed by Kiser and Ostrom (1982), the IAD framework is a conceptual map for examining how institutions affect the incentives individuals face and their resulting behavior (Ostrom 2005). In particular the framework has been used to study the governance of common pool resource systems (Ostrom 1990). The IAD framework emphasizes the actions and outcomes between individuals, especially within the context of policy and governance. The focal unit of analysis is an action situation, in which bounded rational individuals interact with each other and produce outcomes that affect individuals, and their communities and surroundings (Kiser and Ostrom 2000). Each individual, or sets of individuals, make decisions within an action situation to maximize benefits for themselves and the communities with which individuals most identify. Decisions are constrained by and made according to the social, biophysical, and cultural context of a given community (McGinnis 2011). The IAD framework also provides guidance on how to assess a natural resource policy issue by focusing on the rules in use, the characteristics of the resource, and the relevant attributes of a community (Ostrom 2011). For this paper, I focus on the rules in use (i.e., the working rules that water users follow in a WUA), and the characteristics of the resource (i.e., the conditions of irrigation infrastructures).

There are three levels of analysis in the IAD framework for assessing how rule processes take place: 1) operational, 2) collective, and 3) constitutional situations (or rules). Operational rules affect the day-to-day decisions and activities of appropriators. Collective-choice rules affect operational activities by determining who may participate and how participants are involved in a common pool resource system. Constitutional rules determined who may participate in the decision-making processes of the collective-choice rules (Ostrom 2005, Kiser and Ostrom 2000). The rules determines at one level of analysis constrain rules or activities pursued at another level of analysis. Outcomes of interactions between each level of analysis are therefore connected to one another (Ostrom 2011).

Within the IAD framework, I focus on two levels of analysis that are most directly relevant to the maintenance and management of irrigation infrastructures: 1) Collective choice and 2) operational situations. In order to incorporate the effects of collective choice and operational situations on infrastructure conditions, I include an additional outcome level of irrigation infrastructure conditions (Figure 2). Collective choice and operational levels can be analyzed together in the context of irrigation systems, whereby water users participation in activities directly affects irrigation infrastructure conditions (Anderies, Janssen, and Ostrom 2004). Though resource or infrastructure conditions are not included in the original IAD framework, I have included irrigation infrastructure conditions as a third level of analysis.

In relation to each of these levels, I have identified action situations that typically occur at each of these levels. At the level of collective choice situations, water users participate to varying degrees in collective choice arrangements, which are a form of collective choice rules (Tang 1991). Examples of action situations associated with collective choice rules include water user participation in the election of WUA leaders, discussion of issues that affect the WUA, and voting on decisions that affect the WUA's day-to-day operations and activities. Outcomes could include what forms of monitoring and sanctions the WUA could pursue to ensure water users comply with the rules of the WUA.

Operational situations (i.e., the next level of analysis) arise as a result of collective-choice rules. Monitoring and sanctions are forms of operational rules, which define how water users participate in a common pool resource system (Tang 1991). Examples of water user monitoring of irrigation infrastructures can include the payment irrigation service fees to cover the costs of maintenance and the participation in voluntary labor processes to repair or maintain infrastructures. Sanctions refer to the consequences water users face if they do not pay irrigation service fees or participate in maintenance activities. In Tajikistan, sanctions included warnings, fines, and stopping the flow of water resources to water users who do not abide by WUA rules. Sanctions and monitoring rules motivate water users to comply with WUA rules and participate in irrigation infrastructure maintenance activities. Compliance and engagement in irrigation maintenance would then theoretically lead to irrigation infrastructures in good condition.

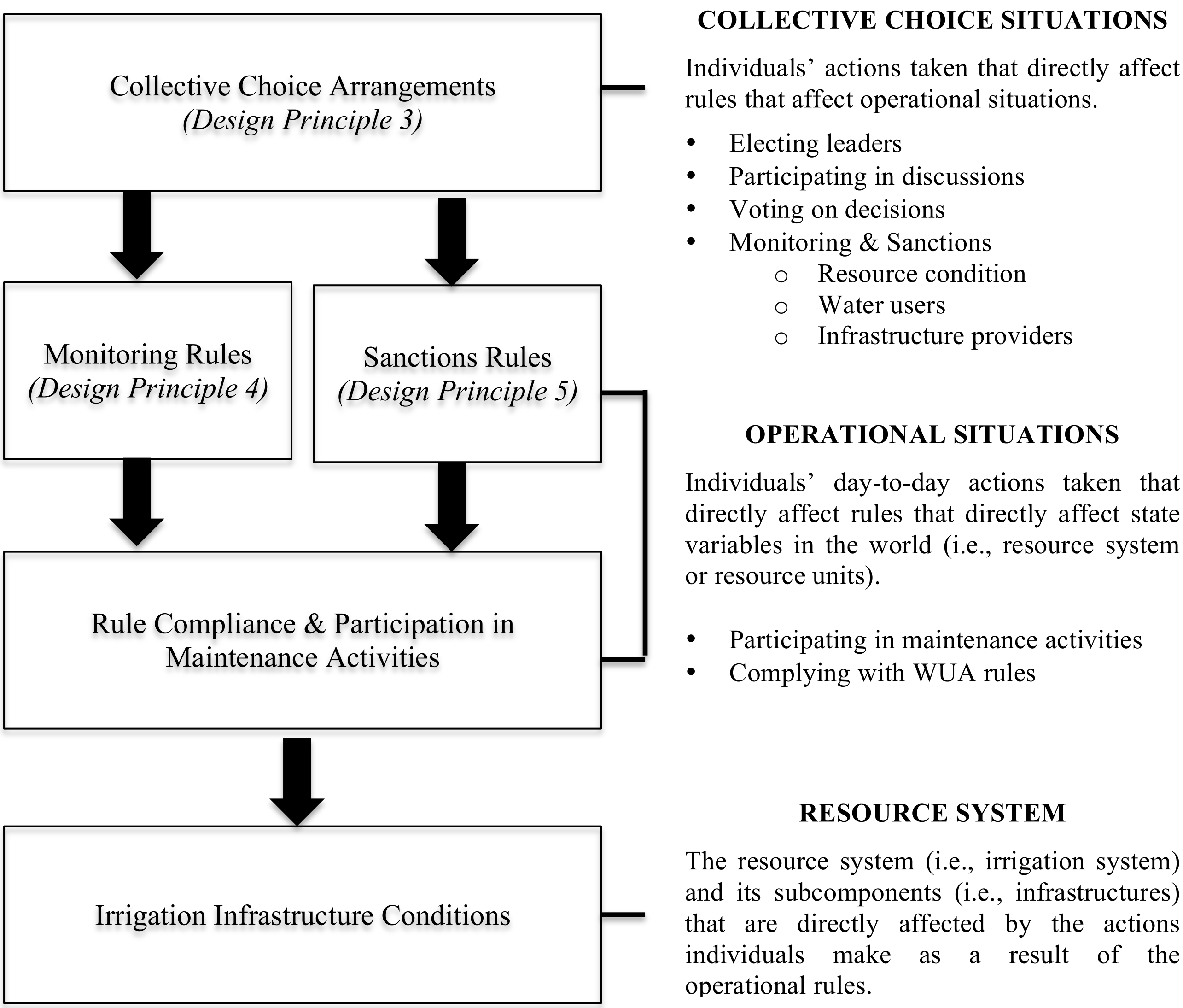

Figure 2. Conceptual model for analyzing the impacts of collective-choice arrangements, monitoring, and sanctions on irrigation infrastructure maintenance and conditions in Tajikistan (adapted from Kiser & Ostrom (1982) and Ostrom (2005)). Each arrow represents an action situation, from which a specified action influences an outcome at another level. The levels of analysis and outcomes contain constitutional, collective-choice and operational situations. Since this study focuses on how infrastructural resources are maintained and managed, I excluded constitutional situations and have instead included infrastructure conditions.

