From Design Principles to Principles of Design:
Resolving Wicked Problems in Coupled Infrastructure Systems
Involving Common-Pool Resources

by

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ABSTRACT

Design is a fundamental human activity through which we attempt to navigate and manipulate the world around us for our survival, pleasure, and benefit. As human society has evolved, so too has the complexity and impact of our design activities on the environment. Now clearly intertwined as a complex social-ecological system at the global scale, we struggle in our ability to understand, design, implement, and manage solutions to complex global issues such as climate change, water scarcity, food security, and natural disasters. Some have asserted that this is because complex adaptive systems, like these, are moving targets that are only partially designed and partially emergent and self-organizing. Furthermore, these types of systems are difficult to understand and control due to the inherent dynamics of "wicked problems", such as: uncertainty, social dilemmas, inequities, and trade-offs involving multiple feedback loops that sometimes cause both the problems and their potential solutions to shift and evolve together. These problems do not, however, negate our collective need to effectively design, produce, and implement strategies that allow us to appropriate, distribute, manage and sustain the resources on which we depend. Design, however, is not well understood in the context of complex adaptive systems involving common-pool resources. In addition, the relationship between our attempts at control and performance at the system-level over time is not well understood either. This research contributes to our understanding of design in common-pool resource systems by using a multi-methods approach to investigate longitudinal data on an innovative participatory design intervention implemented in nineteen small-scale, farmer-managed irrigation systems in the Indrawati River Basin of Nepal over the last three decades. The intervention was intended as an experiment in using participatory planning, design and construction processes to increase food security and strengthen the self-sufficiency and self-governing capacity of resource user groups within the poorest district in Nepal. This work is the first time that theories of participatory design-processes have been empirically tested against longitudinal data on a number of small-scale, locally managed common-pool resource systems. It clarifies and helps to develop a theory of design in this setting for both scientific and practical purposes.

DEDICATION

Dedicated to David, Kinzer, Mama and Papa. Thanks for sharing in this adventure with me and supporting me all the way. I love you guys more than I could ever say.

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INTRODUCTION

> All men are designers. All that we do, almost all the time, is design, for design is basic to all human activity. The planning and patterning of any act toward a desired, foreseeable end constitutes the design process.
>
> Victor Papanek, Design for the Real World, 1971

Design is a fundamental human activity through which we attempt to navigate and manipulate the world around us. It is through design that we find and direct the resources that we need to where we need them in order to both survive and even thrive. As Papanek (1971) points out, design is something that all individuals engage in on a daily basis, but it becomes more complicated and complex when we move beyond the individual to work together in the planning, decision-making, implementation and development of designs for the sharing of resources through processes of collective action. These activities are the basis of society. As our society has evolved and grown more complex, so too have our attempts to control and manipulate the world around us to our collective benefit. Sometimes now referred to as the "anthropocene" (Crutzen 2006), our design processes have clearly become a driving force of global change, deeply intertwined with geological and ecological processes from the local to the global scales. The interactions of natural and human systems, however, are difficult to understand. Studies of coupled natural-human (CNH) systems, sometimes also called social-ecological systems (SES), have greatly increased our understanding of the complexity and dynamics of these systems as well as humanities role within them over the past few decade (Anderies *et al.* 2004;Walker *et al.* 2004; Liu *et al.* 2007; Berkes *et al.* 2008; Janssen *et al.* 2011). These studies, and many more like them, are now a significant part of a larger field of science known as Complex Adaptive Systems (CAS) Science.

The science of CAS is relatively new, and yet it has become an important part of understanding the world in which we live and our place within it. *Complex adaptive systems* (CAS) are defined as dynamic networks of heterogeneous agents that interact locally and self-organize to generate emergent patterns at the system level that cannot be predicted by the behavior of the individual components (Holland 1992; Miller and Page 2009). As Miller and Page (2009) state, "the field of complex systems challenges the notion that by perfectly understanding the behavior of each component part of a system we will then understand the system as a whole" (p.3). CAS are dynamic, meaning they are essentially characterized by constant change, activity, and progress. Examples of CAS include the flocking behaviors of birds as they fly and the schooling of fish, but also the "invisible hand" of the market described by Adam Smith (1776) and the evolution of cities (Miller and Page 2009). In CAS involving humans, we often attempt to control what emerges at the system level through *design*, making coupled natural-human systems both partially designed and partially emergent, or self-organizing (Anderies 2014). Our efforts to design and control, however, sometimes result in unintended consequences, inferring a delicate balance between design and emergence in CAS. While Holland (1992) describes CAS as "moving targets" (p.18) that are difficult to understand and control, design remains a necessary part of humanity's role within them. Complex issues like climate change, water scarcity, and food security have made an understanding of design and emergence within CAS involving shared, or common-pool natural resources, particularly crucial. Yet, while emergence is a well studied and integral phenomenon in CAS science (Holland 1992; Liu *et al.* 2007; Levin 2005; Lansing 2003; Miller and Page 2009; Mittal and Rainey 2015) the concept of *design* is not as well understood for this context.

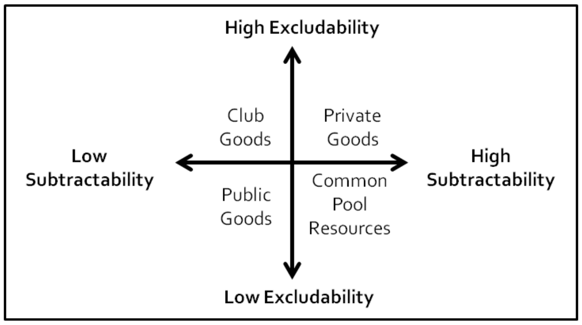


Figure 1.1: Typology of Goods (Ostrom 1990)

All of the basic resources that humans depend on, such as food, water, and energy, are deeply embedded within complex adaptive systems (Liu *et al.* 2007; Levin 2005). These types of natural resources are sometimes called common-pool resources (Ostrom 1990). Common-pool resources (CPR) differ from other types of resources (Fig. 1.1) in that they are both highly subtractable and have a high level of difficulty in the exclusion of other potential users (Ostrom 1990). Take a large pond of fish, for example. When any one person catches and eats an individual fish from the pond, it decreases the number of fish that may be available to any other person also coming to the pond to capture fish. While it is conceivably possible that the entire stock of fish in the pond could be depleted if all of the existing fish were captured and eaten, it would be quite difficult and costly for any one person to control the pond and keep all of the other hungry people from fishing in order to feed themselves as well. Yet if all of the fish are depleted, everyone will starve; this is one example of a classic social dilemma often present in the management of natural resources. The group of people who depend on the resource of fish must somehow figure out how to both feed themselves and avoid obliterating the resource, at the same time. These two overarching goals (appropriation and conservation), can sometimes be at odds with one another and we often struggle to design fitting strategies, especially when the system is dynamic and involves a high degree of uncertainty. To complicate matters even further, however, collective action typically involves multiple layers of preferences and strategies which also interact with a variety of infrastructures and processes and affect one another at various spatial and temporal scales. Inadequate consideration of these interactions can lead to unintended consequences. CPR systems, like the fishery example, are highly dynamic systems that are comprised of many different interacting components and relationships and the problems found in these systems can be approached in a myriad of ways. Perhaps the resource users or governing bodies develop rules to govern access and use of the resource, for example; or perhaps some users decide to work together to build and monitor a fence that keeps others out. Either option may cost time and/or resources, but which configuration is the best option in this specific context? Not only are there complex relationships between humans and the environment involved in this question, but there are also complex relationships between different people, their individual preferencences, and the potential involvement of various strategies and technologies that mitigate those relationships (Anderies 2014). Varying levels of social organization and rules could be effective; or perhaps different types of technology for fishing, monitoring, or enforcement would work. Each of these strategies could be designed to control the appropriation and provisioning of the natural resource in some way so that it is not completely obliterated (Csete and Doyle 2002; Anderies *et al.* 2016). There are many different possible configurations that might accomplish these goals, and yet everything determining what works or does not work in this system may change over time and may not be at all appropriate for a different system and/or different time. This begs the question, then, of how we can move beyond our efforts to merely understand the dynamics and interactions within coupled natural-human systems, but also:

- How can we understand the role of design within these types of complex adaptive systems better?

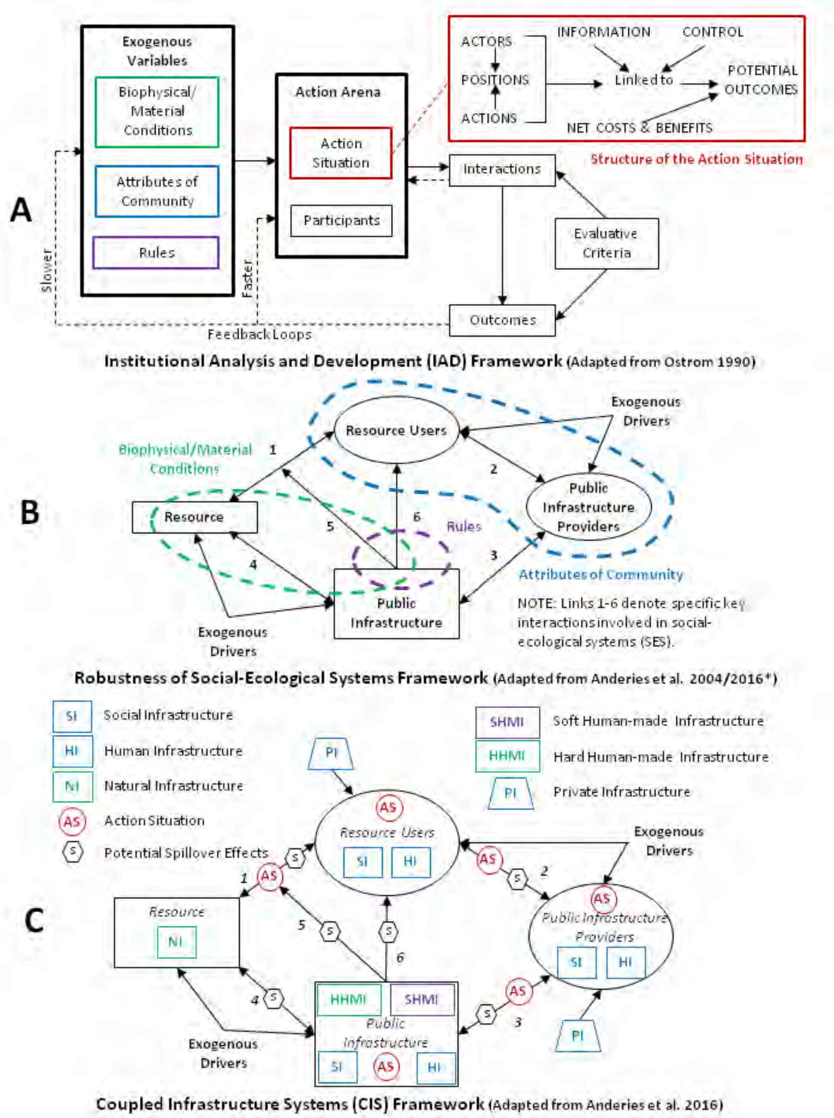
- How can we use this understanding to improve our collective design activities?

In her highly influential book, *Governing the Commons*, Nobel laureate Elinor Ostrom (1990) introduced the Institutional Analysis and Development (IAD) Framework (Fig. 1.2-A) for understanding Common-pool Resource (CPR) systems. These seminal ideas and a number of subsequent developments based upon them, including: the Robustness Framework ((Fig. 1.2-B) (Anderies *et al.* 2004), the Design Principles (Ostrom 2005), and the Coupled Infrastructure Systems (CIS) Framework (Fig. 1.2-C) (Anderies *et al.* 2016) have sought to illuminate the key mechanisms of human decision-making and emergent system dynamics associated with sustainable long-term use of CPRs. This trajectory of research has provided a strong foundation for understanding the role of design in these types of systems. The Ostrom (2005) Design Principles, for example, provide a list of the characteristics of management in common-pool resource systems that have been observed to often be associated with the long-term sustainability of these systems (McGinnis 2011a), including eight tenets:

1. Boundaries of the users and resource are clear;
2. Use and provision rules are adapted to the local conditions;
3. Collective-choice arrangements exist so that most individuals affected by the rules can participate in modifying the rules;
4. There is monitoring of the resource and its users and monitors are accountable to or are the resource users;
5. Resource users who violate the rules are likely to be assessed graduated sanctions that depend on the context of the offense;

6. Conflict-resolution mechanisms are in place that give resource users and their officials rapid access to low-cost local arenas to resolve conflicts;
7. The rights of resource users to organize and devise their own rules are recognized and not challenged by external authorities;
8. For CPRs that are part of larger systems: appropriation, provision, monitoring, enforcement, conflict-resolution, and governance activities are organized within multiple layers of nested enterprises.

While the Ostrom (2005) Design Principles provide insight on how human activities work toward successful management of natural resources within CPR systems, they are heavily focused on decision-making and management structures. Ostrom's work focused on institutions (i.e. rules, norms, and shared strategies) and so this focus makes sense in that context. However, in naming the key characteristics she found, the "Design Principles", Ostrom (2005) touched upon our collective ability to "plan and pattern" these activities "toward desired, foreseeable ends" as Papanek (1971) phrased it, and the configural nature of CPR systems. Human design, however, goes well beyond institutions, and there is much left to understand on how designed institutional structures interact with other human-designed structures (e.g. hard infrastructure) as well as other natural and/or social structures that may or may not already exist in the system during the decision-making and management activities of focus. While there is still much to be discovered, theoretical developments that build off of Ostrom's work, such as the Robustness Framework (Anderies *et al.* 2004) and the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016) make progress toward understanding the interactions of man-made structures (both soft and hard) with each other and the dynamic natural and emergent processes of the larger contextual environment. While our understanding of the key interactions has improved, we still do not really understand what it means to design within the context of CPR systems, how this might differ from traditional concepts of design, and how improving our understanding of design within this context might improve our ability to avoid costly unintended consequences and actually do the "basic human activity" (Papanek 1971) of design better.



Institutional Analysis and Development (IAD) Framework (Adapted from Ostrom 1990)

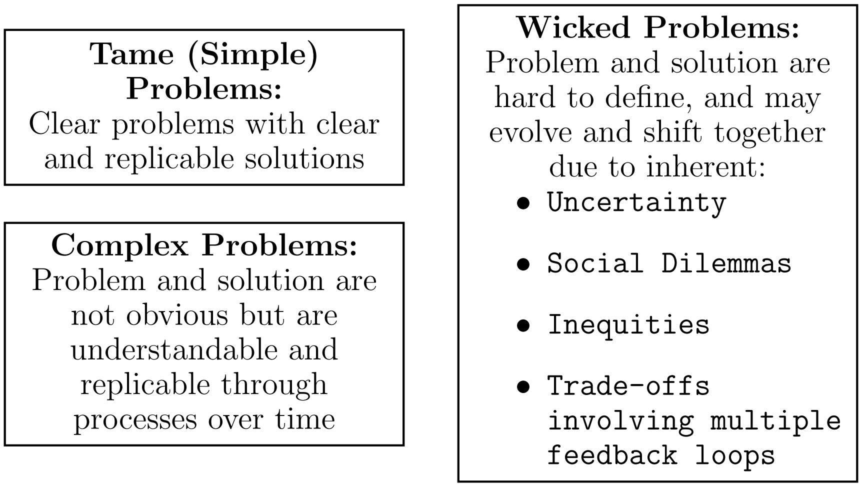
Robustness of Social-Ecological Systems Framework (Adapted from Anderies et al. 2004/2016*)

NOTE: Links 1-6 denote specific key interactions involved in social-ecological systems (SES).

Coupled Infrastructure Systems (CIS) Framework (Adapted from Anderies et al. 2016)

Figure 1.2: Frameworks based on Elinor Ostrom's IAD Framework

While the body of research dedicated to understanding CPR systems has improved our understanding of these systems and how they function, our inability to successfully and consistently apply concepts like the Ostrom (2005) Design Principles in practice for unique systems experiencing their own problems has remained a persistent problem. Rittel and Webber (1973) posit that our inability to cope with the inherent issues we find in these systems, such as uncertainty, social dilemmas, inequities, and trade-offs, may be due to the fact that they can be considered "wicked problems" that cannot really ever be solved but can only be "re-solved over and over again" (p.160). They assert that the design and development of idealized and easily replicable solutions (Fig. 1.3) is prevented within these systems because wicked problems and their possible solutions are both hard to define and may evolve and shift together when trying to affect complex and dynamic systems, resulting in the emergence of unintended features and consequences at the system level (Rittel and Webber 1973). This implies that our efforts to constantly re-solve issues (i.e. design) within these dynamic systems must also be dynamic, involving constant change, activity, and progress.



Tame (Simple) Problems:
Clear problems with clear and replicable solutions

Complex Problems:
Problem and solution are not obvious but are understandable and replicable through processes over time

Wicked Problems:
Problem and solution are hard to define, and may evolve and shift together due to inherent:

- `Uncertainty`
- `Social Dilemmas`
- `Inequities`
- `Trade-offs involving multiple feedback loops`

Figure 1.3: Typology of Problems (Rittel and Webber 1973)

Many studies, in the last decade or so, have emphasized adaptive approaches and ideas such as resilience, robustness and adaptability for coping with these types of issues and reaching toward methods of achieving the type of continual resolution suggested by Rittel and Webber (Walker *et al.* 2004; Janssen *et al.* 2007; Eakin and Wehbe 2009; Anderies *et al.* 2013; Biggs *et al.* 2015; Eakin *et al.* 2016). In addition, some studies highlight the configural nature that CAS approaches allow (Yu *et al.* 2015; Anderies 2014; Anderies *et al.* 2016; Baggio *et al.* 2016; Mathias *et al.* 2017), laying a strong groundwork for an argument in favor of design as an important concept when thinking about CPR systems. The foundational work of Ostrom and others, including the most recent developments of the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016), provides a well-established theoretical and methodological basis for studying the role of design within CPR systems as a CAS of particular interest.

Design, however, is a sometimes-controversial concept within the CPR literature and a difficult concept to map in general. Some scholars assert that design is the essential element of all human activity (Papanek 1971) while others assert that it is solely the domain of the expert, requiring specialized knowledge and skills (Cross 1990). According to common dictionary definitions, *design* can be a noun, meaning "an outline, plan, or sketch", or can also be a verb, stemming from the Latin word *designare*, meaning "to mark-out, devise, or choose" (dictionary.com). It is more often described or represented as a process of connected actions and products, encompassing both noun and verb tenses. Within the CPR literature, Ostrom (1990) described her principles for sustaining CPR systems as "Design Principles" and yet also warned against the "panacea-problem", or the use of these types of principles as a blue-print design (n.) that can simply be applied universally to many different problems and contexts (Ostrom *et al.* 2007; Ostrom and Cox 2010). Other CPR scholars contend that technology driven and engineering-based approaches often use design (v.) to impose technical or scientific solutions upon situations without much regard to other important components such as social and institutional infrastructures (Skjølsvold 2010; Ostrom *et al.* 2011). Much of the CPR scholarship, including the Ostrom (2005) Design Principles, has explicitly sought to highlight design as a process that should actively involve collaboration and the participation of users themselves in order to bridge the gaps between policy, engineering, community goals, outcomes and the emergence of unintended consequences within the system (Ostrom 2005; Daniell *et al.* 2010; Moellenkamp *et al.* 2010; Ostrom *et al.* 2011). These long-time trends in the CPR scholarship not only reinforce the importance of design as a key concept but also highlight the need to better understand the nuances of what is within the purview of design and how design happens within these systems.

In this study, I seek to explore the meaning of design for complex adaptive systems (CAS) involving common-pool resources (CPR). To do this, I utilize the same type of mixed-methodology for new knowledge creation that was the staple for Ostrom and others within the study of CPR systems (Poteete *et al.* 2010, including content analysis through the coding of case studies for comparative analysis and the generation of key themes (Fig. 1.4). This type of structural coding has been a tradition within the CPR scholarship, and Chapter 2 is re-print of a previously published article that explains this tradition and some of the important considerations for its employment. This dissertation, however, pushes the methodology further by moving from the coding of static structures, such as the Ostrom (2005) Design Principles, and binary outcomes, such as "success" and "failure", to the coding of dynamic processes within complex adaptive systems and system functionality in terms of resilience. This is an important step in actualizing the goal of understanding what Anderies (2014) calls "partially designed, partially self-organizing systems" and the role that humans take on within these dynamics.

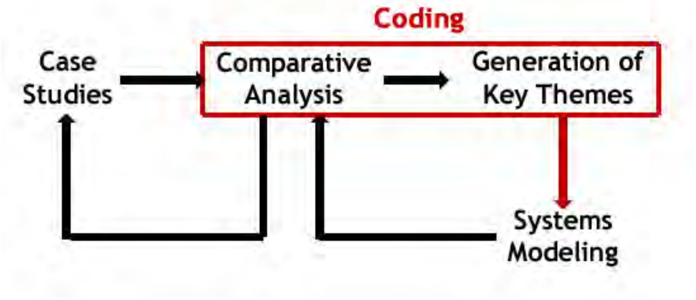


Figure 1.4: Mixed-Methodology for New Knowledge Creation (Poteete *et al.* 2010)

To do this, I first attempt to define "design" as a key process within the complex adaptive systems context (Chapter 3). Because the study of CPR systems is a highly interdisciplinary field, I first investigate and discuss general concepts of design from a number of disciplinary perspectives to identify key features of this conceptual landscape in the context of CPR systems. I also introduce the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016), a relatively new development in the legacy of Ostrom that is still connected to her foundational roots. I identify some of the key developments of this research trajectory that may specifically help in understanding "design" within CPR settings from a CAS perspective. According to Ostrom (2005), frameworks such as the CIS Framework can help to identify key elements and relationships at the broadest level and can also provide the metatheoretic language that is necessary to talk about and compare various theories (p.28). I conclude Chapter 3 with suggestions for a hypothesized theory that synthesizes key concepts from the literature that may be useful in better understanding design in CPR systems.

I then code an empirical case study involving a design-process within a CPR system to test my assumptions about design in this context and utilize the CIS Framework (Anderies *et al.* 2016) to develop an operational model of how design works within these systems (Chapter 4). The design-process under investigation was intended to utilize participatory decision-making and construction activities to improve both the physical and governance capacities of nineteen farmer-managed irrigation systems (FMIS) in the Indrawati River Basin of Nepal. Small-scale irrigation systems, like those included in this study, have been shown to be an important model of larger-scale social-ecological systems (SES) because they can exhibit all of the different types of complex dynamics and components analogous to larger SES, but at a more digestible scale. In fact, Janssen and Anderies (2013) suggest that "small-scale irrigation systems function as the equivalent of the fruit-fly in evolutionary biology to illustrate the robustness of social-ecological systems" (p.3). The investigation in Chapter 4 looks at the design-processes that were utilized at the regional scale by the government/NGO team that led the intervention for the nineteen FMIS included in the study, through the lens of the hypothesized theory introduced in Chapter 3. I finish Chapter 4 by discussing both the usefulness of the theory and some necessary adaptations that have become apparent through this investigation.

Finally, in Chapter 5, I code longitidinal data for each of the individual cases that participated in the previous design-process under investigation to better understand how design-processes affect community resilience at the local-level. I specifically investigate the types of problems that have been reported within each of these systems over the past three decades, the mechanisms (i.e. design actions) that farmers have employed in trying to cope with these problems, and how these dynamics have affected the resiliency of these systems over time. Longitudinal data for this investigation is drawn from the Nepal Irrigation Institutions and Systems (NIIS) Database which has been collected by a number of researchers over the past thirty years. The NIIS is a relational database that includes over five-hundred variables, spanning both the social and ecological aspects of SES, and 274 observations of small-scale irrigation systems in Nepal. Repeated measures in the NIIS database for the nineteen systems included in this investigation have been collected over three primary time-slices (1985-1987, 1991, and 1999), with additional site visits to collect data specifically for this investigation in 2016, following the devastating earthquakes that took place in the study area during the spring of 2015.

I conclude the dissertation in Chapter 6, by synthesizing and discussing the findings of these three investigations and their implications for moving toward a better understanding of design within the context of complex adaptive systems (CAS) involving common-pool resources (CPRs). While the establishment of a conclusive theory of design for CPR systems is beyond the scope of this investigation, it takes important steps toward identifying the gaps in this area for this field of research and beginning the conversation on how to address these gaps. In addition, this study brings together foundational concepts from the literature and tests their applicability as a first step along a research trajectory dedicated to understanding design-processes and our role within the dynamics of coupled natural-human systems involving shared resources. In addition, this study represents a new step in the coding tradition for the study of CPR systems, as past efforts have attempted to link static structures to "success", while this study attempts to link processes of design and emergence within CAS to community resilience.

Chapter 2

CHALLENGES AND OPPORTUNITIES IN CODING THE COMMONS: PROBLEMS, PROCEDURES, AND POTENTIAL SOLUTIONS IN LARGE-N COMPARATIVE CASE STUDIES

2.1 Authors

Ratajczyk, E., Brady, U., Baggio, J.A., Barnett, A.J., Perez-Ibara, I., Rollins, N., Rubiños, C., Shin, H.C., Yu, D.J., Aggarwal, R., Anderies, J.M., and Janssen, M.A.

2.2 Abstract

On-going efforts to understand the dynamics of coupled social ecological systems and common pool resources have led to the generation of numerous datasets based on a large number of case studies. This data has facilitated the identification of important factors and fundamental principles thereby increasing our understanding of such complex systems. However, the data at our disposal are often not easily comparable, have limited scope and scale, and are based on disparate underlying frameworks which inhibit synthesis, meta-analysis, and the validation of findings. Research efforts are further hampered when case inclusion criteria, variable definitions, coding schema, and intercoder reliability testing are not made explicit in the presentation of research and shared among the research community. This paper first outlines challenges experienced by researchers engaged in a large-scale coding project; highlights valuable lessons learned; and finally discusses opportunities for future comparative case study analyses of social-ecological systems and common pool resources.

2.3 Introduction

Long-term efforts to understand social-ecological systems (SES) involving the management of common pool resources (CPR[1]) has led to the generation of a large body of data composed primarily of case studies (Wade 1984; Berkes 1989; Ostrom 1990; McKean 1992; Baland and Platteau 1999; Cox 2014; Epstein *et al.* 2014). If we are to understand CPR governance, we must be able to make comparisons across case studies but are challenged to develop reliable methods of making this often complex and messy data comparable. Meta-analysis, in the field of environmental social science is a mixed methods approach involving data extraction from case studies, through the coding of texts, for use in statistical or other comparative data analysis techniques (Hruschka *et al.* 2004; Rudel 2008; Cox 2015). As the essential activity of meta-analysis, coding involves the classification and quantification of texts or other media segments preserved in a form which can be subjected to formal analysis (Hruschka *et al.* 2004). In this paper, we will contribute to understanding the challenges of coding case studies in environmental social science by critically exploring the experience of a team of researchers at the Center for Behavior, Institutions and the Environment (CBIE) at Arizona State University (ASU) while coding the 69 cases that form the data for Baggio *et al.* (2016) and Barnett *et al.* (2016).

In the next section (Section 2), we will briefly discuss the overall opportunities and challenges inherent in the coding of case studies for large-N meta-analyses and why this is a particularly important methodology in the field of environmental social science. We will discuss three primary challenges which we find can hamper meta-analysis efforts: 1) methodological transparency; 2) coding reliability; and 3)

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[1] CPR theory is based on the assertion that there are many ways in which people are able to cooperate to solve social dilemmas involving shared, or common pool, resources and that there are some fundamental similarities which help people do this (Schlager 2004)

replicability of findings. In Section 3, we discuss our coding methodology in some detail and compare it to recommendations in the methods literature, including: preliminary decisions, codebook development, coding protocols, and intercoder reliability testing. We explore ways of increasing methodological rigor in these areas by adopting certain techniques and strategies from other disciplines in the social sciences and compare the approaches used by the CBIE team to approaches, or “best practices”, recommended by a number of leading authorities within the methods literature. In Section 4, we utilize our findings from this comparison to develop a recommended coding protocol which we think could be widely applicable and easily adaptable to others using a comparative or meta-analysis methodology for research on SESs and the commons. We conclude the paper by sharing some ideas for future research in Section 5. We hope that by sharing these key methodological challenges and opportunities, we will stimulate a broader platform for communication and collaboration among scholars which will lead to better, more transparent research designs, opportunities in meta-analysis and data synthesis, and discoveries that will enhance our understanding of SESs.