VI. HYPOTHESES

I formulated five hypotheses based on the CIS and IAD frameworks. Anderies et al. (2004, 2016) also recommend drawing from the design principles for governing common pool resources and the IAD framework for studying coupled infrastructure systems (Anderies, Janssen, and Schlager 2016, Anderies, Janssen, and Ostrom 2004). The CIS framework provides excellent guidance for identifying the component parts and key relationships between the components of a coupled infrastructure system. However, the IAD framework provides additional insights for how to operationalize the variables according to the action situations that occur between the component parts of the coupled infrastructure system. The directionality of my hypotheses is based off of action situations that occur at one level of analysis and corresponding outcomes at subsequent levels of analysis (Figure 2). The hypotheses and associated theoretical backgrounds are presented as follows:

Hypothesis 1

Collective-choice arrangements may allow for greater participation of local water users to make decisions regarding irrigation management that is most suitable to local conditions (Berkes 1989, Ostrom 1990, Agrawal and Gibson 1999, Baland and Platteau 2000, Berkes, Colding, and Folke 2000). This concept of collective choice arrangements has motivated the development WUA models globally, putting the focus on water user participation in the decision and rule-making to manage irrigation systems (Vermillion et al. 2005). In Tajikistan, the national government and international donors have advocated for the following collective choice arrangements in new WUA models: electing leadership of irrigation management structures, such the head of the WUA, and discussing and voting on issues pertaining to management of the irrigation system, such as budgets, infrastructure, maintenance, sanctions, and resolution of disputes[6]. Within these new WUA models, my first hypothesis is motivated by the question, how has water engagement in collective choice arrangements affected the presence of monitoring and sanctions rules?

> Hypothesis 1: *Water user engagement in collective choice arrangements of the WUA (i.e., electing leaders, discussing WUA issues, voting on WUA rules) is a positive predictor of the presence of monitoring and sanctioning rules (i.e., water users pay fees, collective irrigation infrastructure maintenance processes exist, sanctions are in place in the event WUA rules are not followed).*

Hypothesis 2

Participation in the development of rule enforcement procedures ensures greater compliance of rules (Olson 1971). Communication, such as discussion of rules and irrigation maintenance and management affairs, can encourage cooperation by eliciting preferences of group members, enhancing trust among members, activating social values and responsibility, and facilitating the creation of group identity (Ben-Ner and Putterman 2009, Messick and Brewer 1983). However, in Central Asia, scholars suggest that water users might not fully participate in collective choice arrangements as a result of the post-Soviet transition process and lack of coordination among water users (Dukhovny, Sorokin, and Stulina 2008, Moss and Hamidov 2016); it is therefore unclear how

[6] Lam, Steve & Lauren Schultze. May 27, 2010. USAID/CAR. Assessment of Water User Association Support Program (WUASP)

much rule compliance has occurred in irrigation systems under new post-Soviet WUA institutions. For this second hypothesis, I question how new WUA models for collective choice arrangements affect water user compliance of WUA rules, including the participation in irrigation infrastructure maintenance activities.

> Hypothesis 2: *Water user engagement in collective choice arrangements of the WUA (i.e., electing leaders, discussing WUA issues, voting on WUA rules) is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.*

Hypothesis 3

Monitoring activities can coordinate water user participation in the maintenance of irrigation infrastructures (Tang 1991). The following monitoring activities[7] are promoted in new WUA institutions in Tajikistan in order to improve the management and maintenance of irrigation infrastructures: 1) payment of WUA membership fees to cover the cost of WUA leadership salaries and overhead of WUA management operations, 2) payment of irrigation service fees to ensure regular and updated maintenance of canal systems, and 3) contributions of voluntary labor to provide regular and updated maintenances of infrastructures, such as cleaning canals, repairing leaks, preventing erosion of infrastructures, etc.

In the same way that payments in kind to leaders of irrigation systems hold leaders accountable to water users in traditional irrigation systems (Thurman 1999) payment of WUA membership fees may also incentivize WUA leaders to ensure that water users are properly appropriating water resources. Water user payment of irrigation service fees covers the cost of maintenance and repair of irrigation system, which allows for regular maintenance of irrigation infrastructures (Ostrom 1992). Irrigation service fee payments have also been known to incentivize water users to conserve water resources (Molle 2009), which can be a form of monitoring resource conditions. The main question in this third hypothesis concerns whether water users comply with rules as a result of the presence of monitors and monitoring rules.

> Hypothesis 3: *The presence of monitoring rules is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.*

Hypothesis 4

Sanctions, and preferably graduated sanctions, can be used to encourage resource users to comply with rules for managing a resource (Ostrom 1990). WUAs in Tajikistan have instituted a number sanctions so that water users can manage water resources properly. Some sanctions include warning water users if they are not following the rules, employing fines, not allowing rule violators to appropriate water, or appealing to economic courts or other external authority. Various conditional cooperation mechanisms, such as the social pressure to participate in collective labor processes, called *hashar*, and pay irrigation service fees, are also forms of sanctioning rules that can encourage rule compliance. The fourth hypothesis considers how sanctions motivate evidence

[7] Lam, Steve & Lauren Schultze. May 27, 2010. USAID/CAR. Assessment of Water User Association Support Program (WUASP)

for water user compliance of WUA rules, including the participation in collective irrigation infrastructure activities.

> Hypothesis 4: *The presence of sanctioning rules is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.*

Hypothesis 5

One proposition for improving irrigation infrastructures is to increase the participation of water users in irrigation infrastructure maintenance activities. Frequent water user participation in voluntary labor activities to maintain irrigation infrastructures contributes to regular and updated maintenance of canal systems (Ostrom 1992, Chambers 1977). Additional outcomes of participating in irrigation infrastructure maintenance may also contributes to lower instances of free riding and shirking behaviors (Vollan and Ostrom 2010, Rustagi, Engel, and Kosfeld 2010). The motivation for this fifth hypothesis questions whether water user rule compliance, including the participation in collective maintenance activities can contribute to better irrigation infrastructure conditions.

> Hypothesis 5: *Water user WUA rule compliance and participation in collective irrigation infrastructure maintenance activities is a positive predictor of irrigation infrastructure conditions.*

VII. METHODS

Study Site

My data collection took place across three study sites, located in key agricultural regions in Tajikistan (Figure 3, Table 1). These study sites were located along three 100km rural to urban gradients in three major watersheds – Amu Darya, Syr Darya, and Zerafshan. The three study sites were systematically selected to account for confounding factors that could arise from recent historical events (i.e., Tajikistan Civil War from 1992-1997), sociocultural contexts, international donor influence on WUA development, and the biophysical dimensions of a particular location (Table 1).

A structured interview survey was used to collect data about water users in Tajikistan at the unit of the WUA. The targeted survey population was leaders of WUAs, such as the chairman, accountant or *mirob* of the WUA. In the event that the primary leader of the WUA was unavailable, those most knowledgeable about WUA operations were approached to participate in the survey.

Surveys were conducted at the unit of the WUA (n=160 WUA surveys). I sampled all WUAs within districts that were located in the three study sites. Government permission to conduct the surveys and contact information for WUA leaders were obtained from the regional offices of the Ministry of Water and Energy Resources of Tajikistan. At the time of fieldwork in 2016, 409 WUAs were registered with the Agency for Land Reclamation and Irrigation of Tajikistan (ALRI). Of the 178 registered WUAs located in the study site's districts, 160 agreed to participate in the survey, which resulted in a response rate of 90 percent. One should be cautioned regarding the official numbers of registered WUAs due to the transient nature of some WUAs. One district, for example, established over 20 WUAs in the 2000's and according to ALRI had 5

WUAs in 2016. However, when we visited this district, only one WUA was actually functioning. Some additional WUAs were still undergoing the registration process and may not define themselves WUAs according to the WUA laws of Tajikistan. Thus, official WUA numbers are questionable.

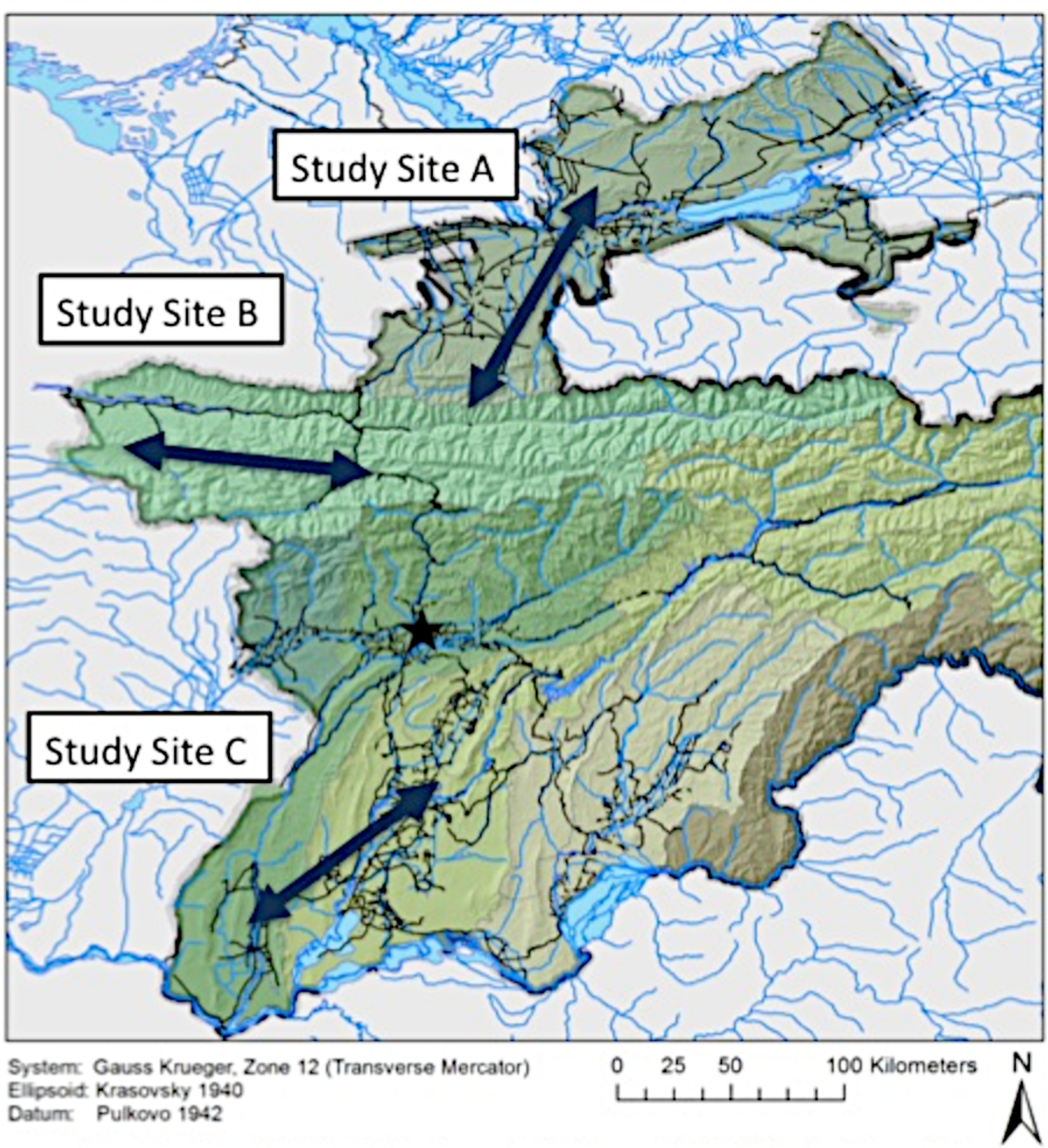

Figure 3. Study sites in Tajikistan

Table 1. Study site characteristics

	A. Northern Site	B. Western Site	C. Southern Site
Extent	Khujand (163,000 pop.) to Basmanda (8,000 pop.)	Panjakent (35,000 pop.) to Ayni (12,000 pop.)	Qurghonteppa (101,000 pop.) to Shahrtuz (13,000) pop.)
Watershed	Syr Darya	Syr Darya/Zarafshan	Vakhsh/Kofarnihon
Topography	Plains, foothills, and mountainous valleys	Mountainous valleys	Flat valleys, Plains
Agricultural Crops	Cotton, wheat, melons, potatoes	Wheat, barley, fruit and nut orchards	Cotton, wheat
Recent history	Minimal influence from the Tajik civil war	Minimal to no influence from the Tajik civil war	Heavily impacted by the Tajik civil war
International donor influence on WUAs	Minimal influence, Helvetas, Swiss Agency for Development and Cooperation	German Agro Action/Welthungerhilfe, 2005 to present	USAID, World Bank, Asian Development Bank, 2000 to present
Ethnic Populations	Tajik populations in Khujand and an fairly even distribution of Tajik and Uzbek communities	Tajik and Uzbek to the east, interspersed with Tajik and Yaghnobi populations until Ayni	Tajik in the north, close to Qurgonteppa and Uzbek & Turkic populations in the south, closer to Shahrtuz

Survey Instrument

I designed a survey instrument with a series of questions to operationalize indicators the following six concepts that correspond to the hypotheses: 1) collective choice arrangements, 2) monitoring, 3) sanctions, 4) rule compliance, 5) water user participation in maintenance activities, and 6) irrigation infrastructure conditions. The majority of data is in an ordinal, Likert type format. Attitudinal questions ranged from “strongly agree” to “strongly disagree” for specific statements regarding monitoring, sanctions, rule compliance, and irrigation infrastructure conditions. Other examples of ordered categories that were incorporated into the survey of WUA leaders in Tajikistan include “nearly all (90-100%)” to “hardly any (0-10%)” for assessing how many water users partake in defined activities, or “every week” to “never” to assess the frequency of certain activities. Similarly, WUA leaders were asked to rank the quality of irrigation infrastructures on a scale of one to five, and also determine how likely infrastructures were likely to fail on a scale of one to five. One variable for whether maintenance is required by the WUA is in a binary format (i.e., 1 is yes, 0 is no). Some ordinal and binary data scales were recoded so as to make the most intuitive sense in terms of analysis. Additional open-ended qualitative answers about the types of sanctions and monitors present in the WUA were coded to determine the number of different sanctions and monitors were in place to ensure rule compliance for appropriating water, paying irrigation service fees, and participating in maintenance activities (Table 2).

Table 2. Structured interview questions for key variables

Collective Choice Arrangements		
Election Participation	How many farmers are involved in selecting water user group leaders?	Ordinal
Discussion Participation	How many water users participate in discussion about WUA decisions?	Ordinal
Discussion Frequency	How often did farmers participate in decision-making?	Ordinal
Decision Participation	How many water users vote on WUA decisions?	Ordinal
Monitoring		
Monitor Water Count	Number of different monitor types associated with water appropriation.	Counts
Monitor Pay Count	Number of different monitor types associated with irrigation service fee payments.	Counts
Maintenance Requirement	Is participation in maintenance activities a requirement of the WUA?	Binary
Sanctions		
Sanctions Water Count	Number of different sanction types associated with water appropriation.	Counts
Sanctions Pay Count	Number of different sanction types associated with irrigation service fee payments.	Counts
Sanctions Maintenance Count	Number of different sanction types associated with participation in maintenance activities.	Counts
Consequences Water	There are consequences (punishments or penalties) for farmers who do not manage water properly.	Ordinal
Consequences Rules	There are consequences (punishments or penalties) for farmers if they do not follow the rules of the WUA.	Ordinal
Rule Compliance		
Farmer Compliance	About how many farmers comply with all the expectations and requirements of the water user group?	Ordinal
Compliance Water	Most all farmers in your village water their crops when they are supposed to.	Ordinal
Compliance Pay	Most all farmers in your village pay water fees when they are supposed to (on time).	Ordinal
Compliance Water Equity	Most all farmers in your village use their fair share of water.	Ordinal
Compliance Support WUA	Most all farmers in your WUA provide the required support to the WUA.	Ordinal
Compliance Water Management	It is easy to see that farmers in the water user group are managing water properly.	Ordinal
Maintenance		
Maintenance	In the past year, did water users participate in the maintenance or repair of the irrigation infrastructure?	Binary
Maintenance Participation	In the past year, how many farmers from the WUA participated in maintenance activities?	Ordinal
Maintenance Frequency	In the past year, how often did farmers participate in maintenance activities	Ordinal
Irrigation Infrastructure Conditions		
Water Access	How accessible are water resources for agricultural production in your village compared to neighboring communities?	Ordinal
Water Access Trend	In the past three years, has access to water for agricultural production become easier or more difficult?	Ordinal
Water Quality	How would you rate the quality of water resources for agriculture production in your village compared to neighboring communities?	Ordinal
Water Quality Trend	In the past 3 years, has water quality for agricultural production become better or worse?	Ordinal
Cultivate	Farmers have enough water to properly cultivate their crops.	Ordinal
Regular	Water from irrigation canals is regularly available to water crops.	Ordinal
Infrastructure Quality	On a scale of 1 to 5 with 5 being the highest, how would you rate the quality of your village's irrigation infrastructure?	Ordinal
Infrastructure Fail	On a scale of 1 to 5 with 5 being the most frequent, how often does irrigation infrastructure in your WUA's service area fail?	Ordinal