2.4 The Challenge

Meta-analysis, comparative analysis, and synthesis rely on the use of a rich resource of case studies which have been collected by numerous researchers over a long period of time. Secondary analysis of data of this kind, gathered for other purposes using diverse measures and variables, is inherently subjective and it is therefore important to take measures to increase coding reliability and replicability. This can present challenges in research design and implementation. Secondary analysis of existing case studies, however, has the advantage of being a relatively low-cost approach, compared to primary data collection, and can enable larger scale comparative analyses (Kelder

2005; Savage 2005). Meta-analysis offers the opportunity to refine findings within a wider community, discover what the dominant discourses are and generate new knowledge through the validation of previous findings. In addition, the use of synthesized datasets allows for the use of existing data in new ways and analyses across multiple time periods, scales and sectors, thereby potentially improving researchers' ability to understand complex system dynamics and adaptation (Ostrom 1990; Ostrom 2012; Kelder 2005; Poteete *et al.* 2010; Cox 2014). Araral (2014) and Agrawal (2014) characterize this type of work in the study of the commons as the "emerging third generation" of research within the legacy of Elinor Ostrom, and see these efforts to generalize and extend her arguments across scales and with increased complexity as being of "fundamental importance" (Agrawal 2014, p.87). Relying on secondary data, however, is often difficult (Poteete *et al.* 2010) as existing data are often limited in their scope and scale, and are separated into independent databases using unique coding schema[2] and storage structures which are not always made publicly available. These limitations and divisions hamper synthesis efforts and comparability. For example, there are a number of data repositories (Table 1 Supplementary Material) based on the work of Elinor Ostrom and her collaborators on CPR theory. These libraries of data represent a rich and mostly unexploited resource for increasing our understanding of CPRs via meta-analysis and comparison with contemporary data (Corti *et al.* 2005). These databases, however, each possess their own idiosyncrasies, sometimes leading to diverse interpretations of theory, coding schemes, organization, variables, and definitions. Researchers often do not disclose sufficient methodological information to replicate, verify or compare findings, including access to the codebooks, information on case or variable selection, theoretical assumptions,

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[2] The term "schema" is defined as the organization and structure for a database as often used in computer programming literature (Roberts 2005).

or intercoder reliability testing approaches. Problems associated with ambiguous or missing information based on unreported assumptions hamper the replicability of study findings and undermine the reliability and validity of such research.

Research is always a work in progress and case studies and comparative analysis done in isolation may be disputed or later found to be wrong. In addition, there may be issues of confirmatory bias or non-representative sampling involved in the selection of cases for secondary analyses, even when they contain sufficient levels of information. Thus, intercoder reliability testing and reporting is critically important, as is the disclosure of coding variables and codebooks. In order to advance the intra- and inter-institutional analysis of data, more rigorous standards should be established, such as common standards and protocols and the explicit reporting of assumptions. Even without consensus on standards or protocols, however, selection criteria should be made transparent by research teams in order to facilitate the emergence of common practices and increased methodological rigor in environmental social science in general.

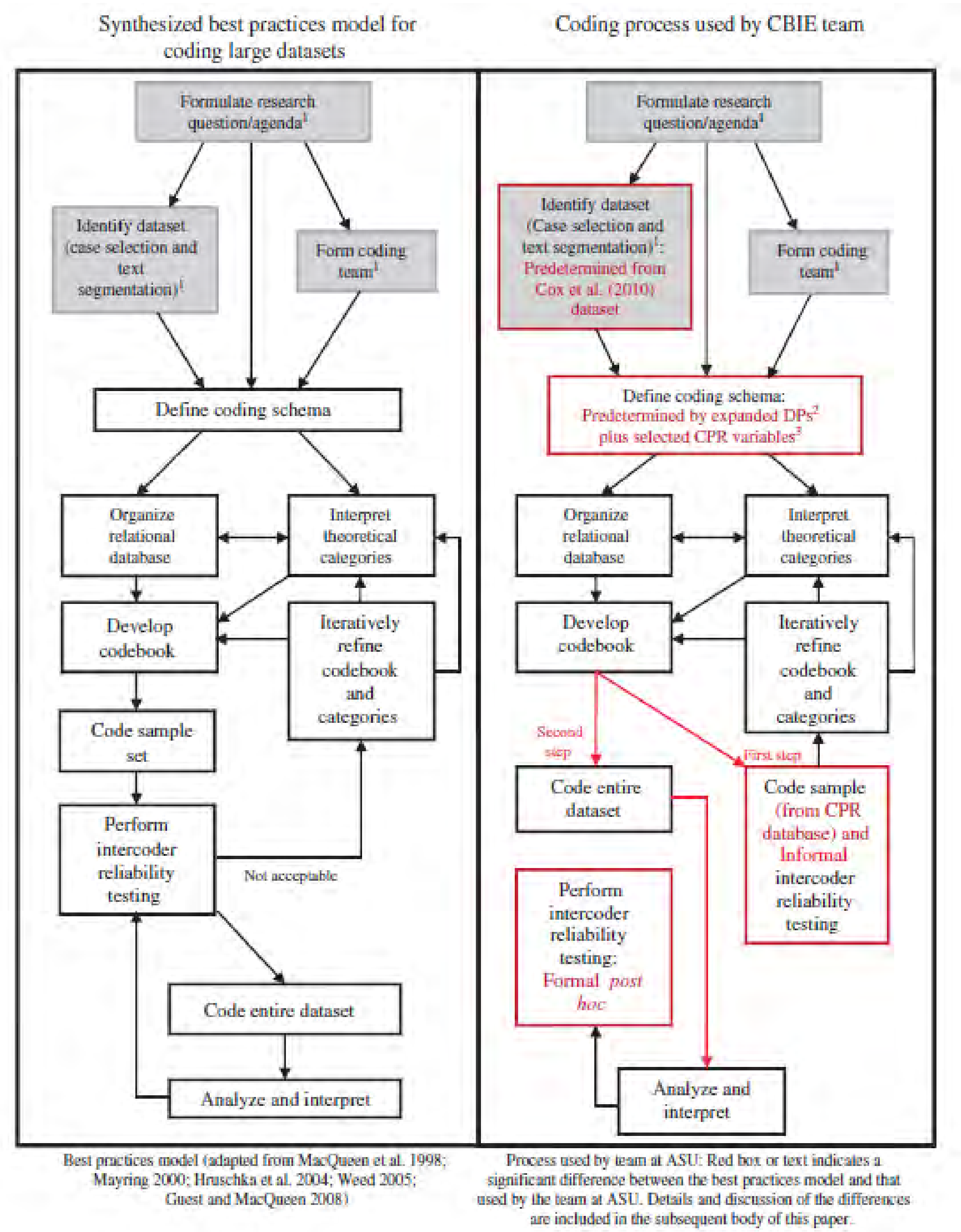
Access to the resource of SES and commons data that currently exists can, itself, be viewed as a public good which is currently underprovided due to lack of transparency and coordination. Institutions which govern the proper and productive use of these resources could effectively reduce issues which private property dataset approaches now generate. The differences in databases and lack of transparency by researchers limit synthesis efforts and the ability to conduct broader, large-N case comparisons. Agrawal (2014) asserts that furthering this research will require methodological innovation, better theoretical sophistication and improved data. Furthermore, he states that the use of new methods involving more qualitative analysis and experimentation are the current drivers pushing the field forward. However, the successful use of these new methods will depend upon substantial amounts of new data, better integration of data, a sophisticated hierarchical organization of datasets, and increased analytical rigor (Agrawal 2014). In order to increase coding replicability, reliability, and transparency, some scholars assert that explicit identification and alignment of the coding rules, organization and work-process knowledge (or coding schema) used in coding may be important in mitigating problems of missing data and interpretations of concepts (MacQueen *et al.* 1998; Stemler 2001; Medjedovic and Witzel 2005). Because meta-analysis of this type is a relatively new methodological approach in social science research (Corti *et al.* 2005), some authors argue that there has not yet been enough published research looking at the issues it may raise (Corti and Thompson 2004). In this paper, we critically explore our experience in answer to these challenges. We hope to offer some guidance and identify valid issues of consideration in the coding of secondary data for meta-analysis, thereby contributing to the dialogue in this area.

2.5 Coding Methodology

In order to increase the replicability and the transparency of our coding process we have created a detailed Coding Manual and a Recommended Coding Protocol (see Section 4). A coding protocol is the common set of systematic procedures that a research team agrees to follow during the coding process (Rourke and Anderson 2004) and a coding manual typically contains the coding questions, answer codes, and information to aid in clarification and coder alignment which embody the research questions being explored in a study (MacQueen *et al.* 1998). Our coding manual was developed incrementally throughout the coding process and our recommended coding protocol outlines the way that we would conduct the project in retrospect, resulting from the analyses and comparison to the methods literature as detailed in the following sections. Figure 1 (below) illustrates how our process compares to practices recommended in the methods literature (MacQueen *et al.* 1998; Mayring 2000; Hruschka *et al.* 2004). We then discuss the comparison between the recommended "best practices" model synthesized from the methods literature (left side of Figure 2.1) and the process used by the CBIE team (right side of Figure 2.1), focusing on the challenges raised during the coding process and how the recommendations from the methods literature could potentially address them.

2.5.1 Formulate research agenda

The formulation of the research agenda for the original meta-analysis project at CBIE (Baggio *et al.* 2016) was related to three objectives. The primary objective of that study was to examine case studies to determine whether particular configurations of Ostrom (1990) design principles (DPs) were indicative of successful CPR governance. The second objective was to replicate and then expand upon a previous study conducted by Cox (2010), which provided some empirical support for the claim that there is a higher chance for each of Ostrom's (1990) individual DPs to be present in successful cases of CPR management across a range of contexts. The third objective was to link the expanded DPs (Table 2.1) found in Cox (2010) with variables found within the existing database for the Common Pool Resources (CPR) Project (Ostrom *et al.* 1989). Since the DPs and the variables used in the CPR database are both founded on CPR theory, we thought it would be possible to link them, thereby facilitating the synthesis of two separate datasets that use similar concepts but different coding schema. Larger datasets of comparable cases improve meta-analyses and researchers' ability to use mixed qualitative and quantitative methods, as well as improve analyses across multiple sectors, scales, and time periods. In doing so, our ability to understand complex system dynamics and adaptation in these system types is potentially enhanced (Poteete *et al.* 2010).



Best practices model (adapted from MacQueen et al. 1998; Mayring 2000; Hruschka et al. 2004; Weed 2005; Guest and MacQueen 2008)

Process used by team at ASU: Red box or text indicates a significant difference between the best practices model and that used by the team at ASU. Details and discussion of the differences are included in the subsequent body of this paper.

Figure 2.1: Coding process comparison illustrating the process utilized by our team compared to the "best practices" model described above and discussed in further detail in the following sections. ¹Preliminary decisions; ²Table 1, this Chapter; ³Ostrom *et al.* 1989

2.5.2 Identify dataset

Decisions about case selection and subsequent text segmentation are extremely important steps in the identification of the dataset to be used for meta-analysis (Hinds *et al.* 1997; Stemler 2001; Weed 2005). Cases should typically be screened and analyzed for fit based on both their applicability to the research questions and data completeness (Hinds *et al.* 1997; Stemler 2001; Weed 2005). Longer texts, like the case studies used in this study, should be segmented into smaller units of text (e.g. a sentence or a paragraph) to increase intercoder agreement and reliability (Krippendorff 2013) and decrease coding discrepancies (Hruschka *et al.* 2004). A coding protocol generally includes guidelines as to how a text should be segmented for data analysis and coding (Hruschka *et al.* 2004; Bernard and Ryan 2010; Bernard 2011). Inclusion and exclusion criteria formally clarify the reasoning behind the selection of cases and segmentation of texts (Hruschka *et al.* 2004). Ostrom et al. (1989) found exclusion criteria to be extremely important and included careful screening criteria for the cases included in the original CPR database.

Because the primary and secondary objectives of the CBIE team's research agenda were to replicate and extend upon the findings of a previous study, the selection of cases was predetermined by the dataset used in the study by Cox (2010). Consequently, this limited our ability to select cases for fitness and data completeness. We did, however, limit our selection of cases to a sub-set of the Cox (2010) dataset by sector (irrigation, fishery, and forestry), based on our third objective of synthesis with the existing CPR dataset (Ostrom *et al.* 1989). This resulted in the coding of 69 out of the 77 cases presented in Cox (2010). During the coding process, our team experienced some difficulties with the fitness of the dataset due to missing data. For example, there were some cases which we found had sufficient social outcome data but not enough biological data, or vice versa, making the overall determination of success or failure in these cases difficult. Without explicit information on the inclusion/exclusion criteria used by the Cox team, it was more difficult for us to replicate and validate findings of success or failure across cases. We also found that some cases had ample data on one or two specific DPs but lacked information on the presence or absence of others. The Cox study may have been less sensitive to missing data on DPs because they were analyzing individual DPs against success, rather than looking for combinations of DPs as in the CBIE approach (Baggio *et al.* 2016). While analyzing combinations of DPs may present increased issues with missing data, Baggio *et al.* (2016) show the potential advantages of this approach.

Cox (2010) segmented text by dividing longer documents into individual cases representing a single geographical location and temporal period. The text segmentation for the CBIE study was pre-determined by the divisions made in Cox study, and inter-related with case selection and the issues previously described. We found that the segmentation of texts contributed to the issues of missing data and fitness because some cases might include a single paragraph within a larger document or might instead include a number of sentences or excerpts related to a specific location scattered throughout the document which were considered one segment. Since criteria for the segmentation of texts into cases from larger regional studies was not explicitly reported in the Cox (2010) publication, the CBIE team initially debated whether to include or exclude cases based on our own screening criteria, but ultimately decided to use the same cases that were also evaluated by the Cox team.

2.5.3 Form a coding team

The use of two or more coders is important for assessing the replicability and reliability of coded data (MacQueen *et al.* 1998). The number of coders sufficient

Table 2.1: Expanded design principle questions (adapted from Cox 2010) as basis of coding variables and questions

Design principle	**Description**
1A	The presence of the design principle 1A means that individuals or households who have rights to withdraw resource units from the common-pool resource must be clearly defined. Is this design principle present?
1B	The presence of the design principle 1B means that *the boundaries of the CPR must be well defined.* Is this design principle present?
2A	The presence of design principle 2A means that *appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions.* Is this design principle present?
2B	The presence of design principle 2B means that *the benefits obtained by users from a CPR, as determined by appropriation rules, are proportional to the amount of inputs required in the form of labor, material, or money, as determined by provision rules.* Is this design principle present?
3	The presence of design principle 3 means that *most individuals affected by the operational rules can participate in modifying the operational rules.* Is this design principle present?
4A	The presence of design principle 4A means that *monitors are present and actively audit CPR conditions and appropriator behavior.* Is this design principle present?
4B	The presence of design principle 4B means that *monitors are accountable to or are the appropriators.* Is this design principle present?
5	The presence of design principle 5 means that *appropriators who violate operation rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, officials accountable to these appropriators, or both.* Is this design principle present?
6	The presence of design principle 6 means that *appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.* Is this design principle present?
7	The presence of design principle 7 means that *the rights of appropriators to devise their own institutions are not challenged by external governmental authorities.* Is this design principle present?
8	The presence of design principle 8 means that *appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.* Is this design principle present?

to establish reliability is not agreed upon in the literature, but in general, the more coder inference required and/or the rarer that codes appear in texts, the greater the number of coders that should be utilized (Bernard and Ryan 2010). We divided all 69 cases among the entire coder team assuring that there were generally three coders per case. This resulted in eighteen distinct coding team combinations. Since our coding project involved case studies that reported on SES conditions from a variety of perspectives requiring a certain amount of coder inference, utilizing three coders, rather than just two, was an appropriate and beneficial design feature.

2.5.4 Define coding schema (categories and organization)

Definition of the coding schema for a comparative or meta-analysis project involves the theoretical interpretation of categories and organization of the relational database (MacQueen *et al.* 1998; Mayring 2000; Hruschka *et al.* 2004; Weed 2005; Guest and MacQueen 2008). The theoretical interpretation of categories refers to a deductive approach to specifying themes, codes, or variables which will be searched for and coded within the texts and which are based on a defined body of theory (Weed 2005). The organization of the relational database simply refers to the way that the data will be organized in the database.

The primary coding categories used within our study were derived from the expanded design principles defined by the Cox (2010) study (Table 2.1). Araral (2014) argues that there are two specification problems in the Cox (2010) study that may also apply to our study. Araral's (2014) first concern is the re-specification of Ostrom's (1990) DP for clear boundary rules (DP1) into two distinct DPs for user boundaries (DP1A) and resource boundaries (DP1B) (Cox 2010). Araral (2014) asserts that Ostrom (1990) intentionally did not separate the original design principle in this manner because within the "context of collective action in the commons" (p.

18), boundaries refer to enforceable property rights, not spatial boundaries. He also points out that the relevant critical literature has previously illuminated that spatially based definitions of community are problematic because the "overlapping, fuzzy and temporal nature of rights" can lead to difficulties in defining community across scales (Araral 2014). This issue has been previously illuminated in the relevant literature, with claims that spatially based definitions of community are problematic because the overlapping and temporal nature of rights can potentially lead to difficulties in defining community across scales (Brewer 2012; Araral 2014; Barnett and Anderies 2014). Others, however, have suggested that this is a faulty argument and that the distinction made by Cox (2010) is a helpful tool in defining clear agent boundaries (Pitt *et al.* 2012). Ostrom (1990) stated that "Without defining the boundaries of the CPR and closing it to 'outsiders', local appropriators face the risk that any benefits they produce by their efforts will by reaped by others who have not contributed to those efforts" (p. 91). The definition of the CPR boundary can be seen as the definition of the spatial boundary (DP1A), while the exclusion of "outsiders" can be seen as the definition of the user boundary (DP1B).

Araral (2014) also points to the definition of a "successful CPR" as the second specification error of concern. Our team found that the definition of success and failure are complex, and ended up using a different approach than that reported by Cox (2010). Cox (2010) defined "success" in cases that "reported successful long-term environmental management" (Cox 2010), while we define success according to a number of dimensions defined by social and ecological outcomes variables (Table 2) drawn from the CPR project coding schema (Ostrom *et al.* 1989), including: 1) resource sustainability (variables 1a-6b); 2) process of collective choice arrangements (variables 7a–9); 3) equity among users (variables 10–13); and 4) overall assessment of Success or Failure for the case (variable 14). Overall success (used in Baggio *et al.*

2016 and Barnett *et al.* 2016) was then coded as “success” when the resource was utilized sustainably, and there was an absence of conflict among resource users. We also used CPR variables to augment each DP variable, making each DP a theoretical category. Fifty-seven variables, in total, were specified and divided into 15 categories; one for each of the four dimensions of outcome “success” and the 11 expanded design principle categories (Table 2.2).

The specification of success may be a fundamental issue in our field (Araral 2014). Ostrom (1990) defined “success” within CPR governance as those “institutions that enable individuals to achieve productive outcomes in situations where temptations to free-ride and shirk are ever present” (p. 15). “Institutions” are the rules, norms, and shared strategies that people use to organize all forms of repetitive and structured interactions at all scales (Ostrom 2005). When Ostrom talks about “success,” she is referring to successful collective action. Cox (2010) used this definition, stating that cases were coded as unsuccessful if there was a “clear failure in collective action and management” (p. 40). Both the Cox (2010) definition and the outcomes variables, which we used to construct our definition of success, capture this part of Ostrom’s (1990) definition. The major difference in Cox (2010), however, comes from including the idea of “long-term environmental management” (p.40) which is not included within the outcome variables used in our study. While the idea of long-enduring CPR institutions is well founded within the literature (Ostrom 1990; Ostrom 2005; Anderies *et al.* 2004; Cox 2010; Poteete *et al.* 2010), we found this to be a difficult concept to assess within the meta-analysis of secondary data. Most cases in the dataset only captured a limited snapshot in time and did not include adequate longitudinal data to indicate the longevity of success within the case. In addition, Cox (2010) divided some texts into separate cases for a single location but different time periods, which further limited any temporal analysis of success.

Table 2.2: Coding variables/questions and categories

Outcomes variables categories

Resource sustainability (12 variables)	Process of collective choice arrangements (4 variables)	Equity among users (4 variables)	Overall success/failure of the CIS (4 variables)
1a and 1b: Quality of units being withdrawn 2a and 2b: Maintenance of public appropriation infrastructure 3a and 3b: Maintenance of public distribution infrastructure 4a and 4b: Maintenance of public production infrastructure 5a and 5b: Balance of resource availability and withdrawal 6a: Changes in condition of natural infrastructure 6b: Changes in condition of human-made hard infrastructure	7a and 7b: Levels of trust among appropriators 8: Changes in trust level 9: Rule following	10: Disadvantaged appropriators 11: Harm to those who are worst off 12: Distance between least and most advantaged 13: Changes in the levels of equity among appropriators	14: Success or failure)

Expanded design principle variable categories

DP1A (2 variables)	DP1B (2 variables)	DP2A (2 variables)	DP2B (2 variables)	DP3 (7 variables)
15: Well defined group 16: Presence or absence of DP	17: Spatial boundary construction 18: Presence or absence of DP	19: Rule flexibility 20: Presence or absence of DP	21: Rule fairness 22: Presence or absence of DP	23: Options to express needs to decision makers 24, 24.1 and 24.2: Chief exec. position 25, 25.1: Proposed collective choice rules 26: Presence or absence of DP

DP4A (5 variables)	DP4B (4 variables)	DP5 (3 variables)	DP6 (2 variables)	DP7 (4 variables)	DP8 (3 variables)
27 and 27.1: Records of use 28 and 28.1: Records of resource condition 29: Presence or absence of DP	30: Self-monitoring 31 and 31.1: Official guard 32: Presence or absence of DP	33 and 33.1: Sanctions vary 34: Presence or absence of DP	35: Arenas for exchange of info 36: Presence or absence of DP	37, 37.1 and 37.2: Right to participate in management 38: Presence or absence of DP	39: Chief exec. report externally 40: More than one organization 41: Presence or absence of DP

Agrawal (2014) has argued that commons scholars have not clearly differentiated between different measures, dimensions, and outcomes but have relied upon relatively vague terms like “sustainability”, “success”, and “long-term viability” instead. This raises fundamental questions within our field about what constitutes appropriate longevity for an assessment of success in a case and/or across comparative cases. Ambiguities involved in the specification of variables and problems with the definition of success and longevity assessments in cases made it difficult to reproduce the results of the Cox (2010), study and hindered our synthesis and meta-analysis efforts. Specification problems, like these, are often key drivers of the missing data problem in studies which can plague both analysis efforts and intercoder agreement and require further dialogue within the field of research (Araral 2014).

2.5.5 Develop codebook and code sample set

According to the methods literature, sample coding should typically be performed on a random sub-set of the dataset and coding questions should be iteratively refined until intercoder reliability testing results are deemed satisfactory (Mayring 2000; Hruschka *et al.* 2004). Sample coding is the testing of the coding schema on a small random sample of the data to facilitate iterative refinement prior to the coding of the full dataset. The variables described in Table 2.2 were initially documented in a set of preliminary coding questions and were pre-tested on a sample of three cases representing each sector (fisheries, forestry, irrigation) randomly selected from the existing CPR database. This allowed us to compare current coding[3] results with those of the

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[3] Results from the sample coding of the three CPR cases were compared to the original results for those cases contained within the relational database for the CPR Project (Ostrom *et al.* 1989) and so were comparable with only those variables extracted from the CPR project (45 variables), not including the “Success” variable or any of the 11 expanded design principle variables.

original coding conducted by Ostrom's team (1989) and determine consistency in the interpretation of the CPR variables. Although the three sample cases from the CPR database were not a part of the dataset for the meta-analysis project, this allowed us to more accurately assess alignment with the CPR variables thereby providing a measure of inter-coder agreement. Coding results from the pre-test sample coding were subjected to formal intercoder reliability testing by one of the primary investigators of the project before coding the entire dataset commenced. Any questions related to further interpretation of variables were discussed and clarified by the entire research team during periodic meetings as an informal means of increasing intercoder alignment. Issues clarified in project meetings were then incorporated into a preliminary coding guide which included the questions for each of the original 57 coding variables supplemented with explanations and answers derived from coder questions and team discussions.

2.5.6 Perform intercoder reliability testing and iteratively refine

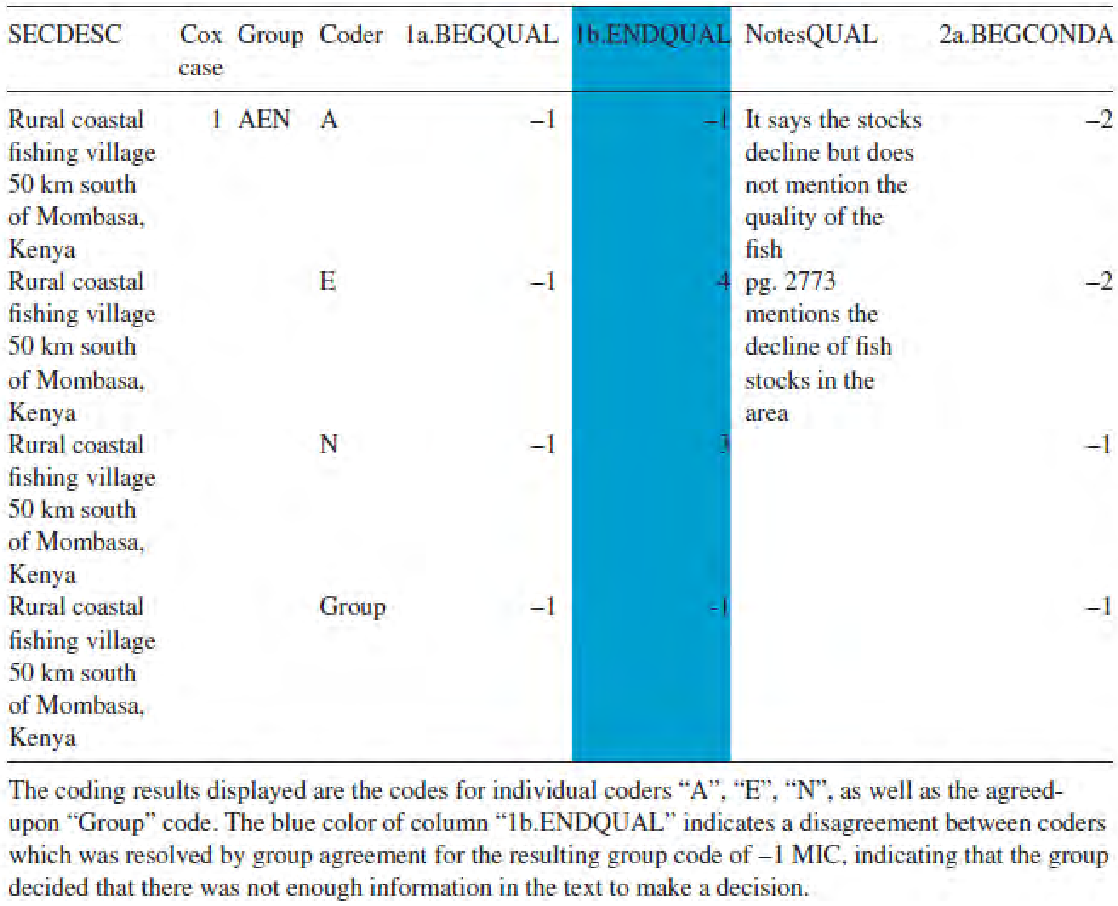
The best practices model (Figure 2.1) recommends formal intercoder reliability testing on a subset of the dataset, as well as iterative intercoder agreement testing throughout and after the formal coding process (MacQueen *et al.* 1998; Mayring 2000; Hruschka *et al.* 2004; Guest and MacQueen 2008). We have found that this step is often missing from reports on studies of CPRs using meta-analyses (Netting 1976; Wade 1984; Berkes 1989; Ostrom 1990; McKean 1992; Baland and Platteau 1999; Bardhan and Mookherjee 2006; Cox 2014; Epstein *et al.* 2014; Fleischman *et al.* 2014; Villamajor-Tomas *et al.* 2014). Hruschka *et al.* (2004) explain that a reluctance to assess coder agreement is common in some branches of social science because: (1) researchers may generally believe that the quantification of qualitative data is unnecessary because qualitative research is a "distinct paradigm" that cannot or should not be subject to a quantitative evaluation; and (2) there is a general skepticism about the ability to actually measure subjective data and reproduce coding results. We believe the latter argument to be the most viable reason for the apparent lack or under-reporting of intercoder reliability testing in our field but have found that it would potentially be helpful when iteratively included throughout the coding process.

Our team only tested intercoder agreement on the initial sample set of CPR cases and did not test for intercoder reliability again until the analysis and interpretation phase of the project. Our informal coding guide development process was aimed at establishing an informal feedback loop of intercoder alignment, refinement of theoretical interpretations and iterative adjustments to the coding questions based on ambiguities and questions that arose during the coding process. Assessment of coding conducted in other studies (Ostrom *et al.* 1993; Wollenberg *et al.* 2007; Cox 2014) suggests that this is a more common practice in our research community than the more formal methods. Hruschka *et al.* (2004) recognize this consensus-based approach toward "interpretive convergence" (p. 321) as a potentially useful method for increasing intercoder reliability, but state that more analysis may be needed to determine the validity of this approach.