Data Collection Strategy

The survey was conducted in a structured interview format with leaders of the WUAs; trained enumerators collected and recorded specified sets of data from the survey respondents (i.e. WUA leaders). The structured interview approach allows for the questions and responses of the survey respondents to be standardized and the differences between various interviews to be minimized. Statistical methods can then be used to test for the relationships between variables that were obtained from standardized responses (Bryman 2012). The structured interview format was preferable for conducting research in rural Tajikistan due to limited literacy in reading formal documentation among some agricultural-based populations, as well as the range of linguistic variation in regional Tajik dialects and use of varying levels of Uzbek, Turkic, and Russian languages. In order to ensure accuracy of the intent and meanings of survey questions across languages, the survey instrument was translated into Tajik and Uzbek languages by one translator, and then back translated into English by a second translator. The survey was conducted in Tajik and Uzbek languages. Enumerators proficient in the local languages were trained in structured interviewing techniques and administered the survey using an electronic tablet with CSPro survey software.

Analysis

Ordered logistic regressions (i.e., ordered logit models) were run for each of the independent indicators representing the response and explanatory variables. In addition, one probit regression was run for the one binary response variable (i.e., whether or not water user participation in maintenance is required by the WUA). Depending on the levels where the action situation of interest and its resulting outcomes occurs, variables in this study are used as both response and explanatory variables (see IAD Framework, Figure 2). For example, in hypothesis one, collective choice arrangements are explanatory variables that predict the response variables of monitoring and sanctions. In hypotheses three and four, monitoring and sanctions are explanatory variables that predict the response variables of rule compliance and maintenance. In hypothesis five, rule compliance and maintenance are then explanatory variables for the prediction of the variables associated with irrigation infrastructure conditions.

Ordered logistic regression is an appropriate model for assessing the relationships between variables that are categorical on a five to seven point ordinal scale (Liao 1994, Agresti 2002). Since my data are in such ordered Likert type formats, ordered logistic regression is the appropriate form of analysis. Classical regression models, such as ordinary least squares and linear regression, is not useful for ordinal data since the dependent variable may not occur at equal intervals. In addition, ordinal data does not often meet the normality assumptions that are required for standard regression techniques.

In an ordered regression model, the values dependent variables are a measured representation of a latent variable that is of key interest to a given research question. The measured variant is categorically grouped representation of the unobserved variable. For example, to determine irrigation infrastructure quality, WUA leaders indicated their level of agreement on whether water from irrigation canals is regularly available to water crops. The latent variable of interest is whether irrigation canals are in good enough condition to regularly appropriate water to farmers. The measured variant is the WUA leaders' perceptions on a ranked scale from strongly disagree to strongly agree.

The regression models were run with missing observations. If missing values were excluded using list-wise deletion, more than three-quarters of the observations would be eliminated from the analysis. The number of observations included in the regression models is presented with in the results tables.

Each model was also tested for the parallel regression assumption (i.e., proportional odds or parallel lines assumption). The parallel regression assumption assumes that the effects of the independent variables are invariant to the thresholds of the model. With all other variables held constant, the beta coefficients of the independent variable should be constant across each ordered category from the response variable (Liao 1994). A Brant test can be used to test whether a model is in violation of the parallel regression assumption (Brant 1990). I therefore ran the brant function in R for each regression model to determine whether the assumption holds. Of the 39 ordinal logistic regressions that were run, 11 did not meet the parallel regression assumption. For models that do not meet the parallel regression assumption, it is possible to pursue other forms of generalized linear modeling to examine the relationships between variables.

VIII. DATA

Table 3. Descriptive statistics for key variables

	Obs.	*Mean*	*Median*	*Std. Dev.*	*Min*	*Max*	*Answer*
Collective Choice Arrangements							
Election Participation	153	1.8105	2	0.6361	1	5	1 - Nearly All (90-100%) - 5 - Hardly Any (0-10%)
Discussion Participation	148	1.8919	2	0.739	1	5	1 - Nearly All (90-100%) - 5 - Hardly Any (0-10%)
Discussion Frequency	151	3.5762	4	1.1913	1	6	1-Once per week - 6-Never
Decision Participation	147	1.7959	2	0.6918	1	4	1 - Nearly All (90-100%) - 5 - Hardly Any (0-10%)
Monitoring							
Monitor Water Count	160	0.9688	1	0.587	0	2	Count
Monitor Pay Count	160	1.0688	1	0.613	0	4	Count
Maintenance Requirement	143	0.6503	1	0.7358	0	1	Yes-1, No-0
Sanctions							
Sanctions Water Count	160	0.525	0	0.5822	0	2	Count
Sanctions Pay Count	160	0.5938	0	0.5822	0	2	Count
Sanctions Maintenance Count	91	0.2198	0	0.4899	0	2	Count
Consequences Water	152	2.4934	2	0.9207	1	5	1-Strongly Agree - 5-Strongly Disagree
Consequences Rules	153	2.4967	2	0.9114	1	5	1-Strongly Agree - 5-Strongly Disagree
Rule Compliance							
Farmer Compliance	156	1.8141	2	0.7256	1	4	1 - Nearly All (90-100%) - 5 - Hardly Any (0-10%)
Compliance Water	159	1.9556	2	0.7492	1	5	1-Strongly Agree - 5-Strongly Disagree
Compliance Pay	157	2.2484	2	0.9034	1	5	1-Strongly Agree - 5-Strongly Disagree
Compliance Water Equity	156	2.1667	2	0.769	1	5	1-Strongly Agree - 5-Strongly Disagree
Compliance Support WUA	156	2.1154	2	0.553	1	5	1-Strongly Agree - 5-Strongly Disagree
Compliance Water Management	158	1.9367	2	0.572	1	4	1-Strongly Agree - 5-Strongly Disagree
Maintenance							
Maintenance	145	0.6897	1	0.4642	0	1	Yes-1, No-0
Maintenance Participation	145	3.5034	3	1.8262	1	6	1 - Nearly All (90-100%) – 5 - Hardly Any (0-10%)
Maintenance Frequency	145	4.7448	5	1.0915	1	6	1-Once per week - 6-Never
Irrigation Infrastructure Conditions							
Water Access	156	2.7692	3	1.1576	1	5	1-much more accessible - 5-much less accessible
Water Access Trend	160	2.5875	2	1.0364	1	5	1-much more easier - 5-much more difficult
Water Quality	159	2.4277	2	0.9377	1	5	1-much better quality - 5-much worse quality
Water Quality Trend	159	2.5723	2	0.8892	1	5	1-much better, 5-much worse
Cultivate	160	2.6938	2	1.1601	1	5	1-Strongly Agree - 5-Strongly Disagree
Regular	160	2.7688	2	1.1667	1	5	1-Strongly Agree - 5-Strongly Disagree
Infrastructure Quality	159	2.5409	2	0.8093	1	5	1-very good quality - 5-very bad quality
Infrastructure Fail	159	3	3	0.9278	1	5	1-all the time - 5-never

IX. RESULTS

The results are summarized below with respect to each of the hypotheses. In this section, coefficients that were statistically significant at the 0.10, 0.05, and 0.001 alpha levels were interpreted using proportional odds ratios, or odds ratios (OR). The interpretation for OR is that while holding all other variables constant in the model, as the dependent variable moves one unit, the odds of moving along the independent ordinal scale is multiplied by the odds ratio. Rather than interpreting every single significant result, I focused on elucidating significant trends across all ordinal regression models.

Hypothesis 1

The first hypothesis states that water user engagement in collective choice arrangements of the WUA is a positive predictor of the presence of monitoring and sanctioning rules.