2.5.7 Code dataset

Coding is the essential activity of the content analysis methodology and requires the identification of themes or categories that appear in text or other media segments (Hruschka *et al.* 2004). Coding can be done in a number of ways ranging from highlighting pieces of text by hand to the use of sophisticated Qualitative Data Analysis (QDA) software packages. While QDA software is sometimes expensive and requires training, some studies have found that use of QDA software has been found to aid in increasing rigor and intercoder reliability during the coding process (Denzin and Lincoln 2000; Rambaree 2007), allowing coders to identify and tag specific text segments and associate them with a particular category or memo. Texts coded by individual coders can later be combined and analyzed, thus allowing for easier identification of coding discrepancies (Bernard and Ryan 2010). In contrast, hand-coding and/or use of spreadsheet software is inexpensive and requires little to no additional coder training.

Individual coders on the CBIE team coded text segments which they felt exhibited explicit evidence supporting their answer to each of the 57 coding questions and documented the answer to the question and the supporting text segment(s) in spreadsheet format (Figure 2.2). QDA software was not used in the CBIE project due to time and cost constraints. Each team of three coders then met to compare answers and decide upon a single group code, reducing the subjectivity of codes and generating more reliable coding (Hruschka *et al.* 2004). Where there was consensus on the answer to a coding question between the individual coders on any variable, the same answer was given as the group code for that variable. Selected text segments were then utilized as "evidence" of an appropriate code when mitigating discrepancies between team members to arrive at an agreed-upon group code. Any coding disagreements were resolved through group discussion among the coding team members and during project meetings where study PIs addressed unresolved issues. Final coding results for all cases were later combined into a single master spreadsheet.



SECDESC	Cox case	Group	Coder	1a.BEGQUAL	1b.ENDQUAL	NotesQUAL	2a.BEGCONDA
Rural coastal fishing village 50 km south of Mombasa, Kenya	1	AEN	A	–1	–1	It says the stocks decline but does not mention the quality of the fish	–2
Rural coastal fishing village 50 km south of Mombasa, Kenya			E	–1	4	pg. 2773 mentions the decline of fish stocks in the area	–2
Rural coastal fishing village 50 km south of Mombasa, Kenya			N	–1	3		–1
Rural coastal fishing village 50 km south of Mombasa, Kenya			Group	–1	-1		–1

The coding results displayed are the codes for individual coders "A", "E", "N", as well as the agreed-upon "Group" code. The blue color of column "1b.ENDQUAL" indicates a disagreement between coders which was resolved by group agreement for the resulting group code of –1 MIC, indicating that the group decided that there was not enough information in the text to make a decision.

Figure 2.2: Example of coding results by case study (column SECDESC) and coding group (AEN)

2.5.8 Analyze and interpret results - *post hoc* intercoder reliability testing

Analysis of coding team dynamics and formal post hoc intercoder reliability testing[4] (see Supplementary Material) were conducted along with other analyses for the meta-analysis study (Baggio *et al.* 2016; Barnett *et al.* 2016). Results showed potential inconsistencies in intercoder agreement and coding team dynamics may have developed from the informal consensus-based process used by the CBIE team. The

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[4] Reflexive analyses, select social network analysis, and intercoder reliability testing were performed to better understand the coding team dynamics and coding processes.

informal methodology may have resulted in distinct advantages for coders who were able to more forcefully argue their positions or better document all instances of text that led them to code a variable in a certain way, highlighting the need for explicit rules of coding and for increased attention to both intercoder agreement and reliability (MacQueen *et al.* 1998; Stemler 2001).

Post hoc intercoder reliability ratings were calculated to examine the overall intercoder agreement by team, but also to determine which coding variables were more difficult to identify within the texts (see Baggio *et al.* 2016). We found that inconsistencies the challenges discussed above contributed to low intercoder reliability ratings, but that these challenges are not insurmountable. They should be considered part of a normal coding process and are typical of many similar projects within our field of study. Coder agreement is generally expected to be low initially, particularly when coding "focuse[s] on identifying and describing both implicit and explicit ideas" (Namey *et al.* 2008, p.138), such as inferring the presence or absence of DPs in case studies. The fact that many case studies in our dataset were lengthy texts may have further contributed to marginal intercoder agreement. These challenges can be decreased through more formal methods, like the "best practices" model presented here (Figure 2.1). For example, to address discrepancies in coder interpretation, the literature recommends coding several iterations of subsets of the data, followed by formal reliability testing (percent agreement and a Kappa statistic that takes chance into account) and iterative codebook revisions until acceptable intercoder reliability ratings have been reached (Hruschka *et al.* 2004; MacQueen *et al.* 2008; Bernard 2011). Once acceptable intercoder agreement has been reached, coding of the entire dataset proceeds which is supplemented by continued random sample intercoder reliability testing to prevent "coder drift" or "code favoritism" (Carey and Gelaude 2008, p.251).

Data preparation

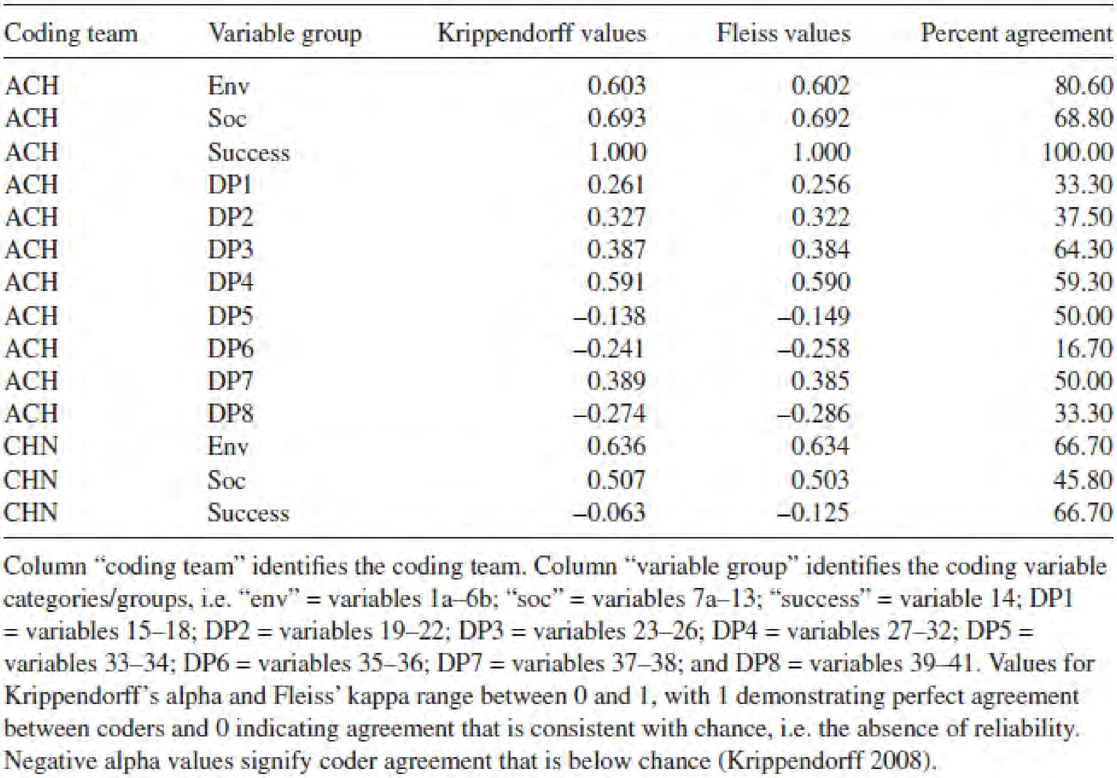
Post hoc intercoder reliability testing required considerable data preparation in order to unify coding data, minimize bias due to incompatible comparisons, and transfer complex coding values into a format that could be analyzed by intercoder reliability statistical software. Details of these processes are outlined in the Supplementary Materials.

Intercoder reliability testing

For coding projects involving ¿2 coders and coding values that are nominal and multiple, Feng (2014) recommends Krippendorff's alpha, Fleiss' kappa, and/or percent agreement. Krippendorff's alpha is a reliability coefficient that is a "generalization of several known reliability indices" (Krippendorff 2013, p.1). Its advantage lies in its ability to calculate intercoder agreement among an indefinite number of coders and any number of scale values. It can handle missing and incomplete data, as well as large and small sample sizes and is considered a robust measure of intercoder reliability (Bernard and Ryan 2010; Krippendorff 2013). Fleiss' kappa is a variant of the popular Cohen's kappa statistic which allows for more than two coders (Bernard and Ryan 2010). Similar to Krippendorff's alpha, Fleiss is a statistic that measures coders' agreement with respect to chance (Bernard 2011). Finally, although simple percent agreement tends to overestimate intercoder reliability because it does not account for chance agreement (Hruschka *et al.* 2004; Feng 2014), it is appropriate to utilize this technique in conjunction with other measures if the variables analyzed are nominal (Feng 2014). Simple percent agreement provides a good yardstick to determine whether the intercoder reliability ratings obtained through Krippendorff and Fleiss may be skewed due to particularly high agreement or missing variables.

Utilizing the irr-package in R (Gamer *et al.* 2012), intercoder agreement for all three statistics was calculated for 11 variable groups in each of the 13 coding teams (see Figure 2.3 for excerpt and the Supplementary Material for complete intercoder reliability ratings and R code). Before evaluating whether coding agreement reached high (¿0.80) or acceptable (0.70–0.79) reliability levels, simply adding the Krippendorff and Fleiss values by variable group and coding team provides a first insight into those variable groups/teams with high/low scores. For the Krippendorff values, Figures 2.4 and 2.5 reveal DP1 (clearly defined boundaries) and coding team "AEN" as those with the highest intercoder agreement. In contrast, DP8 (nested governance) and team "ACH" had the lowest intercoder agreement. Fleiss' statistics mirrored those findings (see Supplementary Material). This suggests that determining the evidence of resource and user boundaries within a case study requires less inference from coders than determining whether the reported institutional structure represents a "nested enterprise." For codebook and coding protocol development purposes, such initial high/low values could be important bellwethers of particularly well or poorly functioning coding questions/teams, identifying weaknesses that may require further investigation in order to strengthen intercoder agreement before commencing with coding the entire dataset.

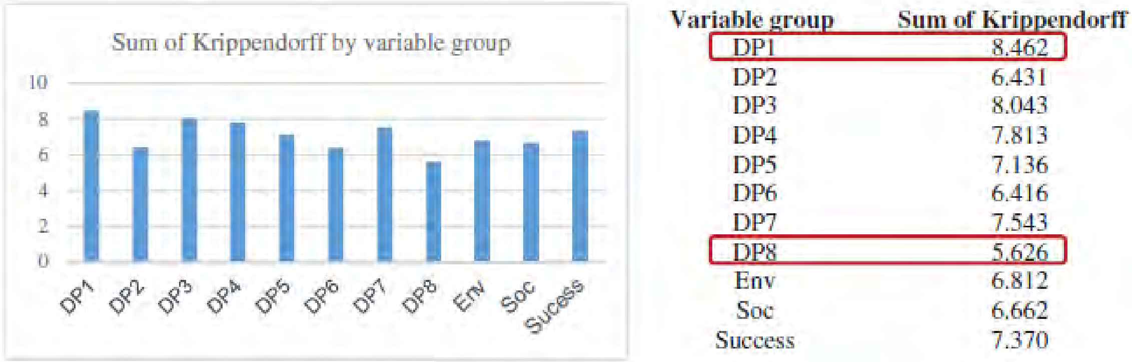
Despite the aforementioned problems, many of the intercoder agreement ratings were ¿0.65 for both Krippendorff and Fleiss statistics. This places our data reliability/replicability factor only slightly below the 0.70 score that is generally deemed as acceptable in the literature. Given the subjective nature of some of the variables, the large number of missing values, and the iterative nature of our coding process, such ratings are defensible for the completed project and may easily be improved in the future through the use of a more detailed codebook and coding protocol. More importantly, by disclosing our intercoder reliability ratings, procedures, preliminary codebook and coding protocol, we have taken additional steps to enhance the ability of others to analyze and replicate our findings as well.



Coding team	Variable group	Krippendorff values	Fleiss values	Percent agreement
ACH	Env	0.603	0.602	80.60
ACH	Soc	0.693	0.692	68.80
ACH	Success	1.000	1.000	100.00
ACH	DP1	0.261	0.256	33.30
ACH	DP2	0.327	0.322	37.50
ACH	DP3	0.387	0.384	64.30
ACH	DP4	0.591	0.590	59.30
ACH	DP5	–0.138	–0.149	50.00
ACH	DP6	–0.241	–0.258	16.70
ACH	DP7	0.389	0.385	50.00
ACH	DP8	–0.274	–0.286	33.30
CHN	Env	0.636	0.634	66.70
CHN	Soc	0.507	0.503	45.80
CHN	Success	–0.063	–0.125	66.70

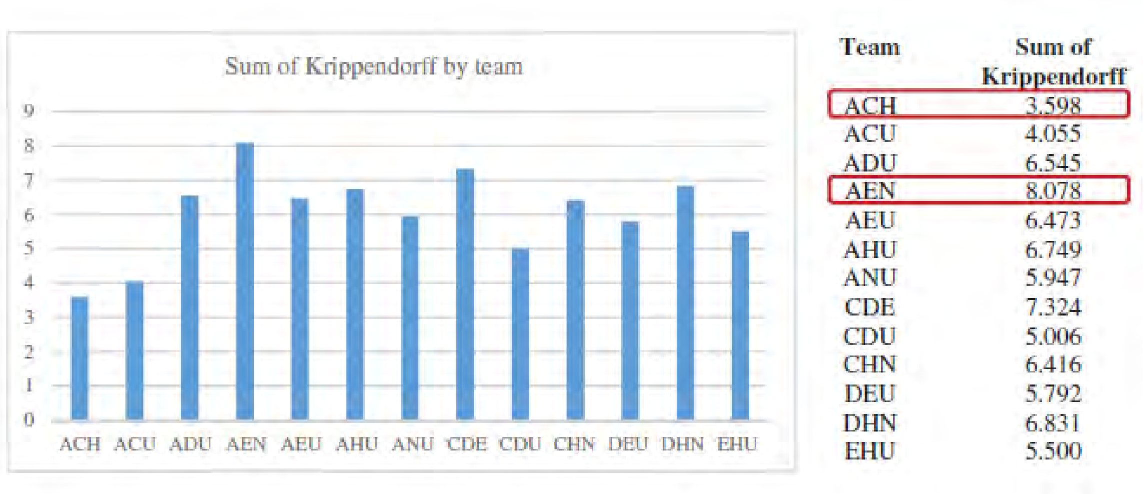
Column “coding team” identifies the coding team. Column “variable group” identifies the coding variable categories/groups, i.e. “env” = variables 1a–6b; “soc” = variables 7a–13; “success” = variable 14; DP1 = variables 15–18; DP2 = variables 19–22; DP3 = variables 23–26; DP4 = variables 27–32; DP5 = variables 33–34; DP6 = variables 35–36; DP7 = variables 37–38; and DP8 = variables 39–41. Values for Krippendorff’s alpha and Fleiss’ kappa range between 0 and 1, with 1 demonstrating perfect agreement between coders and 0 indicating agreement that is consistent with chance, i.e. the absence of reliability. Negative alpha values signify coder agreement that is below chance (Krippendorff 2008).

Figure 2.3: Excerpt of intercoder reliability testing results (all statistics)



Variable group	Sum of Krippendorff
DP1	8.462
DP2	6.431
DP3	8.043
DP4	7.813
DP5	7.136
DP6	6.416
DP7	7.543
DP8	5.626
Env	6.812
Soc	6.662
Success	7.370

Figure 2.4: Sum of Krippendorff values by variable group for all coded cases. Results indicate that generally Design Principle 1 (DP1) had the highest overall intercoder agreement and Design Principle 8 (DP8) the lowest



Team	Sum of Krippendorff
ACH	3.598
ACU	4.055
ADU	6.545
AEN	8.078
AEU	6.473
AHU	6.749
ANU	5.947
CDE	7.324
CDU	5.006
CHN	6.416
DEU	5.792
DHN	6.831
EHU	5.500

Figure 2.5: Sum of Krippendorff values by coding team/all cases coded. Results reflect highest coder agreement for team AEN and lowest coder agreement for team ACH

Coder drift

One important reason we found to assess intercoder reliability is known as "coder drift". Coder drift is the process over time, in which coders may become less reliable in their coding due to the adoption of coding biases and the not-rigorous application of coding criteria (Bartholomew *et al.* 2000). To avoid coder drift, Carey and Gelaude (2008) recommend spot checking of coder agreement throughout the coding process. After coding was completed and intercoder reliability ratings performed, discussion among coders revealed that there may have been some coder drift which could have produced inconsistencies in the way that coders applied information within the text to answer the question of overall success (variable 14). In our study, spot checks of coder agreement throughout the coding process may have mitigated some of the ambiguity with regard to coders' assessment of "success". Subsequent random sampling of the answers given to question 14, as well as purposive sampling of an additional ten cases, revealed notes that indicated several coders may have considered more than the outcome variables in their answer to this question. However, in all but two cases, coders were in agreement with their assessment of the studies overall success or failure, regardless of the potential for coder drift. In the two instances of coder drift where there was no initial coder agreement, the coders were able to resolve the disagreement through discussion. As outlined throughout this paper, a codebook containing detailed coding descriptions that is iteratively updated to include coder questions and coding ambiguities, as well as continuous spot-checking of intercoder agreement, might have resolved these instances of coding bias.

2.6 Recommended coding protocol

Through analysis of our coding process and review of the literature, we have found that increased transparency, reliability, and replicability are of primary importance in increasing our ability to perform meta-analysis and the synthesis of case studies. While qualitative research often generates complex information that is difficult to process and can lead to judgments based on subjective, or "intuitive heuristics" (Hruschka *et al.* 2004), the level of agreement can and should be quantified. It is precisely the subjective nature of the evaluations which makes them more susceptible to individual interpretation and the intentional or unintentional introduction of biases, random errors, and other distortions (Hruschka *et al.* 2004; Krippendorff 2013). The establishment of more rigorous coding protocols including intercoder reliability testing represents an effort to "reduce [such] error and bias" (Hruschka *et al.* 2004) by ensuring that the data meaning remains consistent across a variety of coders and research teams. In fact, it can be argued that coding is an essential element of classical content analysis because it converts qualitative data into datasets that are supportive of robust analyses and can be replicated by other scholars (Krippendorff 2013). Replicability creates greater reliability which empirically grounds confidence in the data and, thus, the study findings (Krippendorff 2013). For these reasons, we include here our *Recommended Coding Protocol* (Figure 2.6). This is based, in retrospect, on the examination of the CBIE meta-analysis project, but we will briefly discuss the considerations which may be affected by project and team type. More detailed information on all steps outlined here can be found in the *Detailed Recommended Coding Protocol* included within the Coding Manual in the Supplementary Material.

2.6.1 Preliminary considerations

We found a number of preliminary considerations (gray boxes in Figure 4) which should precede the coding process.

Identify dataset

We highly recommend that teams develop a screening process during the identification of the dataset to ensure that cases included in the study have sufficient information to answer the research question. Inclusion/exclusion and text segmentation criteria should be clearly defined and reported. This step is likely to decrease missing and ambiguous data for analysis.

Select qualitative data analysis (QDA) software or other technique for coding

Teams should consider the use of QDA software prior to the commencement of the coding process. Although QDA software will add cost and training considerations to the project, it may facilitate data processing, decrease discrepancies, and potentially reduce the time needed to conduct intercoder reliability testing.

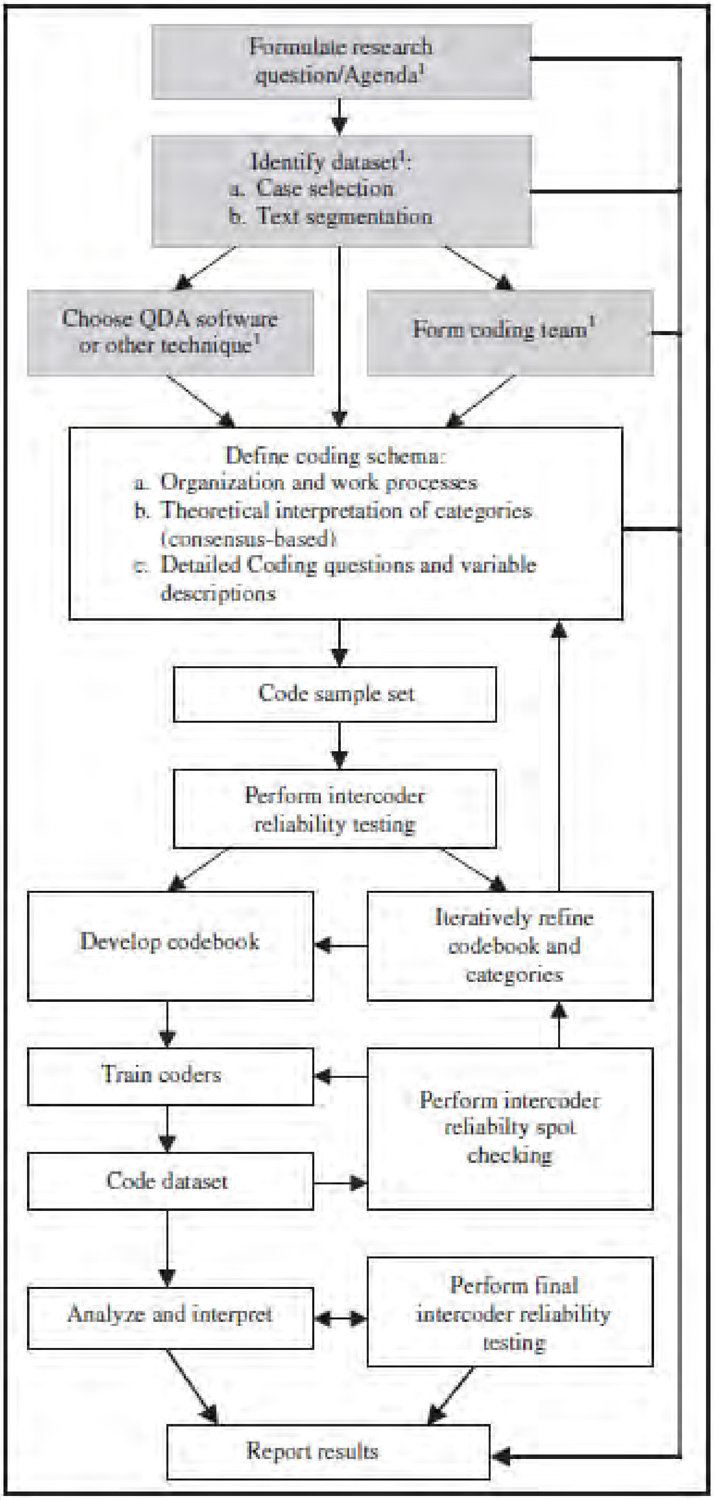


Figure 2.6: Recommended coding protocol. ¹Boxes shaded in gray represent preliminary considerations, while unshaded boxes are a part of the main coding process.

Form coding team

We found that utilizing two or more coders increases data reliability because coding agreement between different people, who have been given the same instructions and have independently coded the same text segments, demonstrates a reduction of subjective biases and increases data reliability (Guest and MacQueen 2008). Coding team dynamics may be a concern, however, such dynamics can be mitigated through the use of more rigorous coding protocols and coder training. Although each additional coder increases the need for iterative intercoder reliability testing and training to achieve intercoder alignment, two coders per text should be a necessary condition for any meta-analyses.

2.6.2 Coding process

Defining coding schema

We recommend that coding schema definition include explicit consideration and documentation of the organization and work processes to be used during the coding process, the development of detailed coding variable descriptions, and the iterative and consensus-based definition of theoretical categories by the entire coding team.

Sample coding and intercoder reliability testing

We recommend that the principal investigator and all coding team members independently test code a randomly selected subset of the actual dataset, followed by formal intercoder reliability testing of the results until acceptable levels of intercoder reliability ratings have been reached.

Codebook development, iterative refinement and training

We recommend that a consensus-based process of codebook development, based on the previous definition of the coding schema, sample coding, and intercoder reliability testing be included in the coding process. This can be considered part of coder training. Discussions on the development of codes and theoretical categories among the coding team will likely result in increased understanding of key issues and variables to be coded. Training should also include coder instruction in the use of any selected QDA software.

Coding with intercoder reliability spot checks

Once acceptable intercoder reliability ratings have been achieved through sample coding and iterative codebook refinement, the entire dataset can be coded. At least one spot-check should be performed during this process to assess coder drift.

Analyses and interpretation of results with final intercoder reliability testing

The coding process should be assessed, along with final intercoder reliability testing, after coding is complete. The results of these analyses should be reported in the final project outcomes.

Reporting of results

Results should include the analyses of the data produced by the coding process, such as that reported in Baggio *et al.* (2016) and Barnett *et al.* (2016), but should also include the explicit disclosure of assumptions made during the preliminary steps of the project, as well as an analyses of the coding process itself and final intercoder reliability testing.

2.7 Conclusions

Social-ecological systems (SESs) vary across spatial and temporal scales and studying them is critical to understanding governance challenges involving common- pool resources (CPRs). Scholars, like Agrawal (2014) and Araral (2014), see current trajectories within SESs research as fundamental, yet still in their infancy. Araral (2014), in particular, argues that Ostrom's theories may only be applicable to the special case of locally governed, small-scale commons and may not be easily generalized. The body of evidence collected within Ostrom's legacy has not been able to effectively assess natural resource issues at larger scales. We question whether there has been a sufficiently sizable body of data gathered and analyzed, including information on larger-scale systems, multi-scalar governance structures, temporal dimensions, and other important factors with which to compare the existing studies, or if there are any sufficiently developed methods by which to conduct such comparisons.

It was one of Ostrom's (2005) deep convictions that SESs are composed of a set of universal building blocks which could be tapped to create adaptive and long-enduring governance systems. Work towards creating a methodology that will foster cooperation and cross-comparison of data could allow us to expand our understanding of these systems. By sharing our coding experience and protocols, we hope to stimulate the development of transparency norms within the commons research community which others may build upon as we move further toward the identification of these universal building blocks. It is important to continue pushing social-ecological science towards greater rigor and a greater understanding of the complex interactions that lead to successful outcomes. Towards this goal, we assert that methodology must be tested and refined for more precise measurement of the dependent and independent variables involved in SESs. Furthermore, the commons research community should work to ensure that studies are replicable and that different research teams are able to achieve similar answers. In conclusion, while there may be many challenges and opportunities associated with the coding and synthesis of case studies, increased collaboration and consensus in a few key areas within the research community may lead to new horizons and possibilities in understanding SESs and the commons.

2.8 Supplementary files

Supplementary File 1: http://doi.org/10.18352/ijc.652.s1 S1 Supplementary material. Dataset repository matrix, coding manual and protocols.

Chapter 3

DESIGNARE: DESIGN IN COMMON-POOL RESOURCE SYSTEMS FROM A COMPLEX ADAPTIVE SYSTEMS PERSPECTIVE

3.1 Introduction

Design is a fundamental human activity through which we attempt to navigate and manipulate the world around us for our survival, pleasure, and benefit. Design is the primary way that humans attempt to exert control on the complex and dynamic systems that we exist within and a key dynamic within these systems. As human society has evolved, so too has the complexity and impact of our design activities on the environment. Now clearly intertwined as a complex social-ecological system at the global scale, we sometimes struggle in our ability to understand, design and implement solutions to complex global issues such as climate change, water scarcity, food security, and natural disasters. Some have asserted that this is because complex adaptive systems (CAS) are inherently "moving targets" that are both partially designed and partially emergent and self-organizing. Furthermore, these types of systems are difficult to understand and control due to the dynamics of "wicked problems", such as: uncertainty, social dilemmas, inequities and trade-offs involving multiple feedback loops, sometimes causing problems and their potential solutions to shift and evolve together (Rittel and Webber 1973). These problems do not, however, negate our collective need to design, produce, and implement strategies that allow us to effectively appropriate, distribute, manage and sustain the natural resources on which we depend. In this chapter, I explore the Coupled Infrastructure Systems (CIS) Framework by Anderies *et al.* (2016) as a tool for systematically organizing and integrating key concepts related to understanding design and emergence in complex adaptive systems (CAS) involving common-pool resources (CPRs). I discuss these findings as an important step forward toward actualizing the goal of understanding ”partly designed, and partly self-organizing systems” (Anderies 2015) and the development of a theory of design for common-pool resource systems.

The study of complex adaptive systems is relatively new, and yet it has become an important part of understanding the world in which we live and our place within it. *Complex adaptive systems* (CAS) are defined as dynamic networks of heterogeneous agents that interact locally and self-organize to generate emergent patterns at the system level that cannot be predicted by the behavior of the individual components (Holland 1992; Miller and Page 2009). As Miller and Page (2009) state, “the field of complex systems challenges the notion that by perfectly understanding the behavior of each component part of a system we will then understand the system as a whole” (p.3). While Holland (1992) describes CAS as “moving targets” (p.18) that are difficult to understand and control, design is a necessary part of humanities role within them. Complex issues like climate change, water scarcity, and food security have made an understanding of design and emergence within systems involving the common-pool natural resources on which we depend particularly crucial. Yet, while emergence is a well studied and integral phenomenon in complex adaptive systems science (Holland 1992; Liu *et al.* 2007; Levin 2005; Lansing 2003; Miller and Page 2009; Mittal and Rainey 2015), the concept of *design* is not as well understood for this context.

Design, however, is a sometimes controversial concept within the CPR literature and a difficult concept to map. In this study, I seek to explore and integrate various features of the concept of “design” and discuss their applicability to CPR systems from a CAS perspective. Because the study of CPR systems is a highly interdisciplinary field, I first investigate general concepts of design from a number of disciplinary perspectives to identify key features of this conceptual landscape. In section 3, I introduce the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016), a relatively new development in the legacy of Ostrom, and identify some of the key developments of this research trajectory that may specifically help in understanding "design" within CPR settings. According to Ostrom (2005), frameworks such as the CIS Framework can help to identify key elements and relationships at the broadest level and can also provide the metatheoretic language that is necessary to talk about and compare various theories (p.28). In section 4, I discuss and utilize the CIS framework to integrate the key concepts and features of design with the foundational theories associated with understanding and sustaining CPR systems from a CAS perspective. Finally, I conclude with some suggestions on moving toward a theory of design that is specific to CPR settings.

3.2 Defining Design

The concept of *design* can be understood in a multitude of ways from a number of different disciplinary perspectives, many of which may influence thinking within the study of complex adaptive systems because of the interdisciplinary nature of this field. It is, therefore, important to begin with a good understanding of the key features within the conceptual landscape of design, itself. This will then help in guiding the analyses of what design means within the context of CAS systems involving CPRs.

3.2.1 Methods

To do this, I use content analysis techniques, which are useful in systematically coding and analyzing qualitative data, usually in the form of texts, images, and other types of media content (Bernard 2011). The analyses can be used both qualitatively and quantitatively for a mixed methods approach (Holsti 1969). Because this is an investigation of a cultural construct, purposive, non-probability sampling from "expert informants" is required (Bernard 2011, p.143). While the determination of appropriate sample size in this type of sampling is not well agreed upon, Bernard (2011) recommends a range of 10-50 observations, depending on the type of study (p.154). Miles and Huberman (1994) recommend merely that sampling be continued until saturation occurs, when no new substantive information is being acquired. A sample of 70 representations were found for this study, derived from online dictionaries, scholarly books and articles, and a number of other sources (i.e. educational and professional web-sites). Over half of the sample (i.e. 45 out of 70) were text-based, including: 28 distinct dictionary definitions of "design" from 5 different online dictionaries (Dictionary.com; Merriam-Webster.com; Oxforddictionaries.com; Macmillandictionary.com; and dictionary.cambridge.org); and 17 definitions derived from scholarly books and articles. Finally, because the concept of design is often found to be represented visually, 25 diagrammatic models of design were also included, derived from a variety of online and scholarly sources (e.g. educational and professional web-sites, magazines, or blogs).

Table 3.1: Sample definitions/representations of "Design" by discipline

Policy/Planning	**Organizational Management / Strategy**	**Design Theory**	**Design Practice***
7	6	6	6
Engineering / Info / Controls	**Systems Science (STS/SES)****	**Sustainability**	**Dictionary**
6	6	5	28

* The Design Practice category includes professional disciplines such as architecture, industrial design, graphic design. Engineering disciplines are separated as a distinct category.

** Socio-Technical Systems (STS) and Social-Ecological Systems (SES) are two different areas of coupled systems research which can be placed under the umbrella of Systems Science.

The sample of both text-based and diagrammatic representations was inductively coded, by two independent coders, to identify the dominant themes present in the sample. *Coding* is the classification and quantification of media segments to preserve them in a form that can be subjected to other formal analysis techniques (Hruschka *et al.* 2004). In this case, a segment of text (i.e. fragment of a sentence) or segment of a diagram (i.e. a word, line or arrow) was highlighted, or coded, when thought to include an important feature defining the concept of design. Inter-coder agreement was achieved through discussion and consensus whenever differences or disputes occurred. While two or more coders are generally required to establish data reliability and replicability (MacQueen *et al.* 1998), research projects are often limited by the increasing amounts of time and funding necessary for the development of larger coding teams and protocols. Bernard and Ryan (2010) state that the number of required coders depends both on the "prevalence of the themes" and the "level of inference required to identify themes" (p.306). If coding themes occur frequently and are easier to infer, it can be assumed that even inexperienced coders would find supporting examples of the theme and thus fewer coders is acceptable. Because the level of inference required to identify themes from words and diagrams defining "design" was considered to be generally low, and because of both time and financial constraints, the use of two coders was considered sufficient for this part of the investigation.

The investigation revealed that definitions of design are divided into three distinct forms: 1) the noun-form of design as a "thing"; 2) the verb-form of design as an activity; and 3) design as a process involving a system of activities and things (see Table 3.2). Within the 45 text-based definitions (See Appendix), 12 are noun-form, 23 are verb-form and 10 are process-form definitions. All 25 of the diagrams represent processes, though some are linear processes while others are iterative or reciprocal.

3.2.2 Design as a Thing

Twelve of the sampled text-based definitions describe design as a particular type of thing, such as a plan, an outline or a blueprint (Table 3.2). In the original introduction to Victor Papanek's book, *Design for the Real World* (1971), Buckminster Fuller defined design as a mental conception or a pattern. Love (2002), however, describes it as something more material though still preliminary, such as a specification or drawing to be used later for making some particular product or performing a particular activity. On the other hand, Hevner *et al.* (2004) describes a design as an organization of resources to accomplish a particular goal. Others define it as a structure (dictionary.com) or "arrangement of the features of an artifact", which are less preliminary in nature and could even be complete end-products in and of themselves. These scholarly definitions are noun-based and yet describe things that range from immaterial to material and preliminary to more fully formed and complete. The noun-form definitions tend more toward describing something that is material, but also tend toward the description of something that is preliminary, or a precursor to something else, rather than something that is complete.

3.2.3 Design as an Action

Gero (1990) defined *design* as a "goal-oriented, constrained, decision-making activity" in which designers are change agents who's goal is to improve the human condition by "positing functions to be achieved and producing descriptions of artifacts capable of generating these functions" (p.p. 28-29). This is an action, or verb-form of the word *design*, in which the product of the act of *designing* is specifically *a design* in the noun-form of the word. In contrast, Victor Papanek wrote in the opening lines of his book, *Design for the Real World* (1971, p.3):

> All men are designers. All that we do, almost all of the time, is design, for design is basic to all human activity. The planning and patterning of any act towards a desired, foreseeable end constitutes the design process. Any attempt to separate design, to make it a thing-by-itself, works counter to the fact that design is the primary underlying matrix of life. Design is composing an epic poem, executing a mural, painting a master-piece, writing a concerto. But design is also cleaning and reorganizing a desk drawer, pulling an impacted tooth, baking an apple pie, choosing sides for a backlot baseball game, and educating a child.

Nearly half of the text-based definitions for design that were found for this investigation (i.e. 23 out of 45 definitions), describe design as some kind of human activity ranging between Gero's (1990) somewhat restricted description and Papanek's (1971) more open-ended definition of design as an action (Table 3.2). Similar to the noun-form definitions, the types of activities that can be included as design can range from preliminary and immaterial to more fully complete and material. For example, the act of defining a problem or conceiving of something is quite immaterial and a precursor to doing something else. The act of drawing or creating a "design thing" (i.e. design in the noun-form), is also preliminary to the creation of something else but is more substantially material than simply defining or conceiving of something. Creating or building something, testing something that has been created, or changing or reforming something that already exists are all activities that more probably work with something material and complete. New features of the conceptual landscape of *design* begin to emerge, however, when it is defined as an action rather than a thing. For example, Simon (1969) states, "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (p.111). This is the first definition that speaks of changing something that already exists, rather than the creation of something new. In addition, design as an activity also begins to incorporate the idea of an on-going activity (e.g. sustainability or management) and begins to differentiate the creation of systems from more singular things like problems and solutions. Furthermore, definitions of design as an activity begins to define who can design (e.g. designer vs. any human being), and how design is to be carried out (e.g. collaboration, experientially, innovation).

3.2.4 Design as a Process

Some design scholars (Cross 1990; Alicke *et al.* 1994; Bjögvinsson *et al.* 2012) assert that *design* is not than just a single thing or activity, but is a process constituted by a range of connected activities that can produce a range of things. Cross (1990), for example, states:

> Designers produce novel unexpected solutions, tolerate uncertainty, work with incomplete information, apply imagination and forethought to practical problems and use drawings and other modeling media as a means of problem solving.

When the sample of diagrammatic representations is included with the text-based definitions, *design* is most often represented (i.e. 35 out of 70 definitions or representations) or defined as a process. Process-form representations are, by far, the richest form in terms of defining the breadth of activities and spectrum of features that can be included in the concept of *design* (Table 3.2). These representations, like the previous two forms, include activities and products that range from preliminary and immaterial to increasingly more material and complete. Design-processes, however, tend to go beyond design activities to include considerations such as implementation, improvement or change, and sustainability. New features of the conceptual landscape emerge at the design-process level including: evaluation, presentation of the products of design, and feedback as part of the design-process. In addition, process-based definitions or representations tend to include more of the features of the conceptual landscape overall such as the ideas of change or improvement, feedback, sustainability, problem-solving, collaboration, uncertainty, innovation and integration.

3.2.5 Key Features and Conceptual Landscape of "Design"

A number of key features defining a model of the conceptual landscape of "design" have emerged from this investigation (Fig.3.1). First, the conceptual landscape of *design* grows richer as we move up in complexity from design as a "thing", to design as an "action", and finally to the process-form, in which design is a system of connected actions and things. This view of *design as a process* aligns well with the CAS perspective, including ideas such as adaptive cycles and resiliency (Anderies 2015). Second, the most prominent feature of design, across all forms, is that it involves intention and/or purpose. This is an important feature, within the CAS perspective, that could help to differentiate between that which is designed and that which is emergent, or self-organizing, within systems. This feature also becomes important to a CAS perspective when considering the emergence of spillover effects, the unintended consequences that are sometimes the cause of wicked problems. In addition, several other features, or important considerations for design-processes in CAS begin to emerge. Design-processes tend to include actions that go beyond the preliminary acts of decision-making and planning to include acts of development, including: actual creation of things (e.g. plans, forms, and structures); evaluation, incorporation of feedback, and learning; sustainability and maintenance of that which is created; and iteration of the design-process through improvement, change, and innovation. This becomes a crucial point in understanding the relationship between design and the wicked problems of uncertainty, social dilemmas, inequities and trade-offs. CPR systems are fraught with wicked problems which require constant resolution, rather than the design of a "solution" (Rittel and Webber 1973). This implies that our efforts to constantly re-solve issues (i.e. design) within these dynamic systems must also be dynamic, involving constant change, activity, and progress. The design-process must include the ability to iterate, innovate, and progress back onto itself. Finally, the study also reveals that certain features or considerations that are crucial for CPR systems, in particular, only begin to emerge as the complexity of the concept increases, including: an orientation that seeks to integrate design-processes into existing structures and systems; the inclusion of participatory and/or collaborative processes, which Ostrom found to be crucial to the longevity of these systems (Ostrom 1990; Ostrom 1992; Ostrom 2005) including attention to uncertainty and the different types of knowledge which sometimes help to mitigate uncertainty in design-processes.

Figure 3.1: Conceptual Landscape of Design-Processes as a Model of Intentional Change for Complex Adaptive Systems

Table 3.2 illustrates the results of the coding and analysis that led to the development of the conceptual landscape of *design* as a model of intentional change in CAS (Figure 3.1). Some dictionary based definitions were combined on a single row (by source) to condense the table. In addition, many of the process diagrams were found to contain similar information. As a result, repetitive diagrams were omitted from the table when it was found that they did not add any substantial information to the table after the concepts were already captured. The colors on the table represent distinctions between those that are more representative of decision-making (cooler colors) versus those that are more representative of development activities (warmer colors) and those that represent important considerations or features of design (gray). This is meant to indicate that the line between decision-making and development can be “fuzzy” for design-processes and that there are important considerations that can, and must, be taken into account at many stages of design.

Table 3.2: Analyzing Conceptual Landscape of "Design"

	Products/Actions Decisions													Considerations/ Features							
							Development														
	Define/Conceive	**Ideate/Brainstorm**	**Explore Options**	**Choose**	**Sketch/Plan/Draw**	**Launch/Present**	**Develop/Form/Structure**	**Create/Build/Implement**	**Test/Evaluate**	**Feedback/Learning**	**Sustain/Manage**	**Improve/Change**	**Innovation**	**Intention/Purpose**	**Problem/Solution**	**Participatory/Collaborate**	**A priori/Theoretical**	**A posteriori/Experiential**	**Uncertainty**	**Integration**	**Systems Orientation**
Noun-Form																					
Cambridge Dictionary					■									■							
dictionary.com		■			■		■							■							
Fuller (1971)		■			■																
Hevner et al. (2004)	■				■									■							
Love (2002)	■				■									■							
Macmillan Dictionary					■									■							
Oxford Dictionary	■				■			■						■							
Verb-Form																					
Bausch (2002)	■	■												■		■	■	■		■	■
Buchanan (2007)		■			■			■						■				■			
Cambridge Dictionary					■									■							
Charnley and Lemon (2010)	■	■					■				■		■	■	■	■	■	■		■	■
Gero (1990)	■				■		■	■				■		■			■				
Love (2002)								■									■				
Macmillan Dictionary				■										■							
Mau (2007)					■		■			■			■	■				■			
Merriam-Webster	■	■			■		■							■							
Oxford Dictionary				■	■		■							■							
Pourdehnad et al. (2011)	■		■											■							■
Simon (1969)	■											■		■				■			
Process-Form																					
Alexander (1964)								■						■						■	
Brown (2011)							■						■	■			■			■	
Cross (2006)	■	■			■		■				■		■	■	■		■		■		
dictionary.com		■		■	■			■						■							
DesignModo	■		■			■	■		■	■		■		■	■						
DiscoverDesign.org	■	■	■			■	■	■	■	■		■		■	■						
EmeraldSeven	■	■				■	■	■	■	■		■		■	■	■		■	■	■	■
FAO	■	■	■	■		■	■	■	■	■	■	■		■	■	■	■	■		■	
Innovation Works	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■
Mental Health Commission	■					■	■	■	■	■					■	■	■	■		■	
NASA	■					■	■	■	■	■	■	■		■		■	■			■	
ORGAP.org	■		■	■		■	■	■	■	■	■	■		■	■	■	■	■		■	■
Papanek (2011)					■									■						■	
ScienceBuddies	■	■		■		■	■		■	■		■		■	■		■				
Stanford Design School	■	■				■	■	■	■					■		■	■	■	■	■	
Zurb.com	■	■			■		■	■	■	■		■		■			■				

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[1] Blue represents decision-making activities and the spectrum represents all development activities

[2] The sample included in the table was reduced from 70 to 55 by combining some of the individual text-based definitions (i.e. all definitions from a single source such as dictionary.com), and removing some of the diagrammatic representations based on similarity to other diagrams (no new information).

3.3 Foundational Frameworks for Understanding Design in CPRs

The next step I took in attempting to understand design-processes within complex adaptive systems (CAS) involving common-pool resources (CPRs) is to develop a theoretical framing based on CPR theory. Common-pool resource (CPR) theory has become an increasingly important and foundational part of our understanding of humanity's interactions with the environment and natural resources over the last few decades, particularly when it comes to our intentional activities and decision-making (Schlager 2004). As part of the study of human-environment interactions, CPR theory draws from multiple disciplines, including both social and natural sciences, as well as engineering, information sciences, and mathematics. Originally based primarily in social theories, such as rational choice and game theory, the study of CPRs has subsequently reached further across disciplines and adopted more and more approaches to explain human-environment relationships such as: feedback and control, adaptation, resilience, and complex adaptive systems approaches. These concepts have converged over the past few decades to become a new field of study known as Social-Ecological Systems (SES) science. The key concepts and theories for the study of SESs, with a focus on CPR systems in particular, are brought together through frameworks such as the Institutional Analysis and Development (IAD) Framework (Ostrom 1990), the Robustness of Social-Ecological Systems Framework (Anderies *et al.* 2004), and the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016). According to Ostrom (2005), frameworks like these provide the "metatheoretic language that is necessary to talk about theories and that can be used to compare theories" (p.28). Theoretical and empirical work based on these frameworks has been done by many scholars over the past thirty years to illuminate the key measures, mechanisms and dynamics involved in our relationship with CPR systems, but these studies have focused primarily on static attributes and binary, linear outcomes such as "success" and "failure". Because these are complex adaptive systems fraught with wicked problems, however, we continue to struggle with how we might practically apply the knowledge we've gained in achieving sustainable natural resource use and our ability to "resolve" the problems that emerge from these dynamic systems. This highlights the gap, and need, for a greater understanding of the links between the dynamic processes of design and CAS concepts such as resiliency.

3.3.1 The Institutional Analysis and Development (IAD) Framework

The IAD Framework (Fig.3.2A), and the empirically-based research methodology from which it grew, was an important foundational development early in the evolution of CPR Theory. Ostrom's work (1990) in *Governing the Commons* challenged the conventional wisdom of the mid-19th century by proving that overexploitation was not inevitable and that alternative configurations to strict Market or State control of natural resources could work. She stated, "Instead of there being a single solution to a single problem, I argue that many different solutions exist to cope with many different problems" (Ostrom 1990, p.14). By comparing many different case studies, she initially identified three primary dilemmas that must be fundamentally resolved for successful resource management in CPR settings - supply, commitment and monitoring (Schlager 2004). Each of these dilemmas involves different forms of the "wicked problems" posited by Rittel and Webber (1973), all involving uncertainty, for example. Rainfall is still highly uncertain and unpredictable, even with decades of aggregated data, and while physical phenomena can be highly unpredictable, social phenomena may be even more so. Ostrom's work showed ample empirical evidence for the fallibility of State and Market controls alone in resolving these types of dilemmas, and focused on the participation of local users as a key component of successful long-term resource management (Ostrom 1990). Ostrom (2005) focuses on institutions as the key mechanisms for solving CPR dilemmas. *Institutions* are “the prescriptions that humans use to organize all forms of repetitive and structured interactions” (p.3), whether those interactions are with each other, with the environment, or any other type of interaction. They are, essentially, designs for how we interact. Institutions are formed within what Ostrom (2005) calls “action situations”, which are the “social spaces where participants with diverse preferences interact, exchange goods and services, solve problems, dominate one another, or fight” (p.14), among other things. According to Ostrom (2005), “Whenever two or more individuals are faced with a set of potential actions that jointly produce outcomes, these individuals can be said to be ’in’ an action situation” (p.32). In the IAD framework, action situations are framed and constrained by “exogenous variables”, which include: biophysical/material conditions; attributes of the community; and the rules that are in use at the moment. The IAD Framework has helped work toward understanding how institutions are crafted and sustained within certain action situations by emphasizing that there are no “one-size-fits-all” solutions, yet allowing for a systematic investigation of the key factors in this process and the outcomes generated by our attempts to affect these systems.

3.3.2 The Robustness of Social-Ecological Systems Framework

The Robustness Framework (Fig.3.2B) by Anderies *et al.* (2004) is built upon the IAD Framework (Ostrom 2005), but provides several important new features which are both foundational to the CIS Framework and further aligned with understanding design and emergence in complex adaptive systems. The Robustness Framework first expands the boundary of the CPR system to endogenize the key variables that frame action situations (Exogenous Variables in the IAD Framework). This approach frames a common-pool resource (CPR) system by identifying linked sub-systems, or holons[1] (Resource, Resource Users, Public Infrastructure Providers, and Public Infrastructure), which are linked to one another in dynamic relationships that can be specified, analyzed and compared. The actors from the IAD Framework are differentiated into two key positions which are Resource Users (RU) and Public Infrastructure Providers (PIP). These are distinct positions that actors may fill (consistent with the structure of the Action Situation) and an individual may potentially be involved in both positions at the same time, performing different types of actions. There are six important internal links within the system (numbered 1-6), denoting key relationships, such as Link 2 between the resource users (RU) and the public infrastructure providers (PIP) or Link 1 between the resource users (RU) and the resource (R). Different types of actions take place along these dynamic links within the system.

The Robustness and IAD frameworks stem primarily from the field of Political Theory and specifically from scholarship and debate dedicated to understanding democracy, self-governance, and local public economies. As such, typical types of actions occurring of interest within focal systems include activities such as: construction of jurisdictional units, provisioning, production, financing, coordination, and dispute resolution, appropriation, investment, maintenance, monitoring, sanctioning, evaluation, rule-making, institutional configuring, lobbying, implementation, enforcement, and coalition-building (McGinnis 2011a, p.10). The Robustness Framework places more focus on how institutional configurations might affect the interactions and dynamics between holons in the system. This focus on interactions and dynamics can help to identify the potential robustness[2] and vulnerabilities of the system in

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[1] *Holons* are nested subassemblies in complex adaptive systems (Ostrom 2005, p.11). "The term holon may be applied to any stable sub-whole in an organismic or social hierarchy, which displays rule-governed behavior and/or structural Gestalt constancy" (Koestler 1973, p.291).

[2] *Robustness* "refers to the maintenance of system performance either when subjected to exter-

question, to different types of disturbances that may occur (Anderies et al. 2004). Disturbances can be generated either from the emergent dynamics within the system, or may come from exogenous drivers outside of the system. A political regime change at the national level, for example, could be an example of an exogenous driver that could potentially disturb or disrupt the dynamics of the Resource Users, the Public Infrastructure Providers and the interactions between them at the local level. This changing exogenous driver could establish a need for the design of new strategies at multiple levels based on the changed context of the system. This focus on relationships between sub-systems, multiple layers and adjacent systems provides important new insights for analyzing CPR systems that go beyond the scope of the original IAD Framework, particularly when thinking about "design" in these systems. First, it goes beyond institutions and social processes, providing a wider focus on the relationship of the social to biophysical features and the context of systems. It also provides a link to other adjacent systems, providing a potential platform for analysis of hierarchical, networked, and polycentric[3] structures. From a CAS perspective, a focus on dynamics and interactions allows the system to move beyond the static snap-shot of individual actions situations, and allows analysts to think about configurations in the context of change and uncertainty over time. In addition, it introduces the notion of "robust performance" in achieving the desired functions that institutions may establish, thus providing a way of analyzing how different types of configurations may produce the same functional outcomes (i.e. adhering to our intentions or purpose).

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nal, unpredictable perturbations, or when there is uncertainty about the values of internal design parameters (Carlson and Doyle 2002)" (Anderies *et al.* 2004, p.1)

[3] *Polycentric* refers to many different centers of decision making that may affect one another but are formally independent of one another (Ostrom 1990)

3.3.3 The Coupled Infrastructure Systems (CIS) Framework

The Coupled Infrastructure Systems (CIS) Framework (Fig.3.2C), by Anderies *et al.* (2016), is a direct evolution of the IAD and Robustness frameworks. It remains rooted in the foundations established by these frameworks, retaining focus on institutions, action situations, relationship links, dynamics and robustness. The CIS framework takes another step forward, however, by re-framing the Robustness Framework's holons as configurations of coupled infrastructures (Anderies *et al.* 2016). For the CIS Framework, *infrastructure* is defined as any coherent structure: 1) that can manipulate mass, energy and information flows (i.e. resources); 2) requires investment; and 3) can be combined with other classes of infrastructure to provide affordances[4] to produce flows valued by humans (Anderies *et al.* 2016). The idea that different types of infrastructure are present and important within CPR systems was introduced with the Robustness Framework (Anderies *et al.* 2004) within the holon of "Public Infrastructure". *Public Infrastructure* is defined as the "physical infrastructure and public services required to manage the use and maintain the functioning of shared resources" (Anderies *et al.* 2016, p.498). This definition builds upon the idea that the way that humans act on the environment is not direct, but occurs *through* human-made infrastructures (Anderies 2014), including physically built hard infrastructure and the protocols (i.e. institutions) for its use. While the holon of "public infrastructure" in the Robustness framework focuses attention on how we create and manage *shared* infrastructure as a key component of the system, the CIS Framework takes this idea a step further by defining six primary classes of infrastructure (See See Table 3.3) which may be combined and configured in different ways to affect the performance of

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[4] An *affordance* is the possible outcomes accessible to individuals, independent of their ability to perceive this possibility (Anderies *et al.* 2016).

the system, making *infrastructure* the primary unit of analysis (Anderies *et al.* 2016).

Table 3.3: Classes of Infrastructure for Common-pool Resource (CPR) Systems

Infrastructure Class	**Description**
Natural Infrastructure (NI)	physical infrastructure that is not human-made
Human Infrastructure (HI)	Human labor and knowledge
Social Infrastructure (SI)	structured human relationships such as groups of people or organizations
Soft Human-made Infrastructure (SHMI)	instructions, protocols (rules), and processes for using other types of infrastructure
Hard Human-made Infrastructure (HHMI)	physical human-made infrastructures and technologies such as roads, canals, computers, etc.
Private Infrastructure* (PRI)	privately owned infrastructure used for investment in shared infrastructure

* Private Infrastructure could be any other type of privately owned assets (e.g. money, property, technology) that is invested (i.e. put to use as a resource) in the provision of shared infrastructures

A good example of a CIS in a CPR setting is a small-scale irrigation system where famers who are resource users (RU) join together to create a social infrastructure (SI) which is a water users association and together decide to build some hard-human made infrastructure (HHMI) in the form of an irrigation canal so that they can transport the resource (R) of water from the nearest source in the natural infrastructure (NI) to their fields, a combination of natural and hard human-made infrastructure (NI+HHMI). In this process, the resources users (RU) are also (Link 2) the public infrastructure providers (PIP) by investing (Link 3) their own knowledge and labor (HI-human infrastructure) to design, build, operate, and maintain the irrigation canal (HHMI). They also to create organizations (SI) and rules (SHMI-soft human-made infrastructure) to govern and operate the canal once it is finished. Some of the participants may also invest their own money, land, or materials (PRI, private infrastructure) in the process and infrastructures they are creating for the group. In this situation the farmers are both Resource Users (RU) and Public Infrastructure Providers (PIP) through their provision of shared public infrastructures (PI: HHMI+SHMI) that combine with the existing natural infrastructure (NI) to create a new CIS that provides the affordance of delivering water across a distance to the farmer's fields. A different configuration that provides similar functions and affordances could be arranged. If the farmer's rights to organize (SHMI) and perform this act of creation are not recognized by over-arching governing bodies (SI), they might need to first appeal and coordinate with these governing bodies to determine the roles, positions, and actions that each type of actor may participate in during each phase of creation, operation, and maintenance of the CIS. More complex social infrastructures, however, may involve different needs and options for investment. In addition, Public Infrastructure (PI) can be comprised of many potential combinations of the other infrastructure types to achieve the same functional goals in different ways. A monitoring function, for example, could take the form of official human monitors (HI) who may operate under some kind of official organization (SI) and rules (SHMI) and/or may even use some kind of technology (HHMI), like cameras, to effectively monitor the resource, also operating under different specified protocols (SHMI). Thus, through these types of examples, we can see how the CIS Framework allows an increased ability to explore different configurations of infrastructures and strategies that may effectively accomplish the same functional goals that are the intention of the actors involved in attempting to affect the system through a process of linked action situations. The ability to organize and analyze potential configurations of linked action situations within a design-process is another major step forward that can be operationalized with the CIS framework (Anderies *et al.* 2016). The idea that action situations are linked and affect one another is not new, as there are a number of CPR scholars who have previously explored this phenomena (Lubell *et al.* 2010; Sendzimir *et al.* 2010; McGinnis 2011b; Kimmich 2013). The CIS framework, however, allows for the systematic investigation of the position and linkages between adjacent action situations within the context of the system. This offers some new pathways to generate insights into how different types of action situations are formed, how they are linked, and what effects they have upon the system.

3.4 Discussion: Integrating Concepts through the CIS Framework

In this paper, I have so far presented: 1) common-pool resource (CPR) systems as a type of complex adaptive system (CAS) involving the "wicked problems" of uncertainty, social dilemmas, inequities, and trade-offs involving multiple feedbacks; 2) an exploration of the conceptual landscape of "design", including a range of activities, products, and important considerations that constitute a model of change through design-processes in CPR systems; and 3) the Coupled Infrastructure Systems (CIS) Framework by Anderies et al. (2016) as a key evolution in a well-founded trajectory of CPR scholarship that may help in understanding the relationship between design and emergence in CPR systems from a CAS perspective. In this section, I discuss the integration of these concepts and how they relate to understanding design-processes in these systems. Finally, I conclude with some suggestions on how the resulting integration may be able to move toward the development of a theory[5] of design in coupled infrastructure systems (CIS) involving common-pool resources (CPRs).