Water user engagement in collective choice arrangements had greater evidence for statistically significant associations with sanctioning rules than with monitoring rules (Table 4). Thus, the notion that collective choice arrangements are positively associated with monitoring rules was not well supported. There were no significant relationships between collective choice arrangements and monitoring, except for the frequency of water user discussions as an explanatory variable for whether participation in maintenance activities is required by the WUA. WUAs were more likely to have a maintenance requirement if water users frequently participated in discussion.

Of particular note, the frequency of water user participation in discussion was statistically significant across all regression models for sanctions. These results suggest that greater frequencies of participating in discussions on issues that concern the WUA is positively associated with the use of sanctions in the WUA. Therefore, the idea that collective choice arrangements are positively associated with sanctioning rules was moderately supported. Specifically, greater water user participation in voting on decisions that affect the WUA was positively associated with the presence of the consequences to water users if they do not use water properly or do not follow the rules of the WUA. However, greater participation in the elections of WUA leaders had the opposite result; greater water user participation in elections was negatively associated with the existence of consequences.

Table 4. Collective choice arrangements as a predictor of monitoring and sanctions.

	Monitor Water Count	Monitor Water Pay	Maintenance Requirement	Sanctions Water Count	Sanctions Pay Count	Sanctions Maintenance Count	Consequences Water	Consequences Rules
	ordered logistic (1)	*ordered logistic* (2)	*probit* (3)	*ordered logistic* (1)	*ordered logistic* (2)	*ordered logistic* (3)	*ordered logistic* (4)	*ordered logistic* (5)
Election Participation	-0.321	-0.381	-0.449	0.572	-0.032	0.406	-0.956**	-1.106***
	(0.413)	(0.418)	(0.293)	(0.413)	(0.399)	(1.275)	(0.416)	(0.415)
Discussion Participation	-0.135	-0.202	0.143	-0.296	0.013	-0.951	0.075	0.107
	(0.309)	(0.308)	(0.228)	(0.326)	(0.313)	(1.183)	(0.315)	(0.309)
Discussion Frequency	0.199	0.056	0.202*	0.384**	0.293*	1.734***	0.353**	0.418***
	(0.147)	(0.144)	(0.111)	(0.151)	(0.152)	(0.393)	(0.158)	(0.160)
Decision Participation	0.459	0.381	-0.428	-0.230	0.331	0.401	1.464***	1.494***
	(0.407)	(0.408)	(0.285)	(0.400)	(0.391)	(1.251)	(0.424)	(0.419)
Constant			2.792**					
			(1.197)					
Observations	142	142	130	142	142	87	140	140
Brant Test	Yes	Yes		Yes	Yes	Yes	Yes	No
Residual Deviance	248	269		228	241	57	283	291
Akaike Inf. Crit.	260	285	160	240	253	69	299	307
Log Likelihood			-75					

Notes: *p<0.1; **p<0.05; ***p<0.01 are associated with the beta coefficients. Robust standard errors are in parentheses. The Brant Test determines whether the proportional odds assumption holds, which assumes proportional distances between each category of the outcome.

Hypothesis 2

The second hypothesis states that Water user engagement in collective choice arrangements of the WUA is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.

With the exception of water user participation in the elections of WUA leaders, the hypothesis that water user engagement in collective choice arrangements is positively associated with rule compliance and maintenance is well supported (Table 5). Water user participation in voting on decisions that affected the WUA was statistically significant (p<0.001) across all models for rule compliance. Theoretically, the ability of water users to partake in the decision-making of the WUA would allow for greater buy in to WUA rules and procedures (Olson 1971). Yet, greater levels of water user participation in the elections of WUA leaders were negatively associated with rule compliance. Greater levels of water user participation in the discussion of WUA issues was only positively associated with compliance on paying irrigation service fees, using a fair share of water, and providing the necessary support to the WUA. However, it is unclear as to why participation in discussion was statistically significant for these particular categories.

The notion that collective choice arrangements are positively associated with maintenance activities was not well supported. Discussion frequencies was negatively associated with water user participation in maintenance activities (p<0.10), but positively associated with maintenance frequency (p<0.001). It would make sense for discussion and maintenance frequencies to have a positive association, since maintenance activities would require greater instances of interactions among water users. However, it is unclear why greater instances of discussion frequency are associated with fewer instances of participation in maintenance activities. Water user participation in voting on WUA issues was positively associated with participation in maintenance activities (p<0.001), but negatively associated with maintenance frequency (p<0.05). Electing WUA leaders and participation levels in discussions were not statistically significantly associated with maintenance.

Table 5. Collective choice arrangements as a predictor of rule compliance and maintenance activities.

	Farmer Compliance	Compliance Water	Compliance Pay	Compliance Water Equity	Compliance Support WUA	Compliance Water Manageme nt	Maintenance Participation	Maintenance Frequency
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)
Election Participation	-0.138	-1.687***	-0.748*	-0.895**	-1.150***	-0.866*	0.695	-0.258
	(0.421)	(0.451)	(0.412)	(0.432)	(0.429)	(0.453)	(0.429)	(0.405)
Discussion Participation	-0.227	0.492	0.621**	0.707**	0.535*	0.462	0.234	0.158
	(0.330)	(0.330)	(0.292)	(0.305)	(0.321)	(0.332)	(0.315)	(0.313)
Discussion Frequency	-0.088	0.229	0.248	0.179	0.515***	-0.031	-0.253*	0.655***
	(0.139)	(0.155)	(0.152)	(0.156)	(0.157)	(0.158)	(0.139)	(0.143)
Decision Participation	1.405***	1.574***	1.481***	1.374***	1.802***	1.096***	1.327***	-0.834**
	(0.401)	(0.423)	(0.408)	(0.413)	(0.439)	(0.425)	(0.400)	(0.372)
Observations	141	142	140	140	141	142	133	132
Brant Test	No	Yes	Yes	Yes	Yes	No	No	No
Residual Deviance	272	236	289	250	253	216	313	336
Akaike Inf. Crit.	286	252	305	266	269	230	331	354

Notes: *p<0.1; **p<0.05; ***p<0.01 are associated with the beta coefficients. Robust standard errors are in parentheses. The Brant Test determines whether the proportional odds assumption holds, which assumes proportional distances between each category of the outcome.

Hypothesis 3

The third hypothesis states that the presence of monitoring rules is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.

The presence of monitoring rules was positively associated with water user compliance was not well supported and there were no statistically significant trends across all variables (Table 6). Instead, the number of different types of water monitors was negatively associated with water user compliance on watering their crops when they are supposed to (p<0.05). This does not make intuitive sense, as one would expect water users to water their crops when they are supposed to with greater numbers of monitors. The numbers of monitors overseeing the payment of irrigation service fees was positively associated with water users providing the required support to the WUA (p<0.001). Finally, maintenance as a requirement of the WUA was negatively associated with the number of water users who comply with WUA rules (0.001). It is very possible that the monitoring covariates used in this study are poor indicators of monitoring rules. Further research could examine how different types of monitors affect rule compliance. For example, if the monitors who are traditional *mirobs* might influence the outcomes in rule compliance in different ways (as opposed to elected or externally appointed WUA leaders).

The idea that the presence of monitoring rules is positively associated with water maintenance activities was also not well supported. The presence of monitors has no association with maintenance activities. Even though WUA maintenance requirements was positively associated with the frequency of maintenance activities (p<0.001), but negatively associated with water use participation in maintenance activities.

Table 6. Monitoring as a predictor of rule compliance and participation in maintenance activities.

	Farmer Compliance (1)	Compliance Water (2)	Compliance Pay (3)	Compliance Water Equity (4)	Compliance Support WUA (5)	Compliance Water Management (6)	Maintenance Participation (1)	Maintenance Frequency (2)
Monitor Water Count	-0.103	-0.711**	-0.431	-0.451	0.015	0.388	0.053	0.296
	(0.294)	(0.316)	(0.291)	(0.305)	(0.295)	(0.326)	(0.325)	(0.319)
Monitor Pay Count	0.058	0.174	0.189	0.307	0.738***	-0.051	-0.006	0.109
	(0.256)	(0.275)	(0.257)	(0.271)	(0.267)	(0.286)	(0.317)	(0.319)
Maintenance Requirement (0/1)	-1.196***	0.572	-0.480	-0.467	0.404	-0.274	-5.302***	5.391***
	(0.355)	(0.374)	(0.343)	(0.357)	(0.346)	(0.360)	(0.652)	(0.697)
Observations	142	142	141	141	140	141	143	143
Brant Test	Yes	No	Yes	No	Yes	Yes	Yes	No
Residual Deviance	287	258	327	295	281	250	272	278
Akaike Inf. Crit.	299	272	341	309	295	262	288	294

Notes: *p<0.1; **p<0.05; ***p<0.01 are associated with the beta coefficients. Robust standard errors are in parentheses. The Brant Test determines whether the proportional odds assumption holds, which assumes proportional distances between each category of the outcome.

Hypothesis 4

The fourth hypothesis states that the presence of sanctioning rules is a positive predictor of water user compliance of WUA rules and participation in collective irrigation infrastructure maintenance activities.

Similar to hypothesis three regarding monitoring rules, the presence of sanctioning rules being positively associated with water user compliance was also not well supported. Few sanctions variables were associated with rule compliance (Table 7). The number of sanctions was negatively associated with water user compliance on paying irrigation service fees (p<0.05). On the other hand, the number of sanctions for participating in maintenance activities was positively associated with water user compliance on paying irrigation service fees (p<0.10). It is unclear as to why sanctions other than ones used specifically for paying irrigation service fees are associated irrigation service fee payment. Only the increasing agreement that there are consequences for water users who do not user their water properly was positively associated with all compliance categories, which suggests that the perception of sanctions existing is related to rule compliance.

The idea that the presence of sanctioning rules is positively associated with water maintenance activities was also not well supported. Indicators for sanctions had no association with the frequency of maintenance activities. Consequences specific to water use was positively associated with water user participation in maintenance activities (p<0.001). Yet, consequences specific to following the rules of the WUA were negatively associated with maintenance participation (p<0.05). Indicators for the sanctions covariates, similar to the monitoring covariates, should be examined further.

Table 7. Sanctions as a predictor of rule compliance and participation in maintenance activities.

	Farmer Compliance (1)	Compliance Water (2)	Compliance Pay (3)	Compliance Water Equity (4)	Compliance Support WUA (5)	Compliance Water Management (6)	Maintenance Participation (1)	Maintenance Frequency (2)
Sanctions Water Count	-0.224	-0.726	-0.836**	-0.197	-0.018	-0.349	-0.255	0.330
	(0.424)	(0.461)	(0.426)	(0.425)	(0.414)	(0.435)	(0.445)	(0.444)
Sanctions Pay Count	-0.362	-0.245	0.179	0.027	0.191	-0.230	0.483	-0.336
	(0.403)	(0.413)	(0.396)	(0.403)	(0.387)	(0.396)	(0.400)	(0.390)
Sanctions Maintenance Count	0.453	0.054	0.888*	0.159	-0.259	-0.176	0.557	0.122
	(0.469)	(0.453)	(0.480)	(0.476)	(0.428)	(0.433)	(0.460)	(0.425)
Consequences Water	0.677*	0.841**	0.837**	0.564	1.030***	0.700*	1.414***	-0.539
	(0.378)	(0.392)	(0.372)	(0.378)	(0.374)	(0.373)	(0.391)	(0.367)
Consequences Rules	-0.131	0.001	-0.005	0.096	0.024	0.074	-0.832**	0.394
	(0.392)	(0.400)	(0.382)	(0.391)	(0.383)	(0.385)	(0.389)	(0.385)
Observations	90	91	89	89	91	91	91	91
Brant Test	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Residual Deviance	183	165	213	193	187	168	183	204
Akaike Inf. Crit.	199	183	231	211	205	184	203	224

Hypothesis 5

Hypothesis five states that water user WUA rule compliance and participation in collective irrigation infrastructure maintenance activities is a positive predictor of irrigation infrastructure conditions.

The notion that water user compliance of the WUA rules is positively associated with irrigation infrastructure performance was moderately supported, though only three rule compliance covariates indicated any statistically significant relationship with irrigation infrastructure conditions. Greater levels of water user compliance were particularly positively associated with better water quality ($p<0.05$) and irrigation infrastructures being less likely to fail ($p<0.05$). Water compliance with regards to water use were positively associated with several covariates for irrigation infrastructure conditions: water quality ($p<0.05$), water quality trends ($p<0.05$), having enough water to cultivate land ($p<0.05$), having a regular supply of water ($p<0.05$), infrastructures in good condition ($p<0.001$), and infrastructures that are less likely to fail ($p<0.05$). The ability to see water users managing water properly was also positively associated with several covariates for irrigation infrastructure conditions: the ease of water accessibility ($p<0.001$), water accessibility trends ($p<0.10$), having enough water to cultivate land ($p<0.001$), and having a regular supply of water ($p<0.001$).

The idea that water user compliance of the WUA rules is positively associated with irrigation infrastructure performance was not well supported. The dummy binary variable, whether maintenance was a requirement of the WUA was positively associated with water accessibility trends ($p<0.10$), but negatively associated with irrigation infrastructures being less likely to fail. Except for water accessibility, the frequency of maintenance activities was negatively associated with all covariates for irrigation infrastructure conditions. These results suggest that greater instances of maintenance activities over the course of the year lead to poorer conditions of irrigation systems. This is counterintuitive to the argument that frequent water user participation in voluntary labor activities to maintain irrigation infrastructures contributes to regular and updated maintenance of canal systems (Ostrom 1992, Chambers 1977).

Table 8. Rule compliance and maintenance activities as a predictor of irrigation infrastructure conditions.

	Water Access (1)	Water Access Trend (2)	Water Quality (3)	Water Quality Trend (4)	Cultivate (5)	Regular (6)	Infrastructure Quality (7)	Infrastructure Fail (8)
Farmer Compliance	0.167	0.337	0.607**	0.102	0.074	-0.157	0.100	0.617**
	(0.291)	(0.287)	(0.308)	(0.301)	(0.284)	(0.281)	(0.313)	(0.287)
Compliance Water	0.323	0.098	0.707**	0.591**	0.645**	0.716**	1.085***	0.666**
	(0.282)	(0.266)	(0.287)	(0.264)	(0.287)	(0.290)	(0.309)	(0.297)
Compliance Pay	-0.104	0.211	0.291	0.239	0.059	0.431	0.171	0.208
	(0.294)	(0.323)	(0.315)	(0.291)	(0.333)	(0.304)	(0.336)	(0.312)
Compliance Water Equity	0.019	-0.062	0.019	0.081	-0.085	-0.362	-0.105	-0.314
	(0.348)	(0.375)	(0.364)	(0.358)	(0.380)	(0.364)	(0.399)	(0.380)
Compliance Support WUA	-0.134	-0.224	-0.136	-0.063	0.232	-0.199	-0.281	-0.411
	(0.263)	(0.283)	(0.278)	(0.290)	(0.273)	(0.266)	(0.310)	(0.280)
Compliance Water Management	1.194***	0.657*	0.390	0.244	1.128***	1.148***	0.556	-0.149
	(0.357)	(0.341)	(0.347)	(0.349)	(0.362)	(0.362)	(0.386)	(0.373)
Maintenance (0/1)	0.441	1.473*	0.806	0.381	0.652	1.792**	0.554	-2.456***
	(0.794)	(0.826)	(0.868)	(0.853)	(0.848)	(0.850)	(0.942)	(0.884)
Maintenance Participation	0.325	-0.442	-0.309	-0.436	-0.435	-0.004	0.270	-0.190
	(0.259)	(0.274)	(0.291)	(0.282)	(0.272)	(0.264)	(0.303)	(0.279)
Maintenance Frequency	0.108	-0.820***	-0.579**	-0.564**	-0.659**	-0.606**	-1.062***	-0.445*
	(0.251)	(0.253)	(0.257)	(0.246)	(0.275)	(0.267)	(0.293)	(0.246)
Observations	136	140	139	140	140	140	140	140
Brant Test	No	Yes	Yes	Yes	No	No	Yes	Yes
Residual Deviance	379	374	326	325	350	355	253	300
Akaike Inf. Crit.	405	390	352	351	376	381	279	326

Notes: *p<0.1; **p<0.05; ***p<0.01 are associated with the beta coefficients. Robust standard errors are in parentheses. The Brant Test determines whether the proportional odds assumption holds, which assumes proportional distances between each category of the outcome.