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[5] Ostrom (2005) states: "*theories* enable the analyst to specify which components of a framework are relevant for certain kinds of questions and to make broad working assumptions about these elements" (p.28).

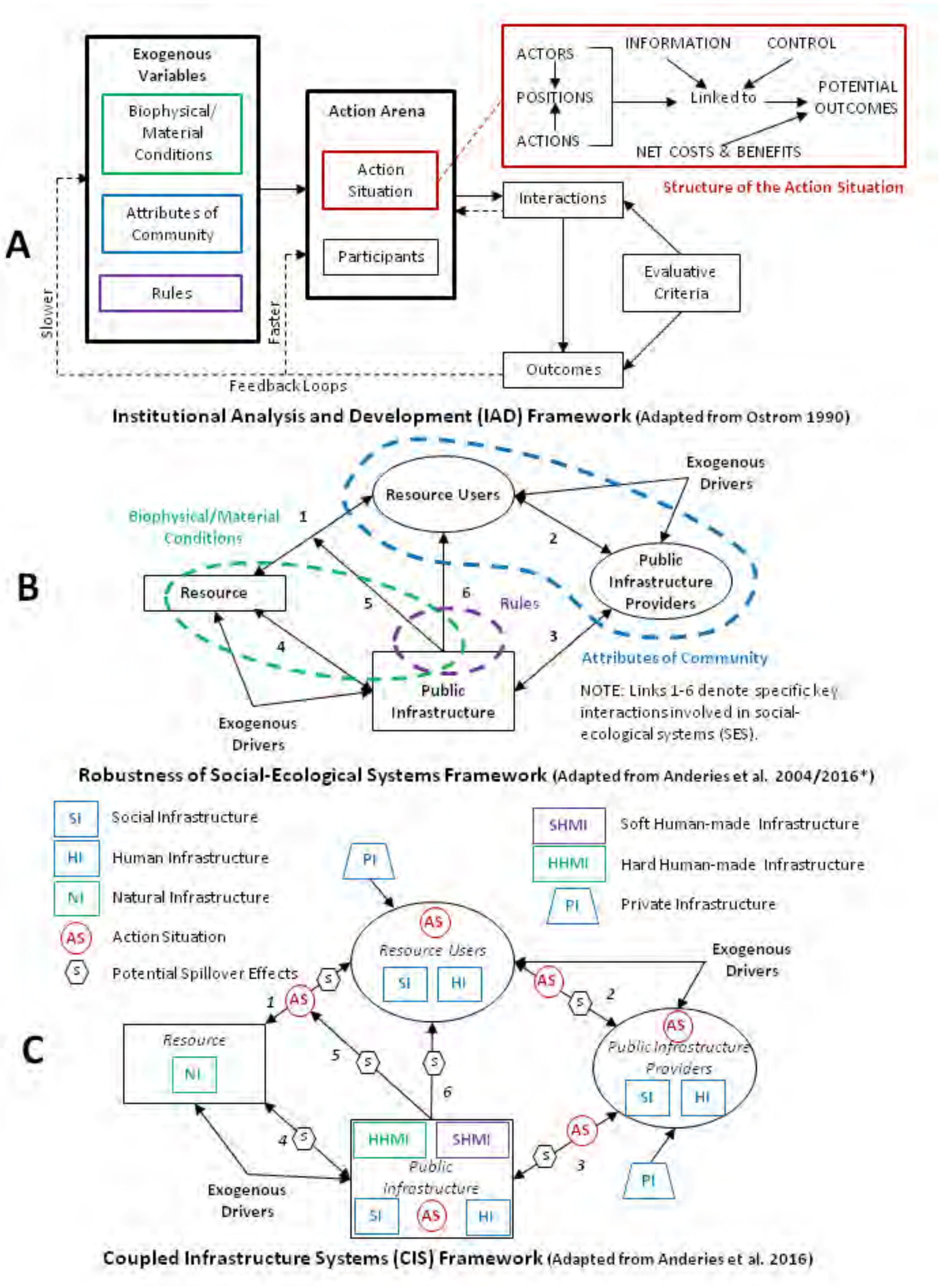

Figure 3.2: Related Common-pool Resource (CPR) Frameworks

* The representation of the IAD Framework's "Exogenous Variables" within the Robustness Framework was originally represented in the CIS Framework diagram by Anderies et al. (2016). They have been moved to the Robustness Framework, here, to illustrate the evolution from IAD through the Robustness Framework to the CIS Framework.

3.4.1 Design Processes in CPR Settings

Complex adaptive systems (CAS) are, by definition, dynamic systems that are constantly changing, sometimes self-organizing and emerging from processes outside of our control. Sometimes, however, they can be affected by our designed (i.e. intentional) attempts at manipulating the system to our advantage. Design for these types of systems can be defined as our intention to affect the system in a purposeful way, yet our designs also often create unintended consequences, or spillovers. The term "design" has been somewhat controversial within the CPR literature and CPR scholars, even Ostrom herself, have oscillated between the terms "diagnosis", "design", and "development" in referring to the types of activities we are discussing here. McGinnis (2011a) explains, "Design has sometimes been used as an alternative D [to development] in IAD, but doing so tends to convey an inappropriate presumption that institutional analysts are in a position to be able to provide unbiased advice concerning how communities might improve their own institutional arrangements; design is better seen as a part of the development processes through which institutions are established, maintained, and transformed" (p.4). Although perhaps just a matter of semantics, I would argue that diagnosis, decision-making and development are key phases of design-processes in CPR systems, rather than the other way around. In the referenced statement, McGinnis (2011a), perhaps, assumes that design is an action solely within the domain of the skilled professional. The term "diagnosis" also tends to invoke this connotation, but referring to a doctor rather than a design professional. Stemming from the previous analysis in this paper, however, I posit that because design for CPR contexts must be a process of linked products and actions, it can and does involve any number of different actors filling different positions and roles within the process (i.e. diagnosis, decision-making, development, monitoring, etc.). Any of these roles may include some kind of skilled professional, but there are also roles within the design-process for the users and other potential stakeholders who would not be defined as skilled professionals. As Ostrom (2005) points out, participation and collaboration are important because sometimes users hold an advantageous position within the system for diagnosis, decision-making, and development. Because of their position within the system, resource users may be more sensitive to and have deeper knowledge about the system and its dynamics than any exogenous professional, and therefore are able to apply their knowledge within the "daily life" of the system (Ostrom 1990, p.34). As shown in the CIS Framework (3.2) representation of a CPR system, the Resource Users (RU) have direct interaction and access to every other holon in the system, but Public Infrastructure Providers (PIP), which is typically the domain of the skilled professional, must obtain information about the resource indirectly through either the Resource Users (RU) or Public Infrastructure (PI). However, while the RU may be more sensitive to the biophysical side of the system at the local level, the PIP may be more connected to social dynamics and exogenous drivers coming in from other levels or other systems. Each of these different types of actors has access to and brings different types of information and other resources into the system dynamics, so while PIP may have broader access to certain types of resource (i.e. more bandwidth), the resource users may be more sensitive to system dynamics. The intended manipulation of any given system at any given point in time may require the collective resources (i.e. information, energy and mass) of a number of different actors involved in a system which they may use to create anywhere from a few to many different types of design actions and products linked together as an overall design-process.

3.4.2 Networks of Linked Action Situations

The investigation into the meaning of design within CAS (above) led to the conclusion that design in these systems most likely involves a series of connected actions and products that are linked through a design-process. We have also previously established that human intention within CPR systems can be thought of as occurring within Ostrom's (1990) Action Situations. Therefore, within CPR settings, design-processes can be conceptualized as networks of linked action situations (NLAS). While McGinnis (2011b) has previously refered to these as "networks of adjacent action situations (NAAS)" (p.52), I posit that the design-process model may actually be able to structure the relationships between adjacent action situations and that the term "linked" is more precise, as it implies a sequence and not just a connection. McGinnis (2011b) states that "two action situations are adjacent to each other when outcomes generated in one action situation help determine the rules under with interactions occur within the other action situation" (p.52). When I refer to linked action situations, they are adjacent action situations, but occur within a sequential chain of events in which the outcomes of one action situation determine the structure and/or options within another action situation and the outcomes of the intended function within the system depend on the outcomes and sequence of the combined action situations. A design-process in CPR settings may involve a sequence of actions and products that work together in an attempt to affect the system according to the intentions of the stakeholders involved, which may in fact also include the design and sequence of action situations themselves. McGinnis (2011b) already recognizes several key aspects of these networks: 1) there are a range of different activities (e.g. provisioning, production, financing, coordination, etc.) that may be occurring within a system at the same or at different levels of analysis; 2) the outcomes of these different types of action situations actually structure other action situations adjacent to them; and 3) stakeholders may "not only inhabit networks of adjacent action situations, but they may also be actively engaged in changing the structure of that network" (p.52). I merely posit two suggestions in addition to these points: 1) the position of each of the action situations within the system structure may be important in terms of what type of AS it is, what products and actions it generates, and how it affects other action situations; and 2) the sequencing of ASs within a NLAS may be important in terms of design-processes that work to transform human intentions into functional dynamics that affect the system. In addition, the ability to identify and account for spillovers that are the by-products of adjacent action situations within the NLAS is an important development of the CIS Framework (Anderies *et al.* 2016).

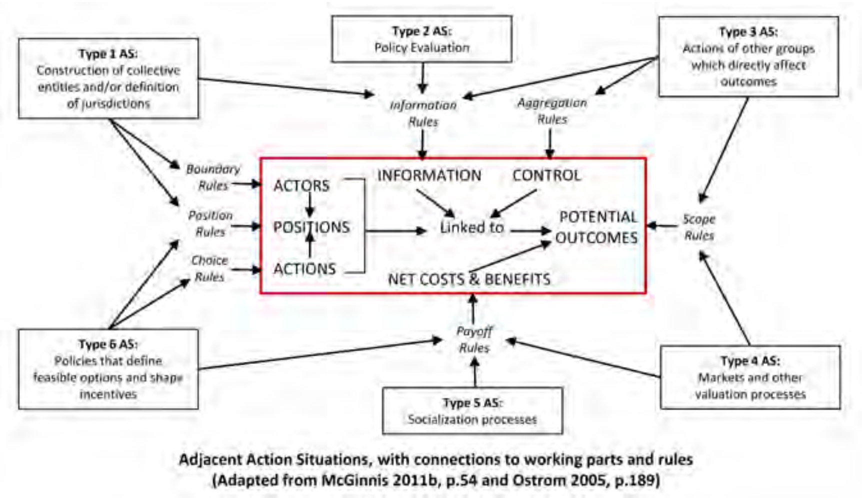

Figure 3.3: Types of Adjacent Action Situations (Adapted from McGinnis 2011b, p.54)

McGinnis (2011b) identifies six different types of adjacent AS (Figure 3.3) that may work together to affect a desired function at the system level, including: Type 1) construction of collective entities and/or definition of jurisdictions; Type 2) evaluation; Type 3) actions of other groups which directly affect outcomes; Type 4) markets and other valuation processes; Type 5) socialization processes; and Type 6) policies that define feasible options and shape incentives. The CIS framework may offer new insights on how to identify and analyze different types of AS and networks of linked action situations (NLAS) which are involved in a design-process. As shown in red on Figure 3.2C, there may be any number of action situations (AS) occurring at different locations within a focal system. Each of these AS may include different types of actors with different preferences and resources that they bring with them into the formation of each action situation and actors may be involved in multiple action situations at the same time.

For instance (see Fig. 3.4), resource users who intend to work together to develop a shared irrigation system (PI) for the function of appropriating water (AS-H* on Link 1) must first form a collective entity (SI+HI) thereby entering into a Type 1 Action Situation (AS-A_1) in which the resource users decide to work together, creating a social infrastructure (SI). Creating this social infrastructure (SI) may be influenced by other ASs, such as: existing rules or policies (SHMI) that have been established (type 6 action situation noted by number 6 subscript) at other levels of the system (AS-B_6); the actions of other groups (type 3 AS) (AS-B_3); and/or the socialization processes at work in the specific community (type 5 AS) (AS-B_5), for example. The group created in AS-A must then work together to decide on their relationship and the structural configuration (SI+HI) of the public infrastructure providers (AS-C_1), which may involve other actors as well (AS-D_1). Each of these different types of actors have different perspectives on the system and potentially bring different types of resources (i.e. information, mass, and energy) to bear on the action situations involved in the process (AS-C; AS-D; AS-G). Once the configuration of the PIP has been created, they then might assess (AS-$F_{2,4,6}$) the existing affordances and options for providing the intended public infrastructure (PI), make decisions about its configuration and how it will be provided and produced (AS-G[6]). This could then result in the configuration of some combination of canals (HHMI) and rules for their use and operation (SHMI), which will affect how the RU can functionally access and appropriate (Link 5) the water that they need. While McGinnis (2011b) provides a solid basis for exploring NAAS, the CIS Framework (Anderies *et al.* 2016) could help expand upon the typology of action situations and understand their sequencing as design-processes in social-ecological systems (SES).

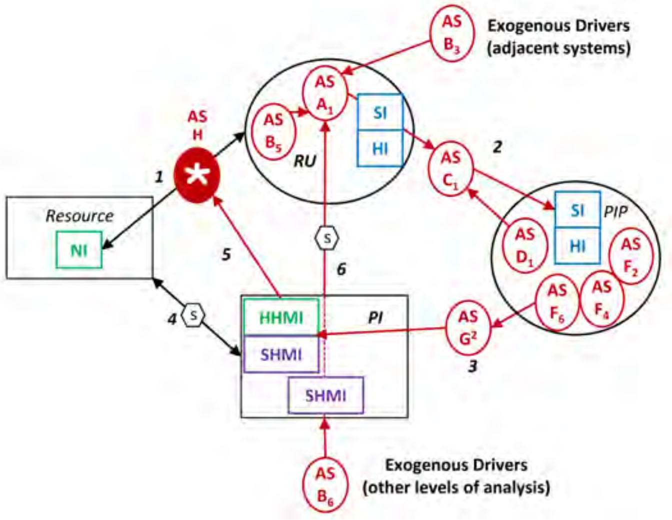

Figure 3.4: Network of Linked Action Situations (NLAS) within the Coupled Infrastructure Systems (CIS) Framework (Adapted from Anderies *et al.* 2016)

[1] AS-H is the focal action situation of interest, but there is a sequence of preceding adjacent action situations that could directly affect the structure of AS-H.

[2] Each AS in the sequence is denoted by a letter, for it's relative place within the sequence. They are also noted with a subscript, denoting which of McGinnis (2011b) AS types they represent. The sequence of action situations is described in more detail in the preceding paragraph. AS-G, representing the production of public infrastructures, is not one of the types listed by McGinnis (2011b), but one that is important within the sequence depicted in this illustration.

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[6] Because it is focused on the creation of institutions alone, McGinnis (2011b) does not identify an appropriate type of action situation for the creation of public infrastructure which may include soft and hard human-made, social, and human infrastructures

3.4.3 Links Across Scales

In addition to the NLAS at the local (e.g. operational) level of analysis, there may also be linked ASs at other levels of the system that are also linked into the design-process occurring at the local level. In the previous example (Fig. 3.4), there is a type 3 AS (i.e. actions of other groups) and a type 6 AS (i.e. policies that define options and incentives) that both occur at higher levels of analysis within the system but may be influencing the type 1 AS (AS-A) where the resource users are constructing a collective entity. As McGinnis (2011b) explains, these types of social processes may be happening at levels that are far removed (i.e. spatially and/or temporally) from design-process within focus. The right to organize, for example, may have been granted by policies at the constitutional choice level that have been in place for many years before the RU decide to take advantage of them. This is an example of a specific type of affordance which may well exist whether or not the RU perceive its existence and value to them. Indeed, the affordance may not have any value to them at all until they have the intention of creating a group for the purposes allowed by the existing policy (SHMI). Examination of these different levels of analysis has long been included as a part of the IAD Framework (Ostrom 2005), but was made more elaborate by McGinnis (2011b) as part of the analysis of networks of adjacent action situations (NAAS). A number of scholars focused on understanding resilience in social-ecological systems (SESs) have similarly described the need to understand both social and ecological processes across multiple scales and speeds (Young 2002; Walker *et al.* 2006; Anderies *et al.* 2013; Anderies 2014; Anderies 2015). Anderies (2014) explains that in understanding the performance (i.e. resilience/robustness) of social-ecological systems (SES), they "can be viewed as networks of subsystems each of which undergo continuous cycles of change (*the adaptive cycle*) that are linked across different scales in a *panarchy*[7]” (p.134). As stated by Walker *et al.* (2006), “the dynamics of a system at a particular scale of interest, i.e., the focal scale, cannot be understood without taking into account the dynamics and cross-scale influences of the processes from the scales above and below it” (p.2).

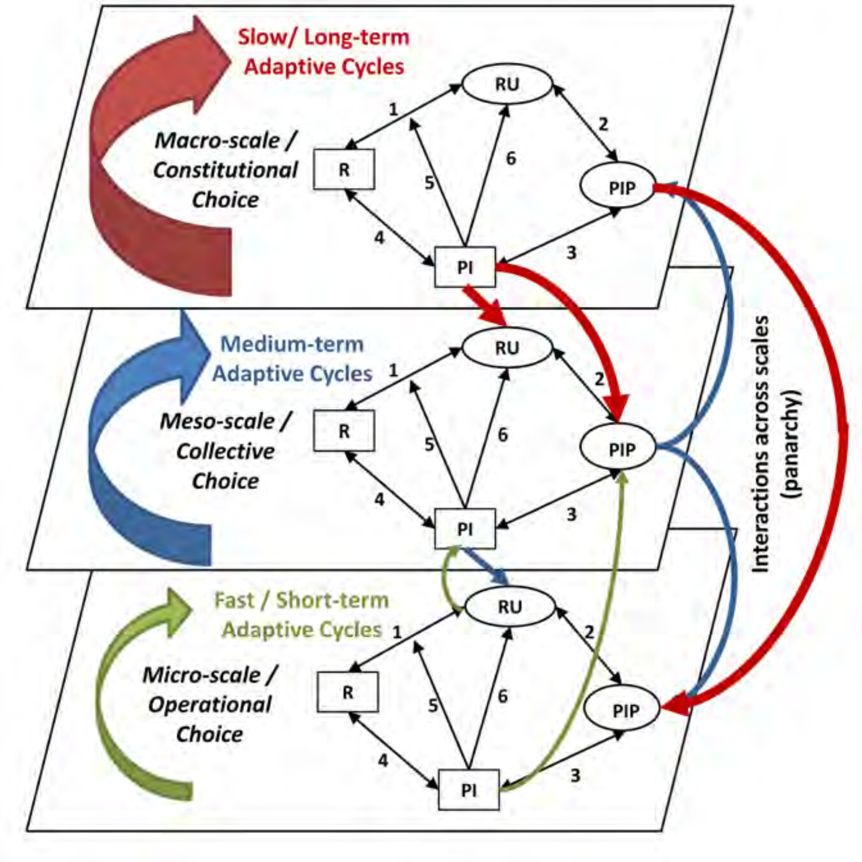

Figure 3.5: Interactions between Scales of Coupled Infrastructure Systems (CIS) with Fast and Slow Processes

Note: Processes at the Macro-scale are slower moving but may have bigger impacts on lower levels, while processes at the Micro-scale may be faster and more sensitive to changes in the system.

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[7] A *panarchy* is described by resilience scholars as ”relationships among a nested set of adaptive cycles arranged as a dynamic hierarchy in space and time” (Holling *et al.* 2001, p.101)

3.4.4 Affordances and Spillovers

The resources that are brought to bear on any given action situation result from other coupled infrastructures within the system and the sequence of ASs could have major impacts on what resources are available within another given AS. Remember that *infrastructure* is anything that can manipulate resource flows (i.e. mass, energy and information) to produce affordances. As stated by Anderies *et al.* (2016), while the design of institutions (SHMI) remains a key focus within CPRs, *affordances* are often the results of "positive spillovers" or "by-products" of combining soft human-made institutional infrastructure with other types of infrastructure (e.g. natural, hard human-made, social, human). I posit that affordances may be intentional (e.g. designed) or unintentional (e.g. spillovers) and may positively influence (e.g. opportunities) or negatively influence (e.g. challenges) other adjacent action situations, making the sequence of linkages in the design-process important. Each AS in the process produces an action (e.g. the link arrow) that may stabilize or transform configurations of coupled infrastructures in the holons that it is linked to. In addition, an AS may produce multiple actions, affordances, and spillovers at the same time but these may also change as time goes by. The production of some intended dynamic function at the system level (i.e. robustness) is the result of aggregated affordances created by the configuration and sequencing of action situations and infrastructures within the system and the conditions may change at any time due to emergence and spillovers within the system. This phenomenon is what makes activities such as monitoring, calibration, evaluation, and management for either sustainability or adaptability important features of the design-process for CPR systems.

3.4.5 Designing for Wicked Problems

Dealing with the wicked problems of uncertainty, social dilemmas, inequities, and trade-offs involving multiple feedbacks remains a pervasive challenge for design in all CAS. While the CIS Framework may help us to better understand CPR systems and the role of design within them, it is the wicked problems we find that make design in this context so difficult to grasp. Perhaps the most prevalent wicked problem for design, is the idea of trade-offs involving multiple feedback loops. This gets to the heart of why there are no solid "solutions" that can be generally and replicably applied in CPR settings. The design process for these types of systems must balance sometimes competing functional objectives, such as resource use and conservation, at the same time. To achieve these types of balances, design-processes for these CPRs often require subjective decisions about who may access resources for what purposes, who must be excluded, and who will bear the investment costs of creating new infrastructures, which inextricably introduces new uncertainties, social dilemmas, inequalities, and tradeoffs. Just as the CIS Framework helps us to systematically parse out design from emergence and the configurations of ASs and infrastructures that work together to affect the function of the system, perhaps we can also map certain types of wicked problems to certain types of ASs within the system. While not commonly labeled as "wicked problems", these issues have long been part of the discussion on CPR management strategies. *Freeriding*[8], for example, is both a type of uncertainty and a social dilemma that is inherent to the nature of common-pool resources because of their difficulty in exclusion, as previously described. This type of wicked problem affects certain ASs within the NLAS, but perhaps not all, becoming

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[8] *Freeriding* is when an individual benefits from a collective good without incurring the costs of participating in the production of the good (Olson 1965)

a part of the bundle of intended functions that must be weighed and accounted for in the design-process.

In addition, there are different types of heuristics for dealing with different types of wicked problems at different levels of the system. Local groups may deal with freeriding through more informal socialization processes such as social disapproval, which may actually be a more effective mechanism than the more formal strategies, like fines or taxation, used at higher levels (Siddiki *et al.* 2010). These heuristic strategies are essentially precise configurations of coupled infrastructures that are often implemented, calibrated, and improved through trial-and-learning processes over time. While not always the optimal solution, they are none-the-less found to be sufficient enough to address the sub-function they are intended for on the way to moving the system toward the overall functional intention. These heuristics are guidelines from which those involved in the design-process may draw inspiration from, and include things like the Ostrom (2005) Design Principles or the principles for resilience in SESs by Walker *et al.* (2006). The CIS Framework could provide a foundation for systematically mapping heuristics like these to the system and the corresponding types of wicked problems, ASs, and holons where they may best fit in. This exercise would help to illustrate to stakeholders involved in all levels of the design-processes for these systems, what types of roles, actions, and resources may best benefit their specific requirements and goals.

3.5 Conclusions

Common-pool resource (CPR) systems are the complex adaptive systems from which we derive our most valuable shared resources. Our intentions to design coupled infrastructure systems (CIS) that create the flows of the resources (mass, energy and information) that we need, however, must fit within a dynamic and emergent social-ecological system which we cannot fully understand or control. These systems are difficult to bound and interdependent dynamics occur across multiple levels of the system, requiring that our design-processes are complex enough to be effective within the complexity of the system.

This study has shown that the concept of design, particularly when applied to complex adaptive systems (CAS), may include a number of linked activities and products that work across multiple parts of a system through design-processes. Because CAS are dynamic, design-processes for these systems must include the capacity for calibration, adaptation, improvement, learning, management and change over time (i.e. the adaptive cycle). At the heart of design-processes in CAS is *intention*. Governance is one type of collective human intention that may be viewed as the continual collective activity of setting intentions and making of commitments within these design-processes, however, there may also be other people who are acting within the design-processes of a system but outside of its governance. An entrepreneurial innovator, for example, may be working to revolutionize or disrupt the system but not acting in a governance capacity. *Design* in CPR systems is human action intended to manipulate the system and produce flows of resources for our benefit. Because CPR systems are specifically about *shared resources*, human action in these systems is collective action which occurs within action situations (AS). The CIS Framework (Anderies *et al.* 2016), an important iteration in the legacy of Elinor Ostrom's work, allows for design-processes to be viewed and analyzed as networks of linked action situations (NLAS). In addition, it allows for the products of the ASs in the network to be viewed as configurations of coupled infrastructures (i.e. natural, human, social, hard human-made, and soft human-made) which work together to provide affordances to stakeholders within the system and manipulate the system dynamics. The creation of these infrastructures requires the investment of resources (i.e. mass, energy, and information) and it is important to include user participation and the collaboration of a variety of stakeholders within design-processes in order to bring the fullest amount of resources to bear on each action situation. While this may introduce complexity into the design-process, it provides the fullest sensitivity and information about the system dynamics and a fuller set of options in terms of the feasible possibilities for configuring infrastructures.

The CIS Framework also provides a platform to systematically identify and map the intentional outcomes of ASs, as well as the unintentional spillovers that may be generated in the process and affecting the system of focus or other adjacent systems. It also may provide a way of identifying patterns in how the sequencing and aggregation of designed affordances, spillovers, and emergent properties work together to affect the dynamics of CPR systems. Finally, it may also provide a useful platform for mapping out and connecting wicked problems, i.e. uncertainties; social dilemmas; inequities; and trade-offs involving multiple feedbacks; with design-processes and the dynamics of CPR systems.

This work has shown that the CIS Framework has a great potential for helping us to integrate theories and better understand design-processes in CPR systems. Utilizing the framework in the way that I have suggested here may be useful in generating new insights that will help in moving beyond the search for “solutions” toward the development of new tools and methods aimed at “re-solutions” that can exist within the flow of these systems. I conclude by positing that the development of a methodology for utilizing the CIS Framework for the investigation of design-processes in CPR systems would be a good next step in testing the hypotheses presented here and moving further toward an integrative theory of design for CPR systems.

Chapter 4

DESIGN AND EMERGENCE: AN EMPIRICAL INVESTIGATION OF A PARTICIPATORY DESIGN INTERVENTION FOR COMMON-POOL RESOURCE SYSTEMS

4.1 Introduction

The previous chapter, design for complex adaptive systems (CAS) involving common-pool resources (CPR) was defined as human intentions to manipulate and control the dynamics of these systems in ways that create, move, transform, or maintain resource flows that humans value. Our ability to achieve this can be viewed as the result of our abilities to recognize and take advantage of the *affordances*[1] produced by our configuring of coupled infrastructures. Essentially, we do not affect system dynamics directly, rather our actions are on systems take place through infrastructures (Anderies 2015). Remember that *infrastructure*[2] is defined here as any coherent structure that can manipulate resources (i.e. mass, energy, and information); requires investment; and can be combined with other classes of infrastructure to provide affordances for flows of resources valued by humans (Anderies *et al.* 2016). Five key classes of infrastructure have been found to be important within CPR systems (Anderies *et al.* 2016), including: 1) natural infrastructure (e.g. water, air, sunlight, soil, etc.); 2) human infrastructure (e.g. knowledge and labor); 3) social infrastructure (e.g. orga-

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[1] *Affordances* are the possible outcomes (i.e. functional dynamics) that are accessible to individuals or groups, independent of their ability to perceive these possibilities (Anderies *et al.* 2016).

[2] As noted by Anderies (2015), *infrastructure*, as defined here, is sometimes also referred to as "capital" in the literature, referring to productive assets. *Infrastructure* is used here to refer to all productive assets, whether public or private, regardless to ownership status.