X. DISCUSSION & CONCLUSIONS

The intention of this paper is to examine irrigation infrastructure governance as an emergent feature of irrigation infrastructure systems and identify the key institutional linkages that ultimately contribute to irrigation infrastructure conditions. The research outcomes span across three broad topics. First, the preliminary results offer insights as to how WUA institutions in Tajikistan are maintaining and managing infrastructures. Second, findings suggest that the proposed hierarchical process of IAD framework may not be so clearly sequential. Finally, a number of methodological considerations can be made regarding approaches for studying the governance of public infrastructure through the lens of a coupled infrastructure system. These three outcomes are discussed as follows.

First, findings provide some insights into how WUAs in Tajikistan maintain irrigation infrastructures in order to improve overall agricultural productivity. All forms of collective choice arrangements were minimally relevant for monitoring rules. The frequencies at which water users participate in discussions on issues that affect the WUAs were most critical in determining the presence of sanctions, yet had very minimal association with water user rule compliance. Instead, water user compliance across all compliance indicators were most evident with greater levels of water user participation in voting on decisions that affect the rules of the WUA, but less evident with the frequency of discussions. As opposed to monitoring, the frequency of water user participation in the discussions of the WUA was important for sanctions.

The presence of monitoring and sanctions rules were poor predictors to water user rule compliance. Instead, water user engagement in collective choice arrangements was a greater predictor of rule compliance. Specific to irrigation infrastructure conditions, water user compliance on rules related to water management was a better predictor for the conditions compared to maintenance activities.

Second, an interesting observation arose with regards to the IAD framework's proposed hierarchy of constitutional, collective choice, and operational situations. Presence of collective choice arrangements was a very good indicator for rule compliance, but not so much for monitoring and sanctioning rules. This suggests that the hierarchical process from collective choice arrangements to operational situations (Kiser and Ostrom 2000) may be less strictly defined. For example, my results suggested that collective choice arrangements were better predictors of rule compliance compared to the operational situation levels of monitoring and sanctioning. Instead, the processes of collective choice and operational situations should considered simultaneously due to the endogeneity of these processes in the process of common pool resource governance.

Finally, a number of methodological topics are worth mentioning. As this dissertation chapter manuscript moves forward with the analysis, I am considering alternative approaches for testing the hypotheses. Currently, I am treating each measured variable independently, which results in running a myriad of regressions, 39 of which are included in this paper. This approach makes the results difficult to interpret. A preferred method would be to develop representative factors for each of the five key latent concepts (i.e., collective choice arrangements, monitoring, sanctions, rule compliance, participation in maintenance activities) that are being tested from the ordinal data, and then proceed with one regression for each of the five hypotheses.

Alternative methods could be to collapse the Likert results into a binary format in order conduct Chi-squared tests. Chi-squared tests is a fairly common statistical approach for analyzing the governance of common pool resource systems, including in irrigation and forest systems (Tang 1992, Lam 1998, Gibson, Williams, and Ostrom 2005). A model comparison could be conducted to determine if Chi-squared tests and ordered linear regression models provide similar conclusions. Modeling exploration could also include an investigation of interaction effects of monitoring and sanctions with collective choice arrangements (Epstein 2017), as well as incorporating control variables for whether WUAs have received some external financial or technical support. Additional community characteristics can be incorporated; such as indicators that account for how well community members work together (i.e., trust and reciprocity). Multilevel or hierarchical modeling may also be a possibility, especially with respect to the levels presented in the IAD framework.

There are some data limitations in the research design. For example, this study falls short of providing measures for infrastructure conditions that are independent of the self-reported conditions from WUA leaders, which may certainly be biased by the opinions of the WUA leaders.

In Tajikistan, I sought out independent assessments of irrigation infrastructure conditions, however data sources were not consistent across all WUAs or reliable in terms of data quality. Ideally an engineer or irrigation specialist should independently assess indicators for infrastructure conditions according to some measurable variable.

On a final note, research on coupled infrastructure systems should take into consideration how the economies of scale of physical infrastructures over time (Merrett 2002) may affect the degree to which individuals can feasibly improve the conditions of the infrastructure (i.e., refer to the concept of feasible improvements from Ostrom, 2000). Related to such issues, I echo the call from other scholars that further collaborations with engineers and infrastructural specialists are needed in order to explore the relationships between governance and infrastructural and resource conditions (Anderies, Janssen, and Schlager 2016). In the same spirit that brought together social scientists, economists, and ecologists to study social-ecological systems, similar collaborations between social scientists, economists, and engineers are recommended for the study of coupled-infrastructure systems. Such collaborations would allow for comprehensive research agendas to engage more fully with the CIS framework.

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XII. REFERENCES

Agrawal, Arun, and Clark C. Gibson. 1999. "Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation." *World Development* 27 (4):629-649. doi: 10.1016/S0305-750X(98)00161-2.

Agresti, Alan. 2002. *Categorical data analysis*. 2nd ed. New York: Wiley-Interscience.

Anderies, John, Marco Janssen, and Elinor Ostrom. 2004. "A framework to analyze the robustness of social-ecological systems from an institutional perspective." *Ecology and society* 9 (1):18.

Anderies, John, Marco Janssen, and Edella Schlager. 2016. "Institutions and the performance of coupled infrastructure systems." *International Journal of the Commons* 10 (2).

Anderies, John M., and Marco A. Janssen. 2013. "Robustness of Social‐Ecological Systems: Implications for Public Policy." *Policy Studies Journal* 41 (3):513-536. doi: 10.1111/psj.12027.

Baland, Jean-Marie, and Jean-Phillipe author Platteau. 2000. *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?* New York: Oxford University Press, Incorporated.

Ben-Ner, Avner, and Louis Putterman. 2009. "Trust, communication and contracts: An experiment." *Journal of Economic Behavior & Organization* 70 (1–2):106-121.

Berkes, Fikret. 1989. *Common property resources: ecology and community-based sustainable development*: Belhaven Press.

Berkes, Fikret, Johan Colding, and Carl Folke. 2000. "Rediscovery of Traditional Ecological Knowledge as Adaptive Management." *Ecological Applications* 10 (5):1251-1262. doi: 10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Brant, Rollin. 1990. "Assessing Proportionality in the Proportional Odds Model for Ordinal Logistic Regression." *Biometrics* 46 (4):1171-1178.

Bryman, Alan. 2012. *Social research methods*: Oxford university press.

Chambers, Robert. 1977. "Men and water: the organisation and operation of irrigation."

Coase, Ronald H. 1937. "The nature of the firm." *economica* 4 (16):386-405.

Cox, Michael. 2014. "Applying a Social-Ecological System Framework to the Study of the Taos Valley Irrigation System." *Human Ecology* 42 (2):311-324. doi: 10.1007/s10745-014-9651-y.

Cox, Michael, and Justin M Ross. 2011. "Robustness and vulnerability of community irrigation systems: The case of the Taos valley acequias." *Journal of Environmental Economics and Management* 61 (3):254-266.

Dukhovny, VA, AG Sorokin, and GV Stulina. 2008. "Should we think about adaptation to climate change in Central Asia." *Adaptation to climate change: regional challenges in light of world experience. SIC ICWC, Tashkent*:14-24.

Eggertsson, Þráinn. 1990. *Economic behavior and institutions: Principles of Neoinstitutional Economics*: Cambridge University Press.

Epstein, Graham. 2017. "Local rulemaking, enforcement and compliance in state-owned forest commons." *Ecological Economics* 131:312-321.

Frischmann, Brett M. 2012. *Infrastructure: The social value of shared resources*: Oxford University Press.

Gibson, Clark C, John T Williams, and Elinor Ostrom. 2005. "Local enforcement and better forests." *World Development* 33 (2):273-284.

Gunchinmaa, T., and M. Yakubov. 2010. "Institutions and transition: does a better institutional environment make water users associations more effective in Central Asia?" *Water Policy* 12 (2):165. doi: 10.2166/wp.2009.047.
Janssen, Marco A., and John M. Anderies. 2013. "A multi-method approach to study robustness of social-ecological systems: the case of small-scale irrigation systems." *Journal of Institutional Economics* 9 (4):427. doi: 10.1017/S1744137413000180.
Kiser, Larry L, and Elinor Ostrom. 2000. "The three worlds of action: A metatheoretical synthesis of institutional approaches." *Polycentric Games and Institutions* 1:56-88.
Kovács, János Mátyás. 1994. *Transition to capitalism? : the communist legacy in Eastern Europe*. New Brunswick, N.J.: Transaction Publishers.
Krutilla, Kerry. 2011. "Transaction Costs and Environmental Policy: An Assessment Framework and Literature Review." *International Review of Environmental and Resource Economics* 4 (3-4):261-354. doi: 10.1561/101.00000035.
Lam, Wai Fung. 1998. *Governing irrigation systems in Nepal: institutions, infrastructure, and collective action*: Institute for Contemporary Studies.
Levi, Margaret. 1989. *Of rule and revenue*. Vol. 13: Univ of California Press.
Liao, Tim Futing. 1994. *Interpreting probability models: Logit, probit, and other generalized linear models*: Sage.
McGinnis, Michael D. 2011. "An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework." *Policy Studies Journal* 39 (1):169-183. doi: 10.1111/j.1541-0072.2010.00401.x.
McGinnis, Michael D., and Elinor Ostrom. 2014. "Social-ecological system framework: initial changes and continuing challenges." *Ecology and Society* 19 (2):30. doi: 10.5751/ES-06387-190230.
Merrett, Stephen. 2002. *Water for Agriculture*: IWA Publishing.
Messick, David M, and Marilynn B Brewer. 1983. "Solving social dilemmas: A review." *Review of personality and social psychology* 4 (1):11-44.
Moe, Terry M. 1984. "The new economics of organization." *American journal of political science*:739-777.
Molle, François. 2009. "Water scarcity, prices and quotas: a review of evidence on irrigation volumetric pricing." *Irrigation and Drainage Systems* 23 (1):43-58. doi: 10.1007/s10795-009-9065-y.
Moss, Timothy, and Ahmad Hamidov. 2016. "Where Water Meets Agriculture: The Ambivalent Role of Water Users Associations." In *Society-Water-Technology*, 149-167. Springer.
North, Douglass C. 1990. *Institutions, institutional change and economic performance*: Cambridge university press.
Olson, Mancur. 1971. "The logic of collective action: Public goods and the theory of groups, second printing with new preface and appendix (Harvard Economic Studies)."
Ostrom, Elinor. 1990. *Governing the commons : the evolution of institutions for collective action*, *Political economy of institutions and decisions*. Cambridge England ; New York: Cambridge University Press.
Ostrom, Elinor. 1992. *Crafting institutions for self-governing irrigation systems*. San Francisco, Calif. Lanham, Md.: ICS Press; Distributed to the trade by National Book Network.
Ostrom, Elinor. 2000. "The Danger of Self-Evident Truths." *PS: Political Science and Politics* 33 (1):33-44.

Ostrom, Elinor. 2005. *Understanding institutional diversity*, *Princeton paperbacks*. Princeton: Princeton University Press.
Ostrom, Elinor. 2007. "A diagnostic approach for going beyond panaceas." *Proceedings of the National Academy of Sciences* 104 (39):15181-15187. doi: 10.1073/pnas.0702288104.
Ostrom, Elinor. 2009. "A General Framework for Analyzing Sustainability of Social-Ecological Systems." *Science* 325 (5939):419-422. doi: 10.1126/science.1172133.
Ostrom, Elinor. 2011. "Background on the institutional analysis and development framework." *Policy Studies Journal* 39 (1):7-27.
Özerol, Gül. 2013. "Institutions of farmer participation and environmental sustainability: a multi-level analysis from irrigation management in Harran Plain, Turkey." *International journal of the commons* 7 (1):73-91.
Rausser, Gordon, and Camille Antinori. 2007. "Collective choice and community forestry management in Mexico: An empirical analysis." *The Journal of Development Studies* 43 (3):512-536. doi: 10.1080/00220380701204471.
Rose, Carol. 1986. "The Comedy of the Commons: Custom, Commerce, and Inherently Public Property." *The University of Chicago Law Review* 53 (3):711-781.
Rustagi, Devesh, Stefanie Engel, and Michael Kosfeld. 2010. "Conditional cooperation and costly monitoring explain success in forest commons management." *science* 330 (6006):961-965.
Salman, Salman MA. 1997. *The legal framework for water users' associations: a comparative study*. Vol. 360: World Bank Publications.
Sehring, Jenniver. 2009a. "Path dependencies and institutional bricolage in post-Soviet water governance." *Water Alternatives* 2 (1):61-81.
Sehring, Jenniver. 2009b. *The Politics of Water Institutional Reform in Neo-Patrimonial States: A Comparative Analysis of Kyrgyzstan and Tajikistan*. 65189 Weisbaden; Palo Alto: Westdeutscher Verlag GmbHebrary, Incorporated [Distributor].
Shivakoti, Ganesh, Douglas Vermillion, Wai-Fung Lam, Elinor Ostrom, Ujjwal Pradhan, and Robert Yoder. 2005. *Asian irrigation in transition: Responding to challenges*: SAGE Publications India.
Small, Leslie E, and Ian D Carruthers. 1991. *Farmer-financed irrigation: The economics of reform*: Cambridge University Press.
Sokolov, Vadim. 2006. "Experiences with IWRM in the Central Asia and Caucasus Regions." *Water International* 31 (1):59-70. doi: 10.1080/02508060608691915.
Svendsen, Mark. 1993. "The impact of financial autonomy on irrigation system performance in the Philippines." *World Development* 21 (6):989-1005. doi: 10.1016/0305-750X(93)90056-F.
Tang, Shui Yan. 1991. "Institutional Arrangements and the Management of Common-Pool Resources." *Public Administration Review* 51 (1):42-51.
Tang, Shui Yan. 1992. *Institutions and collective action: Self-governance in irrigation*: ICS press.
Theesfeld, Insa. 2004. "Constraints on Collective Action in a Transitional Economy: The Case of Bulgaria's Irrigation Sector." *World Development* 32 (2):251-271.
Theesfeld, Insa. 2011. "Perceived power resources in situations of collective action." *Water alternatives* 4 (1):86-103.

Thurman, Jonathan Michael. 1999. "Modes of organization in central Asian irrigation: The Ferghana Valley, 1876 to present." Dissertation/Thesis, ProQuest Dissertations Publishing.
Tomás, Sergio Villamayor, Gwen Arnold, and Michael Cox. 2010. "A Review of Design Principles for Community-based Natural Resource Management." *Ecology and Society* 15 (4):38.
Vermillion, DI, Elinor Ostrom, Robert Yoder, GP Shivakoti, DL Vermillion, WF Lam, and U Pradhan. 2005. "The future of irrigated agriculture in Asia: what the twenty-first century will require of policies, institutions, and governance." *Asian irrigation in transition: responding to challenges*:491-505.
Vermillion, Douglas L, and Juan A Sagardoy. 1999. *Transfer of irrigation management services: Guidelines*: Food & Agriculture Org.
Vollan, Björn, and Elinor Ostrom. 2010. "Cooperation and the Commons." *Science* 330 (6006):923-924.
Vollan, Bjorn, Sebastian Prediger, and Markus Frolich. 2013. "Co-managing common-pool resources: Do formal rules have to be adapted to traditional ecological norms?" *Ecological Economics* 95:51-62. doi: 10.1016/j.ecolecon.2013.08.010.
Wade, Robert. 1987. "The Management of Common Property Resources: Finding a Cooperative Solution." *The World Bank Research Observer* 2 (2):219-234. doi: 10.1093/wbro/2.2.219.
Wouters, Patricia, Victor Dukhovny, and Andrew Allan. 2007. *Implementing integrated water resources management in Central Asia*. Vol. 77: Springer Science & Business Media.
Yu, David J., Murad R. Qubbaj, Rachata Muneepeerakul, and John M. Anderies. 2014.