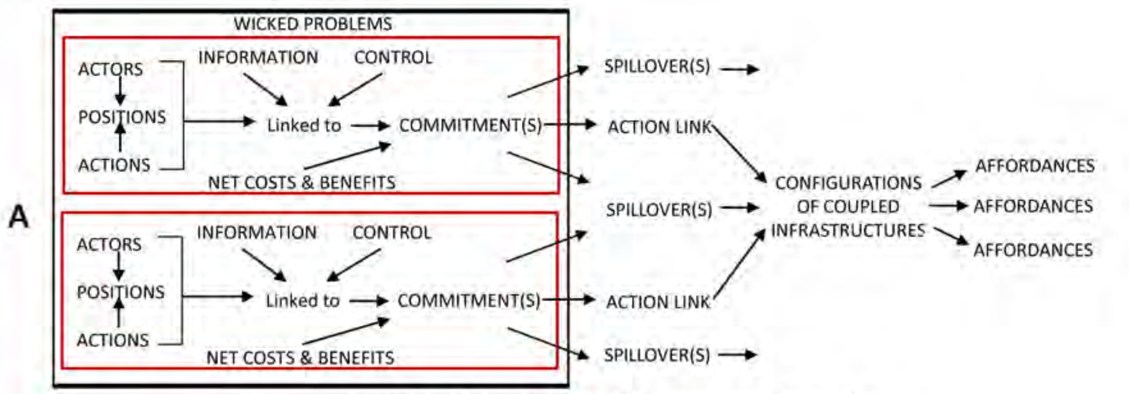
nizations); 4) soft human-made infrastructure (e.g. institutions - rules, norms, shared strategies, etc.); and 5) hard human-made infrastructure (e.g. roads, canals, etc.). From this perspective, we can perceive our ability to manipulate the dynamics of CPR systems as dependent on our ability to recognize and identify affordances and also to understand and effectively manipulate infrastructures in these systems. Because CPR systems are shared systems, our opportunities to act collectively and affect system dynamics occur within the system structure and dynamics from leverage points, referred to here as *action situations* (AS).

An Action situation (AS) occurs whenever two or more individuals are faced with a set of potential actions that jointly produce outcomes and the structure of any action situation (AS) can be analyzed with a common set of variables (Ostrom 2005, p.188):

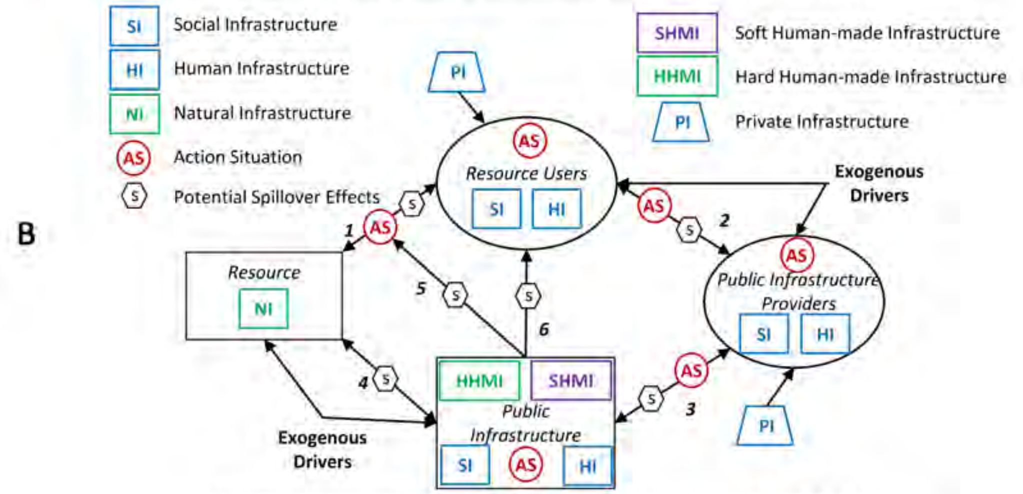
> "*Participants* and *actions* are assigned to *positions*. *Outcomes* are linked to actions. *Information* is available about *action-outcome linkages*. *Control* is exercised over action-outcome linkages. *Costs and benefits* are assigned to action-outcome linkages."

While the structure and mechanisms of ASs are explained in detail in Ostrom (2005) book *Understanding Institutional Diversity*, Anderies *et al.* (2016) add to this by positing that outcomes may depend more on the interactions between, spillover effects and affordances created by different types of infrastructure than just on social interactions alone; and that AS dynamics evolve as they interact with different perceptions, technologies and system feedbacks that occur at faster and slower time scales throughout the evolution of the system. McGinnis (2011b) also added to our understanding of AS by demonstrating that the outcomes generated by one AS often help to determine the interactions and outcomes of other ASs. In Chapter 3, I further extended these theoretical trajectories to posit that the sequencing of these linked AS matters to the actualization of collective human intentions *in design-processes* and that this might be better understood by analyzing the network of linked action situations (NLAS). When brought together, a unified theory suggests that action situations (AS) produce *commitments to intended actions (i.e. intention)* that then produces *potential outcomes (i.e. affordances)* through the creation, configuring, and use of coupled infrastructures. Sometimes, however, these same action situations can also generate unintended consequences in the form of *spillovers* (Anderies *et al.* 2016) and *wicked problems*. These unintended consequences account for, at least in part, the *emergence* of patterns at the system level that are difficult or impossible to predict by the behavior of the system's individual components or sub-systems (Holland 1992; Miller and Page 2009). *Wicked problems* are the inherent *uncertainties, social dilemmas, inequities, and trade-offs* that plague us in our attempts to manipulate CPR systems, causing action situations to become moving targets where there are neither clear problems nor solutions and also cause the interdependent dynamics that operate at different speeds and across multiple levels of the system (Holland 1992; Walker *et al.* 2006; McGinnis 2011b; Anderies *et al.* 2013; Anderies 2014; Anderies 2015).

Anderies (2014) suggests that approaches from the study of social-ecological systems (SES) that incorporate concepts of resilience, robustness, and adaptability into human design-processes are necessary in enabling us "to cope with extensive uncertainty, high levels of variability and potentially rapid change" (p.130) that we find in these types of systems. He and others (Yu *et al.* 2015; Anderies *et al.* 2016; Baggio *et al.* 2016) suggest that the concept of configurable coupled infrastructures offered and the Coupled Infrastructure Systems (CIS) framework (Fig. 4.1) may provide "an explicit, implementable framework" (Anderies 2014, p.131) for bringing these concepts together specifically for CPR systems. In the previous chapter, I posited that an understanding of networks of linked action situations (NLAS) could be a useful addition to the CIS Framework that aids in our understanding of the balance between design-processes and emergence for CPR systems. This may offer a way to improve our understanding of design-processes in CPR systems, both how to make them complex enough to account for and integrate with the complexity of the system and more effectively embed them within the self-organizing and emergent processes at work in these systems.



Internal structure of linked Action Situations (AS) (adapted from Ostrom 2005)



Coupled Infrastructure Systems (CIS) Framework (adapted from Anderies et al. 2016)

Figure 4.1: Structure of Multiple Action Situations (adapted from Ostrom 2005) linked to Coupled Infrastructure Systems (CIS) Framework (adapted from Anderies *et al.* 2016)

In this chapter, I utilize the CIS Framework (Anderies *et al.* 2016) with the addition of NLAS to investigate a case study involving a particular design-process in a CPR context. This helps to demonstrate and test the synthesized theory for understanding design-processes in CPR systems, and whether the design-process model developed in Chapter 3 can help to structure NLAS within the CIS Framework. I posit that this methodology could help further our understanding of partly designed and partly emergent systems by increasing our understanding of the role of design as the key processes used by humans to affect complex adaptive systems. The case study explored here involves a government-led participatory design intervention for nineteen small-scale, farmer-managed irrigation systems (FMIS) in the Indrawati River Basin of Nepal that has also been the subject of a previous longitudinal study presented by Ostrom *et al.* (2011). Their study (Ostrom *et al.* 2011) suggested that participatory design-processes may enhance the capabilities of resource users to manage and adapt their own systems over time and that these systems often perform better than agency-managed systems. They also posit that the design of successful interventions must include a multidimensional feature which considers the interactions between the ecological, technological, and institutional infrastructures through which resources are made available for human use in a social-ecological system (SES) (Ostrom *et al.* 2011). The longitudinal study in Nepal (Ostrom *et al.* 2011), conducted over the past three decades, offers an unprecedented resource of data on the performance and outcomes of a participatory design-process involving a number of different actors operating at multiple scales over a relatively long period of time. In addition, small-scale farmer-managed irrigation systems, like those included in the longitudinal study, are important and may offer valuable insights for understanding the dynamics that are analogous to a variety of SESs at a range of scales because they present all of the important components and dynamics that can be found in these types of systems (Janssen and Anderies 2013). According to Janssen and Anderies (2013), "small-scale irrigation systems function as the equivalent of the fruit-fly in evolutionary biology to illustrate the robustness of social-ecological systems" (p.3). While important and informative, the study by Ostrom *et al.* (2011) focuses on the variation of outcomes within each of the individual FMIS but does not analyze the participatory design-process itself. In addition, it does not utilize the CIS Framework with the incorporation of NLAS, which I suggest may help in developing a better understanding of how design-processes work within CPR systems. By utilizing the CIS Framework and NLAS, the study presented here is intended to extend previous findings and gain new insights into the key dynamics of change in CPR systems.

4.2 Case Study Background

Studies of locally managed small-scale irrigation systems have been conducted in Nepal since the 1970's and have led to field investigations by numerous scholars since that time (Ansari 1990; Yoder 2011). Nepal is especially suited to the study of small-scale irrigation systems because of its long tradition of allowing local governance of resources, such as water and forests (Ostrom *et al.* 2011). This local governance of natural resources has spanned hundreds, if not thousands, of years in Nepal and has survived despite tumultuous political regime changes (Ostrom *et al.* 2011). The design-process under investigation here was an intervention implemented in nineteen FMIS in the upper Indrawati river basin in the Sindhupalchok district of Nepal's mid-hills region (Fig.5.1). The intervention was part of a project initiated in 1985 by the Water and Energy Commission Secretariat (WECS) of Nepal with assistance from the International Irrigation Management Institute (IIMI)[3] and the Ford Foundation to develop and test experimental new methods using participatory design and

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[3] Now known as the International Water Management Institute (IWMI) www.iwmi.cgiar.org/

construction activities to improve three primary functions, including (Yoder 2011, p.xv): 1) agricultural productivity; 2) capacity for self-support; and 3) capacity for self-governance.

A number of rising pressures in Nepal led up to the WECS project and intervention. In the early 80's, agricultural activities accounted for nearly two-thirds of the gross domestic product (GDP) of Nepal and employed at least 94% of the working population (Khadka 1985). In addition, the rate of population growth was climbing fairly steadily toward a peak rate of 2.7% in the early 1990's (World Bank, n.d.). This was further confounded by significant in-migration from neighboring countries, such as India (Khadka 1985). The more densely populated hill and mountain regions of Nepal faced the brunt of the food crisis in the early 80's, as food production and productivity in those areas fell and high transportation costs hindered subsidized aid and the affordability of surplus food coming up from the more bountiful Terai region (Khadka 1985). Political upheaval and the push for democracy that had begun in the 1950's had remained tumultuous and even remains so now more than seven decades later. A corrupt and ineffective government struggled throughout the 1980's to overcome in-fighting between parties and find stability while also in the midst of a severe food crisis (Khadka 1985). The 1980's were the beginning of the end for both the monarchy and panchayat system of governance in Nepal, which briefly became a constitutional monarchy in 1990, and then was abolished altogether for democracy under an interim constitution in 2008. From 2008-2015, the fledgling democracy of Nepal was unable to pass and enact a constitution for the nation due to continued fighting among various factions and parties (Iyengar 2015). Although a democratic constitution was finally passed, following the devastating earthquakes of 2015, protests from minority ethnic groups, strikes by both the government and competing political parties such as the communist Maoist Centre, and rampant corruption among officials at all levels have continued to be pervasive problems (Nepali Times 2018).

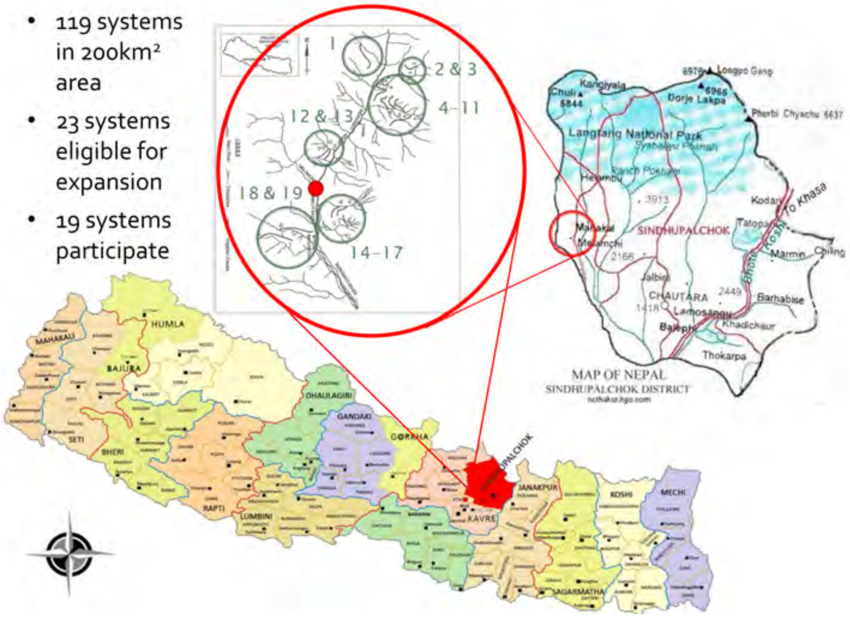

Figure 4.2: Map of irrigation systems in the Indrawati River Basin of Nepal

4.2.1 Study Area

The study area for the project is located near the town of Melamchi on the western border of the Sindupalchok District (Fig. 5.1). Located approximately 45 km away from Kathmandu, the area was chosen, in part, because of its proximity to the capital city (WECS and IIMI 1990; Ostrom *et al.* 2011). The sites are approximately one and a half hours from Kathmandu, located relatively near the confluence of the Melamchi and Indrawati Rivers, making them more easily accessible to the research team than more remote locations (WECS and IIMI 1990). Many of the systems have been established for some time, some were even established more than two centuries ago (Ostrom *et al.* 2011, p.86). FMIS and other types of user managed resource systems have been able to function over long periods of time in Nepal, despite many external pressures such as conflict, change in large-scale governance, and fluctuating market pressures

(Bastakoti *et al.* 2010; Karna *et al.* 2010). This shows the remarkable resilience of these systems and the potential effectiveness of user-managed resource systems in this context (Ostrom *et al.* 2011). As Ostrom *et al.* (2011) point out, however, "context matters" (p.21) and locally managed resources may not be the best solution for all contexts. This emphasizes the need for a better understanding of design-processes that take unique contexts and dynamic circumstances into account. The project under investigation was an attempt to avoid the application of the so-called 'cure-all' or 'blue-print' approaches which are often typical in policy and intervention development because they do not regard contextual factors to a high degree (Ostrom *et al.* 2011). The use of these types of generalized approaches is sometimes also known as the 'panacea problem' (Ostrom and Cox 2010). A number of scholars have identified common pathologies, such as the panacea-problem, that are associated with narrowly focused, linear and top-down management designs in both the ecological and social domains (Scott 1999; Walker *et al.* 2006; Anderies 2014; Cox 2016). As Cox (2016), however, this does not imply that there should be no controls over social-ecological systems, but rather, we must learn how to effectively understand "how much and what types of control" (p.6) are needed.

In addition to unique contextual factors, the dynamics of social-ecological systems and the functions that we desire from them are not static and neither are the opportunities and challenges that we face in attempting to manipulate them to our advantage. As asserted by Rittel and Webber (1973), the systems that we try to manipulate and the required actions necessary to achieve the functions we desire tend to shift and evolve together. I posit that by utilizing the CIS Framework as a roadmap to these systems and foundation for looking at design within them as processes of linked action situations for the configuring of infrastructures, we can change the question from one of searching for "the answers" to one of understanding "the flows". Chapter 5 of this volume will explore the different configurations of infrastructures and the resilience of the nineteen individual FMIS that participated in the intervention. The remainder of this chapter will investigate the overall design-process implemented across these systems at the regional level and analyze this process using the CIS Framework plus NLAS model.

4.3 Methodology

The CIS Framework (Anderies *et al.* 2016) provides a structure for systematically identifying and analyzing the elements and relationships between elements in a system (Ostrom 2005). *Frameworks* both "organize diagnostic and prescriptive inquiry" and "provide the most general set of variables that should be used to analyze all types of settings relevant for the framework" (Ostrom 2005, p.28). Frameworks differ from *theories*, which Ostrom (2005) states "enable the analyst to specify which components of a framework are relevant for certain kinds of questions and to make broad working assumptions about those elements" (p.28). With the addition of the NLAS (adapted from McGinnis 2011b), I have suggested a theory for how design-processes might work in CPR systems that brings together important ideas from studies of design-processes, decision-making in common-pool resource systems, and resilience/robustness of social-ecological systems (Chapter 3).

4.3.1 Robustness Analysis with the CIS Framework

As suggested by Anderies (2014), the CIS Framework can be utilized as an organizing framework for integrating ideas about design, planning and decision-making with the concepts of resilience, robustness, and adaptability in CPR systems. While we have discussed the former set of concepts in some detail, it is beneficial at this point to clarify the latter set of concepts for this analysis. Resilience, robustness, and adaptability are related concepts that are used in a number of different disciplines related to CPR systems (Walker *et al.* 2004; Anderies 2014). Originally derived from the field of ecology, the concept of *resilience* has been defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.* 2004, p. 2). This implies that *resilience* is an over-arching concept that is operationalized by the concepts of robustness and adaptability (Fig. 4.3) (Walker *et al.* 2004; Husdal 2008; Välikangas 2010; Anderies 2014). *Robustness* can be viewed as the capacity of the system to absorb disturbance without fundamentally changing its functions, while *adaptability* is the capacity of the system to reorganize while undergoing change (Husdal 2008). As Husdal (2008) puts it, these are two sides of the same coin, i.e. resilience. The CIS Framework incorporates these concepts by focusing on the overall performance of systems in achieving or maintaining intended functions while also adapting to emergence in the system and coping with uncertainty, social dilemmas, inequities and trade-offs. In using the CIS Framework for dynamics and configuration analysis, we are analyzing the resilience of the system in a methodology known as robustness analysis (RA). RA is used in a variety of decision-making and design fields for understanding problem situations where decisions should or must be staged sequentially and where there are high levels of uncertainty (Rosenhead 2002). RA can aid in flexible planning and adaptability by providing a means of exploring the complexity of decisions and potential alternatives while allowing future options (i.e. adaptability) in the process to be 'left open' (Wong and Rosenhead 2000). The method focuses on sequencing, which supports my assertion that design-processes in CPR systems include a variety of decision-making and development activities and that outcomes affecting the functional dynamics of the system depend upon the sequencing of these activities.

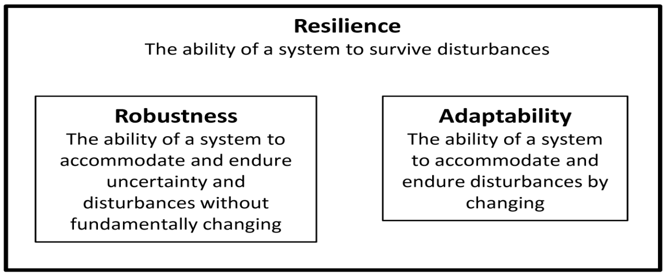

Figure 4.3: Resilience, Robustness, and Adaptability (adapted from Husdal 2008)

Design-processes for CPR systems are divided into two iterative phases including decision-making and development (Fig. 4.4). This model was derived from the analysis in Chapter 3 and modeled to generally fit with resilience literature around adaptive cycles. Wong and Rosenhead (2000) call these two distinct phases the “decision-period” and the “implementation-period” (p.177). To Wong and Rosenhead (2000) unique acts upon the system occur within the “decision-period”, which is “a period of time during which a decision needs to be made from a number of available commitments” (p.177). A *commitment* is “a single unique, indivisible action that will cause specific changes to the system” and these commitments may be bundled into “commitment sets” that work together to act upon the system (Wong and Rosenhead 2000, p.177). For CPR systems, there are some key considerations that affect how the activities that take place within the design process are structured, positioned and sequenced within the system (Chapter 3). These include: 1) intention - what is the primary system dynamic or function that is being intentionally manipulated?; 2) orientation - is the scope of the design-process geared toward problem-solving and replication or integration with the unique features of a system?; 3) participation - who should and/or will be included and participate in which design activities within the process?; and 4) knowledge - where is the knowledge and information about the system and its dynamics coming from (e.g. expert knowledge, local knowledge, etc.)? Points 3 and 4 may be of particular importance in CPR systems because complex systems and their dynamics are hard to define, understand and manipulate (Holland 1992; Ostrom 1990; Walker *et al.* 2006; Anderies 2014; Anderies 2015), making information about these systems a very valuable resource in any decision-making and design process for CPR systems. Participants who occupy different positions within a system, such as that of resource user (RU) or public infrastructure provider (PIP), have different relationships and perspectives on the system, and may thereby bring different types of information about the system and its dynamics to bear, for their own benefit or that of the group (Ostrom 2005), within any given action situation (Fig.4.1).

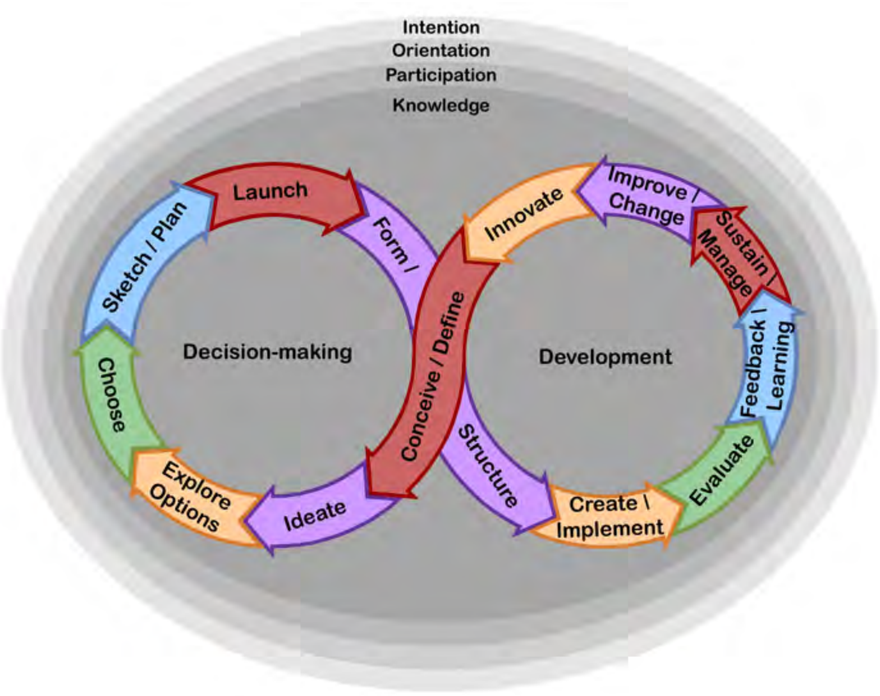

Figure 4.4: Design-process for Coupled Infrastructure Systems

In the CIS Framework, *commitments*[4] are the particular actions that are chosen by participants in an action situation (AS). An AS may occur during any activity in the decision-making or development phases of the design-process. Any particular commitment or commitment set may result from a single action situation or a network of sequentially linked action situations (Fig. 4.1). The commitments that come out of each AS translate into acts upon the system represented in the framework by the numbered links. The implementation of commitments result in forms, shapes, or patterns within the system, called *configurations*, and more than one combination of commitments can potentially result in the same configuration (Wong and Rosenhead 2000). Any particular sequence of commitment sets that can result in a particular configuration is called a *configuration composition* (Wong and Rosenhead 2000, p.178). When applied within the CIS Framework (Anderies *et al.* 2016), the configurations that result from commitments are configurations of infrastructures that can be classified into the five key classes, including: natural, human, social, soft human-made, and hard human-made infrastructures. These configurations of coupled infrastructures produce certain types of affordances in the system that can be further utilized in subsequent action situations to continue toward the realization of prior commitments and ultimately the primary initial commitment of maintaining the desired system functions (i.e. robustness) and/or manipulating and changing certain structures or dynamics within the system (i.e. adaptability).

Robustness Analysis (RA) is typically utilized as "a decision-aiding rather than a decision-analytic approach" (Wong and Rosenhead 2000, p.176) as it is useful for analyzing the availability and attainability of different sets of options but is not necessarily useful for identifying or aggregating individual preferences and utilities or

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[4] Ostrom (2005) refers to these as the "choice" of an action by a participant in an action situation from among the set of potential actions, or moves, available to that participant (p.45)

estimating the probabilities of success. The simplification of these types of tasks makes the methodology more accessible to those not specifically trained in the highly technical aspects of econometrics or other mathematical approaches, perhaps making this methodology more useful in working with communities, practitioners, and policy-makers. According to Wong and Rosenhead (2000) it "throws the burden of forming these judgments and trade-offs back to the decision-makers" and yet also provides a way of eliciting and structuring information so that "the problem, otherwise insurmountable through complexity and uncertainty, is rendered tractable" (p.176). This study couples RA through the CIS Framework (Anderies *et al.* 2016) and NLAS with content analysis techniques to analyze historical documents detailing the intervention project at the time it was being conducted to understand the design-process used in the Sindhupalchok intervention. While the use of historical written documents may be somewhat limited by their availability and biases of the information that was preserved within these documents for the purposes of their authors at the time that they were written, it would be infeasible to attempt to elicit further factual information about the actual decision-making and development activities or potential alternatives that may have been considered at that time. These events occurred more than thirty years ago and are thus subject to the limitations of human memory. The historic documents that have been collected, however, offer interesting detail about the design-process that occurred during the intervention and at least some of the actual considerations and changes that occurred during that process. These documents are useful for testing the proposed theory and garnering insights on participatory design processes for CPR systems. While the analyses presented here are primarily qualitative, a number of researchers (Wong and Rosenhead 2000; Anderies 2015; Yu *et al.* 2015) have demonstrated additional ways of mathematically modeling and quantifying RA, leaving room for potential extension of these findings in the future.

4.3.2 Content Analysis and Coding of Historical Documents

The data for this study was collected from historical reports and documents[5] that were gathered through contact with previous researchers, practitioners, and government authorities involved with the both the WECS project and the subsequent longitudinal study. When necessary, these original documents were scanned and converted into searchable PDF files for import into qualitative data analysis software (i.e. MaxQDA) and archival within the Social-Ecological Systems (SES) Library (https://seslibrary.asu.edu/). The documents were coded by a single coder in MaxQDA version 12. While more than one coder is always preferable (Bernard 2011), it was not possible in this study due to time and funding limitations. Coding categories were established using the CIS Framework (Anderies *et al.* 2016) and Ostrom (2005) structure of the action situation (4.1) to identify the structure of the system and the dynamic actions taking place within the system related to the design-process (Fig. 4.4). Coding categories included:

Action (ACT) This is an action taken by an actor (A) within an AS that combines with the actions of other actors to result in a commitment (C).

Action Link (AL) This is the action link (i.e. verb) that results from an action situation (AS) which effects (i.e. creates, transforms, maintains, or destroys) configurations (CFG) of coupled infrastructures. These typically correspond to tasks within the decision-making or development phases of the design-process. An action link may be intentional and therefore backed by commitments (C) or could also be an unintentional spillover (S). Action links from one action situation may affect various elements within the internal structure of another action situation, including the Actors (A), possible Actions (ACT), Information (I), Control (CTL), and Net Costs and Benefits (NCB) that combine to form Commitments (C).

Actor (A) This is the animate agent (e.g. individuals, groups of individuals, or organizations)

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[5] Historical documents from the original intervention process are marked with an * in the bibliography for this chapter.

that is making a commitment (C) to carry out an action(A) in an AS.

Commitment(s) (C) These are the total sum commitments made by participants in the AS that combine to lead to a particular action link (AL).

Configuration(s) (CFG) These are the configurations of coupled infrastructures that emerge from single or combined action links (AL). Different types of infrastructure may be labeled as:

- **Social Infrastructure (SI)** Social infrastructures are groups of people or organizations
- **Human Infrastructure (HI)** Human infrastructure is the knowledge and labor of individuals within the system.
- **Natural Infrastructure (NI)** Natural infrastructure is hard infrastructure and naturally occurring processes (soft infrastructure) that are not human-made but are critical for the functioning of society (Anderies *et al.* 2016).
- **Soft Human-Made Infrastructure (SHMI)** Soft human-made infrastructure is the institutions (i.e. rules, norms, protocols and shared strategies) that structure repeated interactions.
- **Hard Human-Made Infrastructure (HHMI)** Hard human-made infrastructure is all of hard things and technology that humans manufacture to act upon systems.
- **Primary Initial Commitment (PIC)** This is the primary intended function that is intended to manipulate the dynamics of the system being analyzed.
- **Private Infrastructure (PRI)** This is some asset that is privately owned by an individual or organization that is invested to affect shared action situations.
- **Coupled Infrastructure System (CIS)** This coding identifies a particular configuration of infrastructures that is nested within a particular holon of the system model. The coding of a CIS will be accompanied by a notation of which types of infrastructures (above) are included in the configuration.
- **Alternative(s) (ALT)** This is an alternative configuration (CFG) that is or was under consideration during the design-process.

Control (CTL) This is the mechanisms of control that affect an AS and the formulation of commitments (C).

Information (I) This is information that is brought into a particular AS that affects the formulation of commitments (C).

Position (P) This is the position that the Actor (A) is taking in the action situation (AS). The primary positions may include that of Resource User (RU) or Public Infrastructure Provider (PIP) within the holons of system model. An individual may have multiple positions, sometimes as both RU and PIP. There may be other positions (PO) that other actors may fill in the system such as support positions like that of an engineer, an analyst, a funding agency or an outside governing agency.

Problems (PRB) This code was used to code any problems identified in the texts. Problems were then also coded to what element of the system model they were affecting and/or identified as a specific type of wicked problem, including: Uncertainty (WPU); social dilemma (WPSD); inequity (WPI); or trade-off (WPT).

4.3.3 Mapping Coded Data to the CIS Framework and NLAS

Once coded, the data was utilized to generate and discuss a representative system model showing the sequencing of the design process and its resulting action situations and configurations within the CIS Framework (Fig 4.5). Representations of the system model were mapped by analyzing the following elements of the CIS Framework in relation to the design-process: 1) what scale or level of analysis is most appropriate for examining the design-process under investigation; 2) each of the holons involved in the system (even if they are non-existent or are combined); 3) each of the links between holons in the system, including external links to other levels of analysis or other adjacent systems; 4) the position and sequence of linked action situations including all related commitments, configurations, and possible alternatives; 5) the position and occurrence of spillovers (both positive and negative) that could affect other action situations, configurations, or systems; and 6) the position and occurrence of wicked problems including uncertainties, social dilemmas, inequities, and trade-offs.

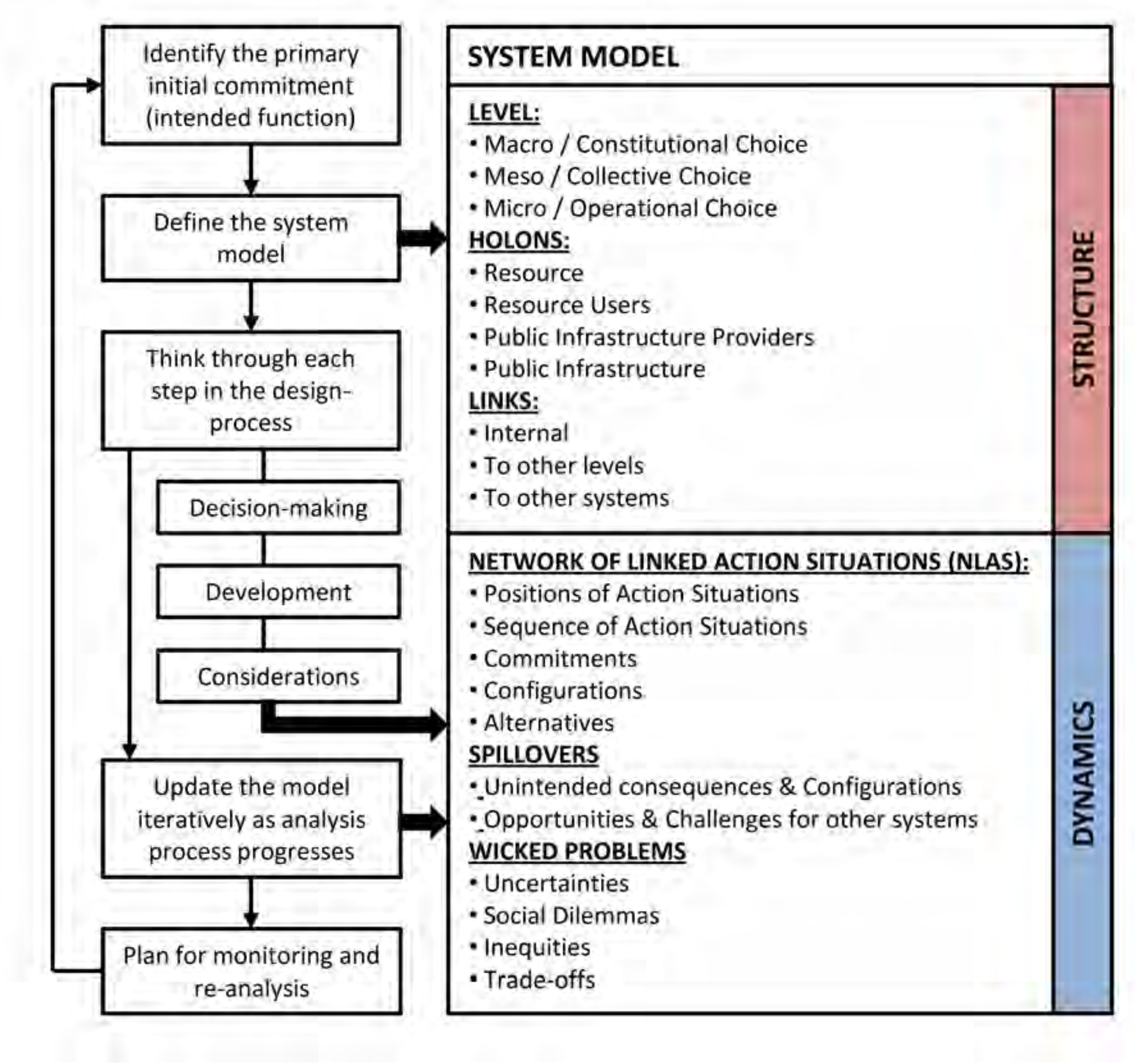

Figure 4.5: Methodology for Mapping Data to a CIS-Based System Model

4.4 Analysis

The analysis presented will walk through the mapping of the coded data to the CIS Framework and NLAS as a qualitative form of Robustness Analysis (RA). Excerpts from the historical documents (i.e. key informants) are presented "as exemplars of concepts and theories or as exemplars of exceptions" (p.438) as suggested by Bernard (2011). Some examples of coding are also provided for illustration of the methodology, but not all coding for the exemplars is included here for readability. The mapping of coded data to the system model is illustrated in both written and graphic forms and proceeds iteratively along the pathways indicated in the methodology (Fig. 4.5).

4.4.1 Primary Initial Commitment (PIC)

Analysis of the intervention began by identifying the primary initial commitment (PIC) that the process was focused on manipulating in the system. While there may be multiple commitments and potential configurations that go along with or are necessary for achieving the PIC, it helps to first identify, or at least prioritize the main objective(s) of the design-process in question. The over-arching goals for the project were stated as follows in the official Inception Report for Phase II (i.e. implementation) of the project (Acharya 1988, p.1):

> *The main purpose of this project is to develop processes, and test methods, techniques, and technologies for assisting existing farmer-managed irrigation systems, so that appropriate ways and means are found to intensify and/or expand irrigated agriculture.*

The PIC in this statement, made by the WECS team (A), is to "assist" (ACT) *existing* farmer-managed irrigation systems (CIS). The Inception Report goes on to further delineate subsidiary goals, i.e. improving the "physical system" and "management problems" (Acharya 1988, p.1), but these are potential ways (i.e. secondary commitments) to support the PIC. There could be any number of alternative configurations that could potentially achieve the PIC, at this point. In this case, they state that their strategies to "assist" (PIC) the FMIS have already been determined to include: 1) developing (ACT) processes (SHMI); and testing (ACT) methods (SHMI), techniques (SHMI), and technologies (SMHI +/or HHMI). In addition, at the end of the statement, they state a secondary PIC which is over-arching their intention to “assist”, which is to “intensify and/or expand” (ACT) irrigated agriculture (CIS made of HHMI+SHMI). The complete PIC in this case, therefore, is to develop and test participatory processes (SHMI), as a public infrastructure (PI), that assists FMIS in the intensification and/or expansion and long-term management of their irrigated agriculture activities.

4.4.2 Define the Initial Structure of the System Model

The identification of the PIC allows us to begin identifying the various elements of the system and model the initial structure of their relative relationships.

Identifying the Focal Level of Analysis

It is well known that policy, planning, and other such processes for managing shared resources are typically linked across multiple levels of analysis (Ostrom 1990; Walker *et al.* 2004; Siddiki *et al.* 2010; Anderies 2015). The WECS intervention was applied across all of the FMIS within the study area, the scale of our focus is the regional or meso-level of analysis. There are, however, other processes happening at both higher (macro/constitutional choice) and lower (micro/operational) scales of the system that affect the intervention. For example, higher levels of governance continue to allow local natural resource management. The specifics of how the intervention is implemented within each of the individual FMIS occurs at the micro-scale (Fig.4.6). It is, therefore, important to think carefully about what level each activity occurs on and the differences in the meaning of the activity at different levels, as well as to explicitly identify and include important cross-scale interactions.

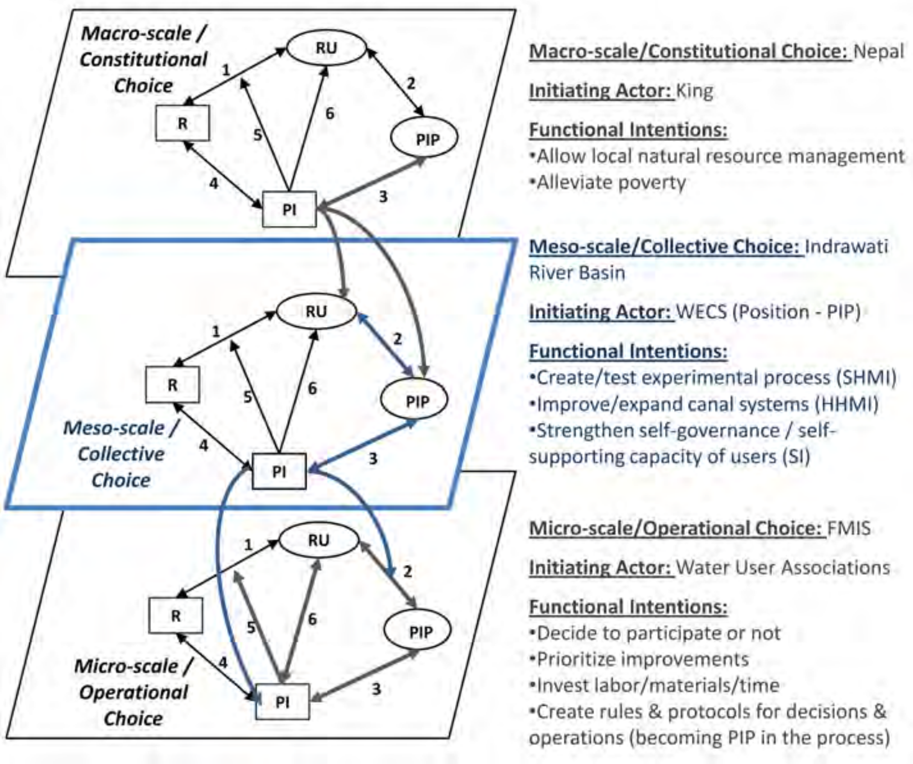

Figure 4.6: Preliminary system representation framing meso-scale as focal scale with connected processes at other scales

Initial Definition of the System Model

Now that we have identified the PIC of this design-process and what scale of the system we are starting with, we can begin mapping out the components of the system using the CIS Framework (Anderies *et al.* 2016) by trying to identify what key components already exist at the beginning of the design-process being analyzed. The Field Report for Phase I of the WECS Project (Hydro-Engineering-Services 1986, p.1) states:

> *In spite of the problems and difficulties [PRB] of the natural phenomena [NI] such as land sliding [PRB], flooding [PRB], gully crossing [PRB], drainage*

> *crossing [PRB], and steep slopes [PRB] in the hilly region of Nepal, the farmers [A-RU] have been practicing [ACT] for centuries to build [ACT] irrigation facilities [HHMI] to increase their crops [PCI]. Groups of farmers [SI] with common command area of an irrigation system worked together [SI-PIP] to divert water [R] from the stream or river [NI] to their fields [PRI]. They have their own rules and laws [SHMI] for running [ACT] the system [HHMI].*[6]

From the coding of the passage, we can see that the resource users (RU) are farmers who need to appropriate (ACT-Link 1) water (R) from the tributaries of the Indrawati River (NI) to their fields (PRI). They (RU) have previously formed (ACT-Link2) groups (SI) and have worked together to collectively create (ACT-Link 3) and maintain (ACT-Link 6) both physical infrastructure (HHMI) and rules (SHMI) forming a FMIS (PI) (Fig. 4.7-A). While the individual systems are separate from one another in terms of structure and management at the micro-scale, they are physically connected geographically (NI) because they draw from the same natural infrastructure (i.e. river basin) and resources (i.e. tributaries) of water at the meso-scale (Fig. 4.7-B). As Figure 4.7-B shows, at the meso-scale of analysis each of the individual FMIS (CIS) can be looked at as a CIS that is an existing unit of public infrastructure (PI) and each individual Farmer's Association (SI) can be viewed as an existing resource user (RU/PIP). At the initialization of the WECS project, the WECS team enters the system with the primary initial commitments (PIC) to provide assistance to the farmers associations (RU) by working with them (ACT-Link2) and creating a process (i.e. the intervention=SHMI) (ACT-Link3) but as they enter the system, these are commitments, but not yet actions resulting in configurations (Fig. 4.7-C). For analysis purposes we assume that the WECS Team enters the system without any established relationships either to the Farmer's Associations (SI) or the FMIS (CIS) (Fig. 4.7-C).

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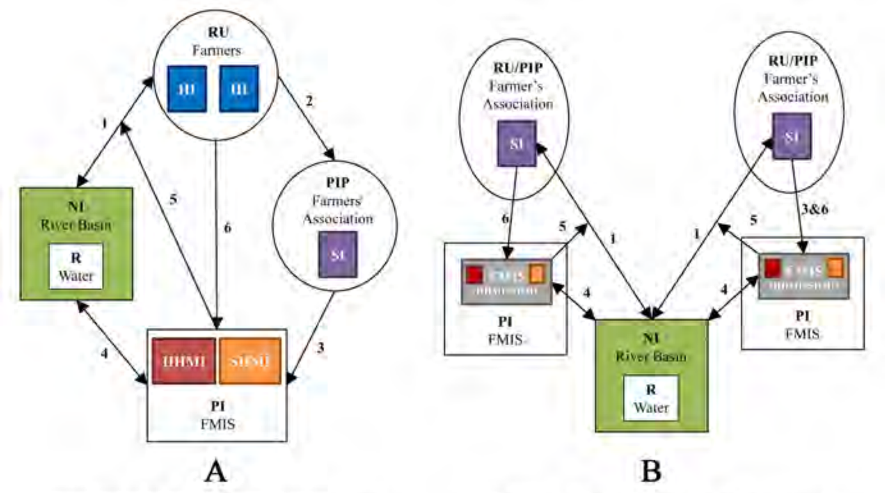
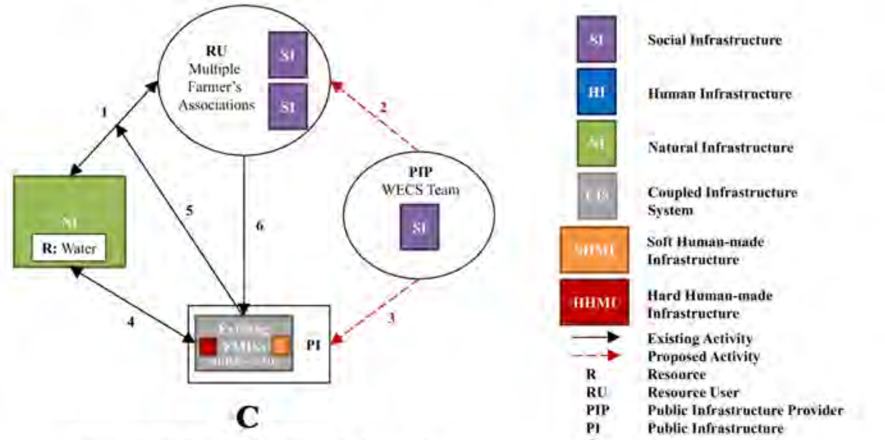
[6] The portions of this excerpt shown in brackets [ ] are the codes for this sample of text.

This initial mapping of the system model begins to identify the four major holons[7], or sub-systems, within the system at the focal scale of analysis as well as the relationship links that exist between them (Fig. 4.7).



Single FMIS at the Micro-Scale using CIS Framework
(Adapted from Anderies et al. 2016)

Multiple FMIS at the Meso-Scale using CIS Framework
(Adapted from Anderies et al. 2016)



Entrance of WECS Team into the System at the Meso-Scale
(Adapted from Anderies et al. 2016)

Figure 4.7: System Models Using the Coupled Infrastructure Systems (CIS) Framework (adapted from Anderies *et al.* 2016)

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[7] *Holons* are nested subassemblies in complex adaptive systems (Ostrom 2005, p.11). “The term holon may be applied to any stable sub-whole in an organismic or social hierarchy, which displays rule-governed behavior and/or structural Gestalt constancy” (Koestler 1973, p.291).

Holons

Resource (R) The key resource (R)[8], for irrigated agriculture (CIS) in this system is the water (R) in the Indrawati River Basin (NI). This primary resource directly supports the overarching PIC of improving (ACT) irrigated agricultural productivity (Link 1). It is interesting to note here that instead of the infrastructure being nested within the holon, resources are nested within infrastructure and so the Resource holon is nested within the Natural Infrastructure.

Resource Users (RU) At the meso-scale of analysis, the resource users (RU) are each of the 23 farmers associations[9] (SI) that could choose to participate (ACT) in the intervention program (SHMI).

Public Infrastructure Providers (PIP) The WECS and their team[10] (SI) are the public infrastructure providers (PIP) at this scale of analysis.

Public Infrastructure (PI) The primary public infrastructure that is created to achieve the functional intentions at this scale of analysis is the CIS of the intervention protocol (SHMI) and team (SI) with their individual knowledge and expertise (HI) to assist in the process. In addition, there is also the existing FMISs within the PI holon at the beginning of the intervention process.

In addition to the holons (i.e. sub-systems) we have also identified some key relationship links. These links are the pathways where actions and the dynamics between areas of the system take place (Fig. 4.7-C).

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[8] In the CIS Framework, resources are forms of mass, energy, and/or information that are manipulated by different classes of infrastructure.

[9] Individual farmers, rather than the collective group of farmers, would be resource users at the lower micro-level of analysis.

[10] The members of IIMI, the engineers, and any other types of professionals contracted by the WECS would be considered agents of the WECS

Endogenous Links

Link 1 The farmers (RU) need to appropriate (ACT) water (R) from where it can be found in the natural river basin topography (NI) to where it is needed at the farmer's fields (PRI).

Link 2 This is the relationship between the farmer's associations (RU) and the WECS Team (PIP).

Link 3 This is the relationship between the WECS Team (PIP) and the public infrastructure.

Link 4 The FMIS (CIS) are partially made of canal systems (HHMI) that modify and work with (i.e. gully/drainage crossing (PRB); steep slopes (PRB)) the natural landscape (NI). In addition, the natural topography and water cycles (NI) can sometimes modify (i.e. land sliding (PRB); flooding (PRB)) the canal systems.

Link 5 The FMIS (CIS) are built to modify and/or govern the ability of the farmers (RU) to appropriate (ACT-Link 1) water (R) and bring it back (ACT-Link 1) to their fields (PRI). This link provides affordances to Link 1.

Link 6 The FMIS (CIS) also modifies and/or governs the behaviors and choices of the farmers (RU) and their associations (SI). The farmers (RU) and their associations (SI) are responsible for the monitoring, maintenance, and operation (ACT) of the FMISs (CIS).

Links Internal to Holons Current versions of the CIS Framework (Anderies et al. 2016) do not include links that are internal to the holons, yet our analysis shows that these links are possible, particularly when analyzing linked action situations (AS). In this case, we have already discovered a relationship between the new PI of the WECS intervention procedures (SHMI) and the existing PI of the FMIS. Because these are both forms of PI, they would both be contained within that holon at the meso-scale level of analysis, as would AS-3 in which the participants (i.e. WECS Team and Farmer's Associations) would work through the intervention process to decide how to improve each FMIS system.

Exogenous Links

Exogenous Links are not currently numbered or further defined within the latest version of the CIS Framework (Anderies et al. 2016). However, these links would be coming into the system from other systems or other levels of analysis and could directly affect any holon or any link that is endogenous to the system. Some of these have already been identified while determining our Primary Level of Analysis (Fig.4.6), including:

Link from Macro-Scale PI to Meso-scale RU This is an incoming exogenous link that maintains (ACT) policies (SHMI) at the national level that allow (ACT) local resource users to manage natural resources.

Link from Macro-Scale PI to Meso-scale PIP This is an incoming exogenous link that directs (ACT) the government agency WECS to study (ACT) and intervene (ACT) to alleviate poverty (i.e. food crisis) in the Sindhupalchok District.

Link from Meso-Scale PI to Micro-Scale PI This is an outgoing exogenous link from the intervention process (PI) to improve or expand (ACT) the canal systems (HHMI) and rules (SHMI) within each of the individual FMIS (PI) at the local level.

Link from Meso-Scale PI to Micro-Scale Link 2 This is an outgoing exogenous link from the intervention process (PI) to strengthen the self-governance and self-supporting capacity (RU ability to perform within the position of PIP) at the local level.

Developing a Network of Linked Action Situations

In this section, I continue the previous analyses of the system structure and dynamics by systematically analyzing each step in the design-process to create a NLAS for the case study. The NLAS analysis includes: 1) the positions of AS; 2) the sequencing of AS; 3) the commitments, configurations, and potential alternatives resulting from each AS; and 4) the advent of spillovers and wicked problems. These analyses culminate in the RA, which identifies the points in the system that increase or decrease the qualities of resilience, robustness, and adaptability in the system.

Stepping through the Design-Process

Design-processes for CPR systems are iterative and can move back and forth between decision-making and development (Fig. 4.4). The preliminary analysis and initial system mapping of the WECS intervention previously discussed (Fig. 4.7-C), and the beginning of Phase II, occur when the intervention protocol is being implemented, near the beginning of the development phase. To understand the NLAS involved in the design-process, however, we must step backward from this point to discuss the decision-making that structured the intervention prior its implementation. While decision-making sometimes involves very distinct activities and potentially different decision-makers within each one, the lines between these activities are not always clear. Some activities may be combined or may not occur in the order specified in my design-process model (Fig. 4.4). The following analysis discusses each of the activities in the design-process model and the development of ASs as they occur in the system model (Fig. 4.1).

Decision-Making

Conceive The final report on lessons learned in the WECS Project (Phase I and II) states that the project was "initiated by the Water and Energy Commission Secretariat (WECS) with support from Ford Foundation and International Irrigation Management Institute (IIMI)" (p.ix) and discusses the initial conception of the project (WECS and IIMI 1990, p. vii):

> *In 1985 IIMI held an international workshop to identify issues upon which to focus its work. One recommendation was to examine small farmer-managed systems, particularly with regard to the role of government irrigation agencies in upgrading their physical and/or institutional infrastructure. Studies of farmer-built and -managed irrigation systems have documented a range of farmer management capacity in diverse and difficult environments. While some systems are run extremely well even with high operating costs, others are struggling to survive. Assistance to make such systems more productive and sustainable has become an important goal of many countries. Because of the large number of farmer-managed systems in Nepal, IIMI welcomed the opportunity to collaborate with the Water and Energy Commission Secretariat (WECS) to examine ways to assist and improve these systems.*

These passages contain the first action situations that occur to bring the WECS Team into the system with the farmers and their irrigation systems. In the first action situation (AS-1), the WECS Team (i.e. WECS, IIMI, and Ford Foundation) decide to collaborate with one another (i.e. for SI) and then they make (AS-2) the primary initial commitments (PIC) to initiate the overall project and

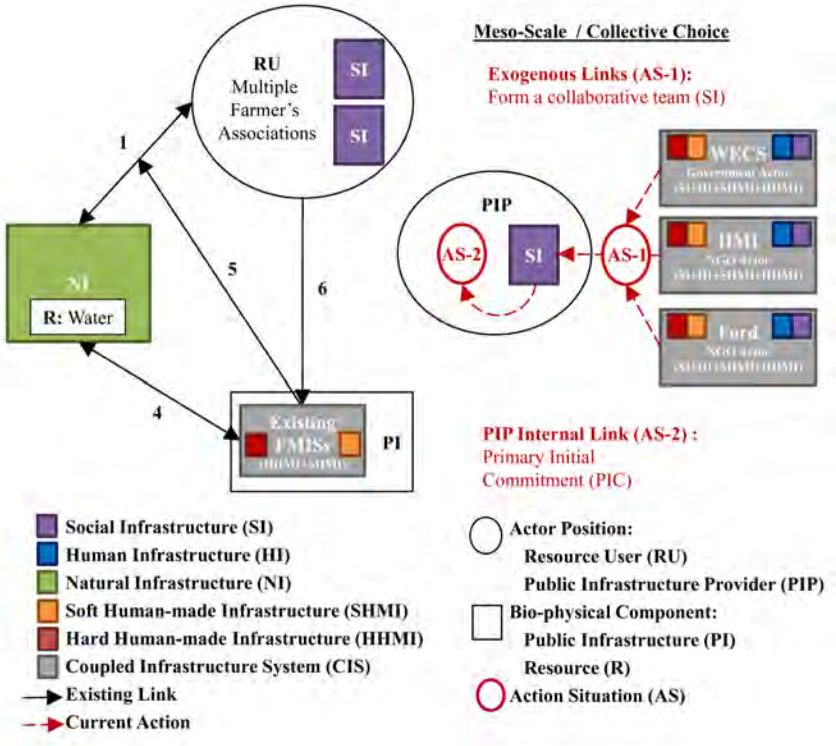

Figure 4.8: System Model During WECS Team Formation and Project Conception

assist FMIS. While the WECS Team enters into the system at the focal meso-scale, they are still separate from the farmers and their FMIS at this point (Fig. 4.8). The role of the WECS is to initiate the intervention, provide "direction and vision" for the project, and manage the process; the IIMI provides expertise (HI) and staff (HI) support (HI) to the project; and the Ford Foundation provides financial support (PRI) for the project (WECS and IIMI 1990).

Define After initiating the project and deciding to collaborate with one another, the WECS Team then began to define the scope, structure and objectives of the project in Phase I (WECS and IIMI 1990, p.3):

> *The objective of determining relative needs among systems and establishing criteria for selecting systems to assist required that all the systems in the*

> *project area be identified and some minimum level of information collected about each of them. An inventory activity was used to fulfill this objective. ... Hydro-Engineering Services, a local consulting firm, was engaged to visit all tributary streams of the Indrawati River in the project area and identify each canal diversion point. Using farmer informants to describe the variation of discharge in the stream at the diversion in each season compared to that being observed, the water resource available throughout the year was assessed. The consultant was required to walk from the canal diversion to the command area of each canal with a group of water users and note difficulties that the farmers face in operating the system. By asking a group of farmers, a rough estimate was made of the area irrigated for each crop and reasons why it was not presently receiving water was also accomplished with the help of the farmer group. ...As a result of the inventory, 119 irrigation systems were identified with canals longer than 0.5km in the 200-square kilometer project area (Hydro-engineering Services 1986). These systems irrigate about 2,100 ha owned by more than 5,000 households.*

This quote summarizes Phase I of the project, in which the next step in the process (Fig. 4.9) was identifying the need to gather information and making commitments (i.e. deciding) on how to do accomplish this task (AS-3). They create (AS-4) a process (PI-SHMI) for gathering information about the systems and hire (AS-5) an outside consultant (CIS), Hydro-Engineering Services, to collect (AS-7) the data (R). It is important to note that the consultant is an exogenous CIS that becomes a part of the public infrastructure (PI). As part of the inventory process (PI), the consultant is directed to find informants (HI) from the farmers associations (SI) to provide (AS-6) some knowledge and information (HI) on the functioning of the FMIS. These resources of information (R) are then provided back to the WECS Team in the form of the Phase I Reports (Link 3).

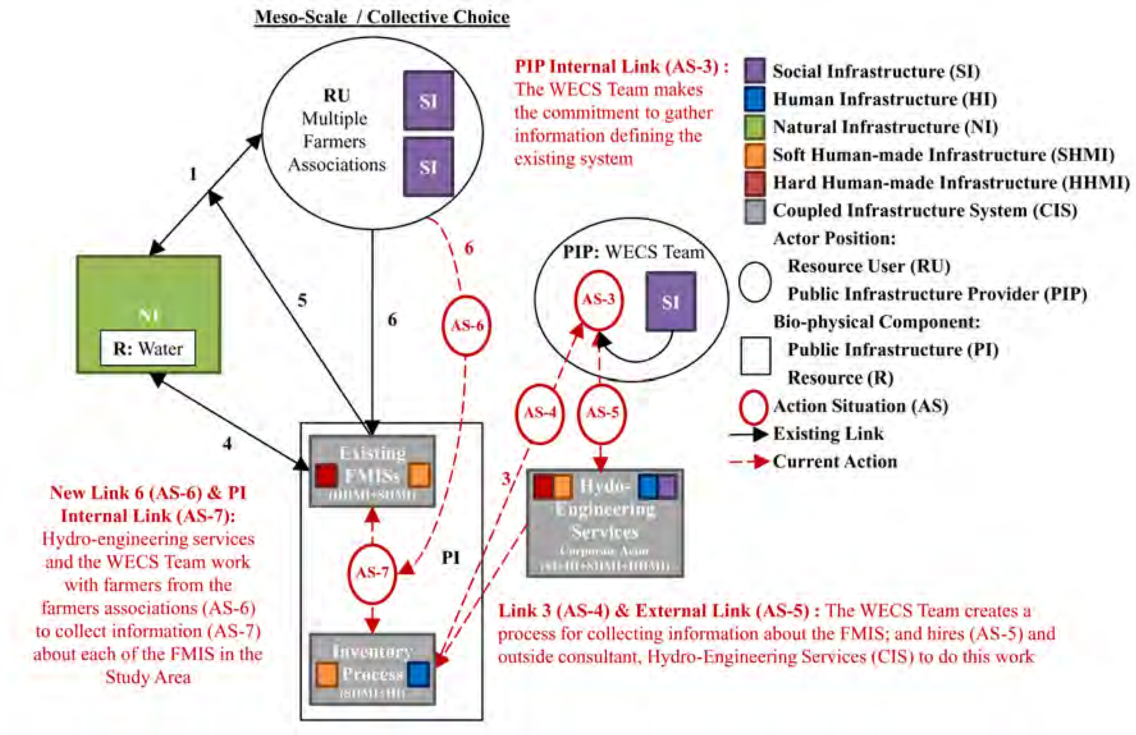

Figure 4.9: System Model During Inventory Process

Ideate/Brainstorm/Explore Options Phase I resulted in an inventory of 119 systems within the selected 200 km^2 Study Area. The impetus (PIC) behind the entire project was "to help planners in decision making for assisting [FMIS]" (Hydro-engineering 1986, p.1). While the concept of "assisting" the farmers in FMIS predated the entire WECS project, ideating and exploring options for how that assistance would take shape was based on the results of the Phase I inventory (i.e. defining the system). The fact that the intervention would assist *existing* systems was based on prior studies and expert knowledge that pre-dated Phase I of the project. The study area was selected, in part, because there were a high number of existing FMIS in this area that could potentially benefit from expansion. Not all systems in the hilly areas of Nepal had the capacity for expansion; however, as described by a researcher from IIMI on the WECS team (Yoder 1988):

> *A conservative estimate is that there are 17,000 existing irrigation systems in the hills [of Nepal]. My guess is that it may be as high as 100,000 if one includes all diversions where more than two families work together to control water. Fortunately I would guess less than half of these really need any external assistance. With all due respect to those who would like to build new systems to open up new areas to irrigation, I do not believe there will be more than maybe a few hundred to a maximum of a thousand new systems built in the next 12 years. I have not traveled in East Nepal nor extensively in the Far West, but I have walked through most of the middle hill area of the Western and Central Development Regions and have not seen many sites where a new system could be built where a substantial portion of the area was not already irrigated.*

This shows that there were recommendations, prior to the inception of the overall project, that the capacity to help existing systems in the study area had more potential than the construction of completely new systems. Therefore, the option between focusing on new or existing systems had already been made either by the WECS team or at a higher level of governance. The WECS team did not ask for or include the resource users in this part of the decision-making process or exploration of options. Roberto Lenton, a director of IIMI during the project, explains also that the decision to focus on the social and institutional infrastructure of the farmers' associations, in addition to the physical infrastructures, was also based on prior expert-knowledge of these systems (WECS and IIMI 1990, p.vii):

> *A strategy of rehabilitating farmer systems with large inputs from a government agency is sometimes necessary. However, there is a tendency in this approach to focus only on physical improvement and to ignore the management dimension. Failure to recognize existing farmer institutions such as water rights and methods of resource mobilization sometimes caused government intervention to decrease farmers' organizational capacity, often shifting part of the operation and maintenance burden to a government agency. The WECS activity reported here is an effort to improve and expand existing farmer systems while ensuring that farmers retain full responsibility for management. The WECS work suggests an alternative strategy to full-system rehabilitation by providing minor financial and material assistance as a means to strengthen local management capability.*

This passage illustrates that there was a systems-orientation, rather than a problem-solving orientation, from the inception of the intervention. It also shows that a number of secondary commitments resulting in limitations to the particular configurations of assistance that would be offered to the farmers associations were decided prior to the design-process in this case study. However, the intervention was considered to be an "action research" project throughout the process, showing a commitment to exploration and experimentation during the process itself, as articulated by Lenton (WECS and IIMI 1990, p.vii):

> *WECS is to be commended for testing this strategy in an action-research mode. It brought together the experience of assistance programs in Nepal and other countries, plus lessons learned from the studies of existing farmer-managed irrigation systems. From these, a set of procedures and sug-*

> *gestions for physical and management improvement of existing systems evolved.*

Choose/Plan/Present The Phase I inventory found that among the 119 existing FMIS in the study area, 23 were found to be eligible for an intervention (WECS and IIMI 1990). In choosing which systems would be included and planning the intervention (Fig. 4.10) the WECS team first determined (AS-8) which systems were eligible based on the information coming back to them (Link 3) from the inventory, including: water availability; the need for physical improvement; and the potential for expansion of command area, crop intensification, and/or reducing maintenance (Ostrom *et al.* 2011). It was also determined (AS-8) that additional information on these 23 eligible systems was necessary and a new contract with Hydro-Engineering Services was created by the WECS team (AS-10) to conduct a second stage of information gathering (AS-12) and collect further baseline data. The WECS team created (AS-9) a methodology (SHMI) for this secondary data collection, calling it a Rapid Appraisal Study for the eight selected micro-areas where these 23 systems are located (Hydro-Engineering-Services 1986). In this process Hydro-Engineering services again worked with (AS-11) informants (HI) from the farmers' associations (SI) to identify: the number of users in each system, the role and strength of each farmers' association, irrigation management practices, and critical needs for physical improvement of the technical infrastructure, as explained (WECS and IIMI 1990, p.19):

> *The rapid-appraisal report identified far more work to be done than available project money could cover. One option was to reduce the number of systems assisted to allow full funding for a few. Another alternative was to*

> *only provide assistance for the most urgent needs in each system. Since it was noted that some work was essential for system expansion, while other improvements reduced maintenance or made the system easier to operate, it was decided to divide all improvements into three categories: 1) first-priority work was essential for expansion but difficult for farmers to do without assistance, 2) second priority included work desirable for improved system operation and maintenance, and 3) third-priority work was identified as improvements farmers could accomplish with their own resources – skills, labor, and materials. The project assistance funds were allocated among the irrigation systems in proportion to the estimated cost of completing the first-priority work. Most first-priority improvement costs were covered. Once the allocation of funds was made, a fixed amount of money was available to each system. As an incentive to the farmers, the project decided that if farmers could save money by working efficiently, or by paying themselves lower wages, or by donating labor, they would be able to use the savings for additional, second-, or even third priority work within the system, i.e., all the funds allocated to a system would be used in that system rather than stopping assistance when the first priority work was complete.*

During this process, the WECS team established an on-going dialogue and rapport (Link 2) with each of the 23 farmers' associations, presenting themselves and the conceptual intervention to them (AS-13). This is when the participatory features of the intervention begin to be engaged, as each farmers' association was asked to collectively decide[11] (AS-13): 1) whether or not they would accept

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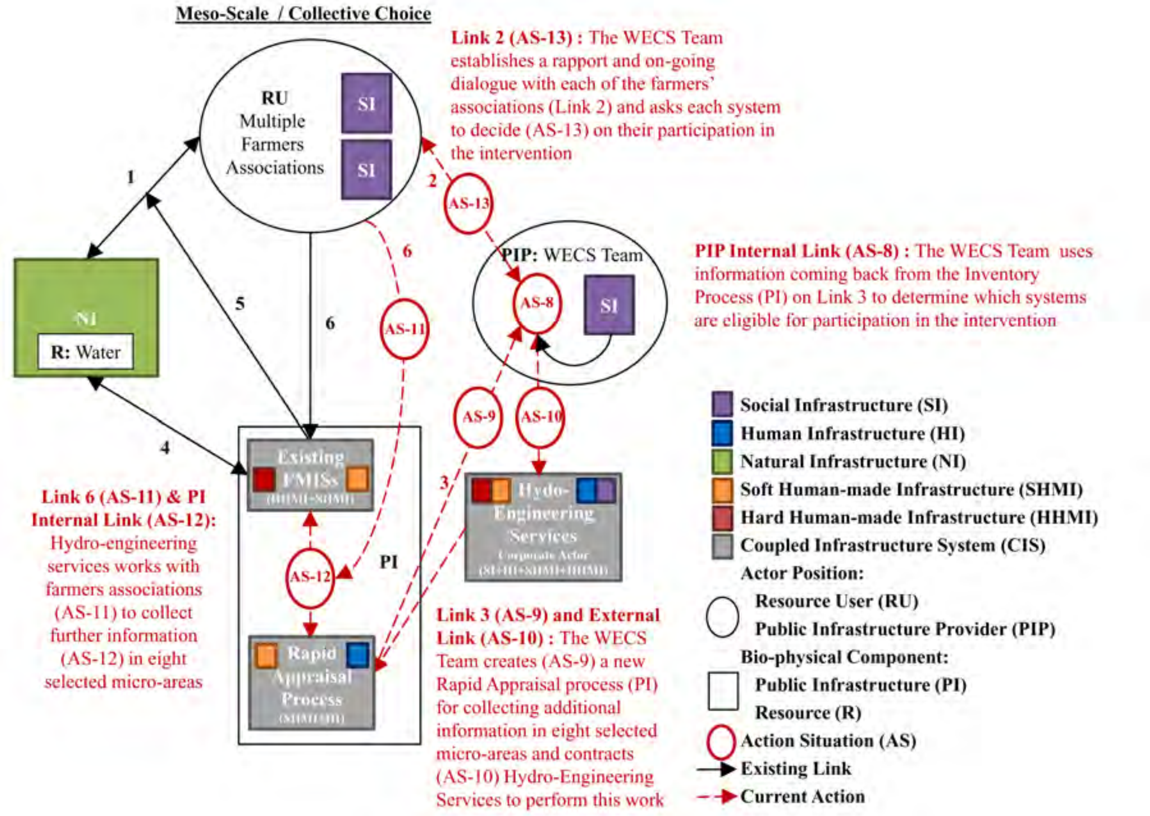
[11] Each individual farmers' association was asked to decide on participation in the intervention within their own group. Although geographically connected by sharing a water source, the program did not attempt to intentionally create relationships between connected systems in any of the micro-



Link 2 (AS-13) : The WECS Team establishes a rapport and on-going dialogue with each of the farmers' associations (Link 2) and asks each system to decide (AS-13) on their participation in the intervention

PIP Internal Link (AS-8) : The WECS Team uses information coming back from the Inventory Process (PI) on Link 3 to determine which systems are eligible for participation in the intervention

Link 6 (AS-11) & PI Internal Link (AS-12): Hydro-engineering services works with farmers associations (AS-11) to collect further information (AS-12) in eight selected micro-areas

Link 3 (AS-9) and External Link (AS-10) : The WECS Team creates (AS-9) a new Rapid Appraisal process (PI) for collecting additional information in eight selected micro-areas and contracts (AS-10) Hydro-Engineering Services to perform this work

Figure 4.10: System Model During Choice Process

new members; 2) if they wished to participate in the program; and 3) what kinds of contributions they could make to the future improvements. Nineteen of the twenty-three eligible systems opted (AS-13) to participate in the program.

Development

Develop/Form/Structure/Create After defining the systems, exploring the options, making some initial commitments, presenting the opportunity (i.e. intervention) to the selected farmers' associations, and then jointly choosing to participate in the intervention (AS-13), the WECS team decided on (AS-14) the form of the intervention for attempting to achieve the PICs (WECS and

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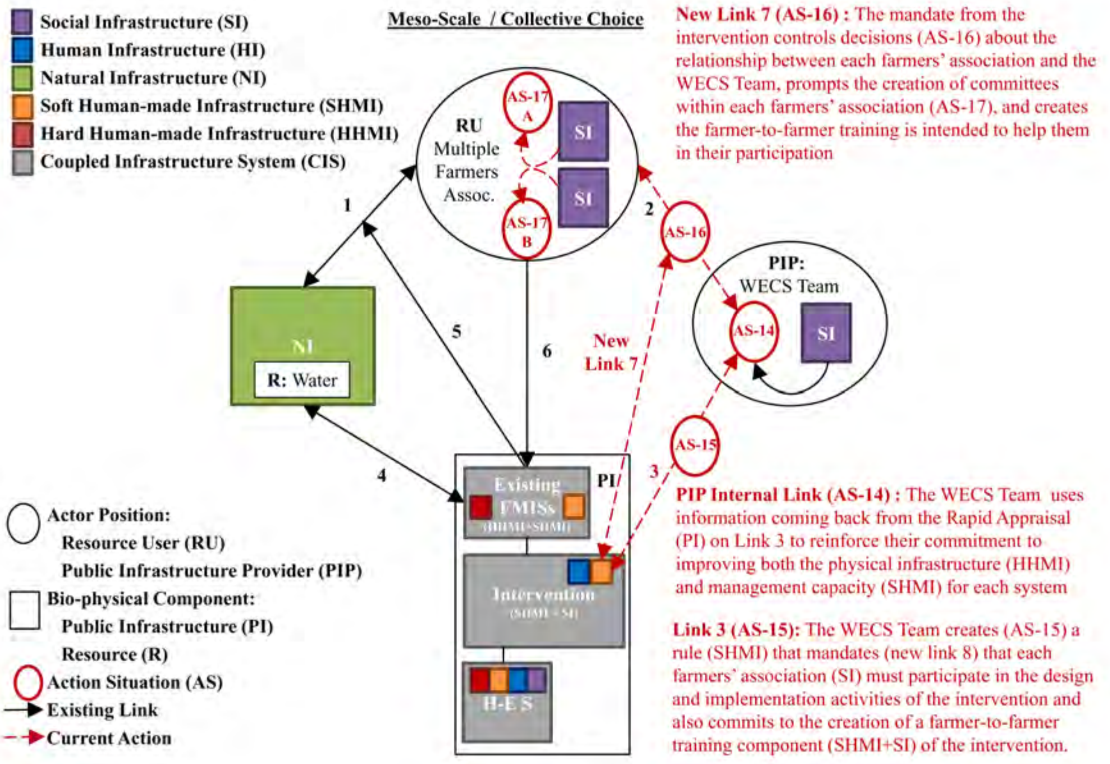
areas.

IIMI 1990, p.xi):

> *While all of the systems selected required improvement of their physical infrastructure (e.g., enlargement of canal sections through rocky cliffs, construction of retaining walls and stream crossings, and lining segments of the canals), it was concluded that the absence of strong users' groups was a major factor in the farmers' inability to improve their systems by themselves. These systems lacked an organization able to carry out cooperative action for maintenance, to establish rules, to elect leaders, and to enforce sanctions. In the second phase of the project, improvements were designed and implemented. Farmer participation in the design and implementation was mandated to insure that operation and maintenance activities remained the responsibility of the farmers. In a public assembly to which present and future water users were invited to attend, the farmers selected a management committee to be responsible for day-to-day construction activities and continued management of the system.*

This passage reveals that, based on the results of the Rapid Appraisal coming back to the WECS team on Link 3 of the system (Fig. 4.11), a commitment to assisting these systems in both the improvement of their physical infrastructure (HHMI) and management capacity (SI+SHMI) was made (AS-14). This represents a good example of a key leverage point for adaptation in the design-process where a change might have been made based on the results of the rapid appraisal, but in this case resulted instead in a re-commitment to the PICs. Furthermore, these commitments were institutionalized (AS-15), i.e. the commitments were transformed into a rule (SHMI) that mandated the participation of the farmers' association in the design and implementation activities. The affordance of the rule (SHMI) created by (AS-15) creates a defined relationship (i.e. a new internal Link 7 in the system) that has not been previously been included in the CIS Framework (Anderies *et al.* 2016). The new Link 7 links the rule (SHMI) as public infrastructure (PI) to the action situation on Link 2 (AS-16), where the relationship between the farmers' associations (RU) and the WECS team (PIP) is determined and responsibility for future operation and maintenance activities (Link 6) is allocated to the management committees that must be formed (AS-17) by each farmers' associations (SI), thus establishing them as the permanent PIP (AS-16) following the intervention process.



New Link 7 (AS-16) : The mandate from the intervention controls decisions (AS-16) about the relationship between each farmers' association and the WECS Team, prompts the creation of committees within each farmers' association (AS-17), and creates the farmer-to-farmer training is intended to help them in their participation

PIP Internal Link (AS-14) : The WECS Team uses information coming back from the Rapid Appraisal (PI) on Link 3 to reinforce their commitment to improving both the physical infrastructure (HHMI) and management capacity (SHMI) for each system

Link 3 (AS-15): The WECS Team creates (AS-15) a rule (SHMI) that mandates (new link 8) that each farmers' association (SI) must participate in the design and implementation activities of the intervention and also commits to the creation of a farmer-to-farmer training component (SHMI+SI) of the intervention.

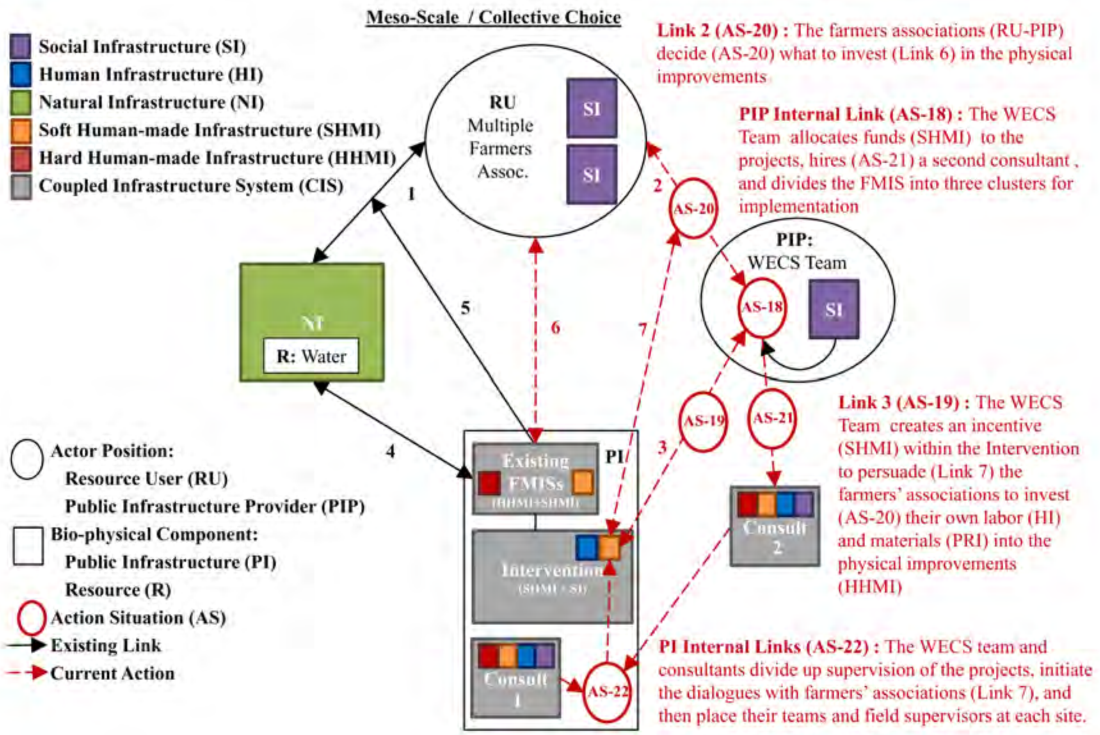
Figure 4.11: System Model While Structuring Intervention

In addition to the creation of the mandate for participation of the RU in the design-process, a farmer-to-farmer training (SHMI) component of the intervention was also identified as a priority, resulting in a commitment (AS-15) to including this in the configuration of public infrastructure, providing affordances to increase the success of the farmers' participation (Link 7) (WECS and IIMI 1990, p.19):

> *A major problem identified during rapid appraisal was that the water users of the systems selected for assistance did not function as organized bodies to manage the operation and maintenance activities of their canals. Labor mobilization for maintenance was not systematic, and in many cases it was unclear how many households actually received water from the canal for irrigation. Cash mobilization for making system improvements or paying someone to patrol the canal daily was unknown. Only one of the systems had any written records – and that was for only a few days of labor mobilization. This was in sharp contrast to well-managed farmer systems studied in many other districts of Nepal (Khatri-Chhetri et al. 1988; Martin and Yoder 1988b; and Pradhan 1989). The systems selected for assistance by the action-research project had only recently begun development of their institutions, – i.e, formulating rules, rights, and obligations, and organizing themselves to make decisions and manage irrigation tasks. From the results of the action research, it is clear that the primary reason these systems had not developed the full extent of their land and water resources was due to the lack of a strong users' organization rather than technical or economic difficulties. During the rapid-appraisal study, farmer training for irrigation management in each system was identified as a priority in implementation of the project.*

This passage not only reveals some of the types of uncertainty that are faced in these systems when the successful operation of the physical infrastructure (HHMI) depends upon the inputs and efforts from the group. It also shows the potential importance of organization (SI) and protocols (e.g. record-keeping) (SHMI) for mitigating these types of uncertainties. Following the decisions to focus on improvement of the social and institutional infrastructures, as well as the physical infrastructure, the WECS Team allocated funds for each of the FMIS participating in the intervention. Funds were allocated (AS-18) based on the estimated cost of completing first-priority works, most of which were completely covered. The creates (AS-19) an incentive (SHMI) in the design of the intervention that is intended to persuade (Link 7) the farmers' associations (RU) to invest (AS-20) their own labor (HI) and materials (PRI) into the physical improvements (Link 6) of the canal system (HHMI) by allowing any money saved by working efficiently, paying themselves lower wages, donating labor or materials to be used for additional, second-, or third-priority work, i.e. all fund allocated to a system would be utilized within that system instead of stopping funding assistance once first-priority works were completed (WECS and IIMI 1990). An additional outside consulting firm was hired (AS-21) and the systems were divided up (AS-22) into three clusters for supervision in one cluster by the WECS team, in one cluster by the consultant hired to do the inventory and rapid appraisal (i.e. Hydro-Engineering Service), and in one cluster by the new consultant hired (i.e. B. N. Acharya Consulting Civil and Structural Engineers). Supervision teams responsible for directing and implementing the work "consisted of engineers, overseers, agriculturalists, social scientists, and persons with construction skills" (WECS and IIMI 1990, p.19) and a full-time field-supervisor who stayed at each site throughout the process was put into place (Link 3 and Exogenous Links from Consultants).

Implement The field supervisors (HI) for each cluster first initiated (Link 7) a series



Link 2 (AS-20) : The farmers associations (RU-PIP) decide (AS-20) what to invest (Link 6) in the physical improvements

PIP Internal Link (AS-18) : The WECS Team allocates funds (SHMI) to the projects, hires (AS-21) a second consultant , and divides the FMIS into three clusters for implementation

Link 3 (AS-19) : The WECS Team creates an incentive (SHMI) within the Intervention to persuade (Link 7) the farmers' associations to invest (AS-20) their own labor (HI) and materials (PRI) into the physical improvements (HHMI)

PI Internal Links (AS-22) : The WECS team and consultants divide up supervision of the projects, initiate the dialogues with farmers' associations (Link 7), and then place their teams and field supervisors at each site.

Figure 4.12: System Model During Development and Implementation

of dialogues with the farmers' associations in each system (AS-20). All users and prospective users were invited to these meetings where the scope, funding, priorities, processes and terms of the intervention were discussed, sometimes resulting in the modification of priorities (WECS and IIMI 1990, p.19). The farmers then began working together to identify potential existing and future users that were not present; prepare a plan and rules (SHMI) for the improvement process and future management, operations, and management; and processes (SHMI) to work with the field teams (AS-20). This AS represents another significant leverage point in the intervention process, where the general form of the intervention (SHMI) links to the micro-/operational level of decision-making and also becomes varied between systems to achieve the best fit for each system.

The farmer-to-farmer training component was then implemented (AS-23), including five training tours (SHMI) to well-performing FMIS outside of the study area. From 1-9 farmers (RU) from each of the systems participating in the intervention attended (AS-24), where they were exposed to “a variety of organizational and management options that other farmers in well-managed systems have developed” (WECS and IIMI 1990, p.21). Each tour included an inspection of the intake and canal (HHMI) of the host system and then a facilitated meeting where the host and visiting groups discussed the ways (SHMI) that the well-performing system had “devised to deal with issues such as labor mobilization for emergency maintenance, water allocation, water distribution, conflict management, and the structure of organization” (p.21). A facilitator from the supervising field team (HI) listened and sometimes interjected (Link 7) questions to assure that all topics were discussed (AS-24) in adequate detail. As part of the farmer-to-farmer training (SHMI), the WECS team also hired (AS-25) representatives (HI) chosen by the well-performing FMIS as consultants to visit nine of the systems participating in the intervention, provide observations (Exogenous Link from Outside FMIS to WECS Team) on the similarities and differences to their own systems and make suggestions (AS-25) for improvement (AS-26) of the process and outcomes of the intervention. Their primary observation and suggestion was that it was the organizational (SI) and institutional (SHMI) infrastructure that required strengthening, more so than the physical infrastructure (HHMI) in these systems. Their observations were described as follows (WECS and IIMI 1990, p.22):

> *The observations and input of the farmer-consultants at each system reflected their perception that it was not due to the lack of resources or difficult technical problems that these systems were not functioning well, but rather that the water users had not developed a strong organizational struc-*

> *ture that enabled them to make and carry out decisions that benefited all users equitably. The farmer consultants' report at the end of their ten days of work indicated some frustration that government assistance was being provided to irrigation systems where physical improvement was relatively easy. They identified the irrigators' unwillingness to sit down and work out personal differences and to work cooperatively as the main reason the systems had not been improved by the farmers themselves. In the farmer-consultants' own systems, they had overcome more difficult technical problems with much less outside assistance. When it was pointed out to them that they had been hired as farmer-consultants because they could communicate this self-help attitude so well, they accepted the rationale with great pride.*

The historical documents indicate that the farmer-to-farmer training (SHMI) was considered one of the most useful and successful components of the intervention by the WECS team and the farmers' associations (AS-26). It fostered pride in the example systems that were working well and "created a great deal of enthusiasm among the visiting farmers when they realized that most of their own systems faced fewer physical obstacles [than the exemplar systems] and that they could achieve the same level of intensive irrigated cropping" (WECS and IIMI 1990, p.21). These aspects were also reinforced (Link 3) by the field supervisors (HI) from the WECS team (PIP) who lived at the site of each system full-time throughout the improvements and acted as a liaison between the WECS team and the farmers (WECS and IIMI 1990, p.21): "In many cases, the field supervisor lived with the farmers and learned to know them well, came to understand community problems, and became able to identify factions among farmers - all of which were essential in the process of motivating and helping the farmers build a viable water users' organization". According to the historical documents, although the field supervisors' job was to "oversee completion of the physical improvements, ensure the integrity of the design, and control quality ... they found that the majority of their time and effort was spent motivating the farmers to work as an organization" (WECS and IIMI 1990, p.21).

Design development for the physical improvements in each system was also implemented (AS-24) in this phase as a participatory activity and all designs and expenditures were kept transparent throughout the process in a construction book that was used to record all meeting minutes and decisions, a daily summary of work, labor mobilization, local materials collected, all costs and transactions (WECS and IIMI 1990). This not only supported the incentive for farmers' investment into the project, but also facilitated the development of increased trust between the farmers and the WECS team (WECS and IIMI 1990). The initial design work, drawings, and cost estimates were created by engineers in the field teams with input from the farmers' associations to begin work on all of the first-priority improvements.

Test/Evaluate/Feedback/Learning/Improve/Change The changing and evolution of a design-process for a public intervention, like the one presented here, is often difficult but sometimes necessary based on evaluation and learning during the process. While it was considered crucial in the case-study intervention that "the design work should be field based with full participation of the beneficiaries, it was also necessary to comply with the rules and regulations of the government" (WECS and IIMI 1990, p.20). This resulted in the creation of design drawings and cost estimates that were based on the national standards of the Ministry of Works and Transport, but done in the offices of engineers in

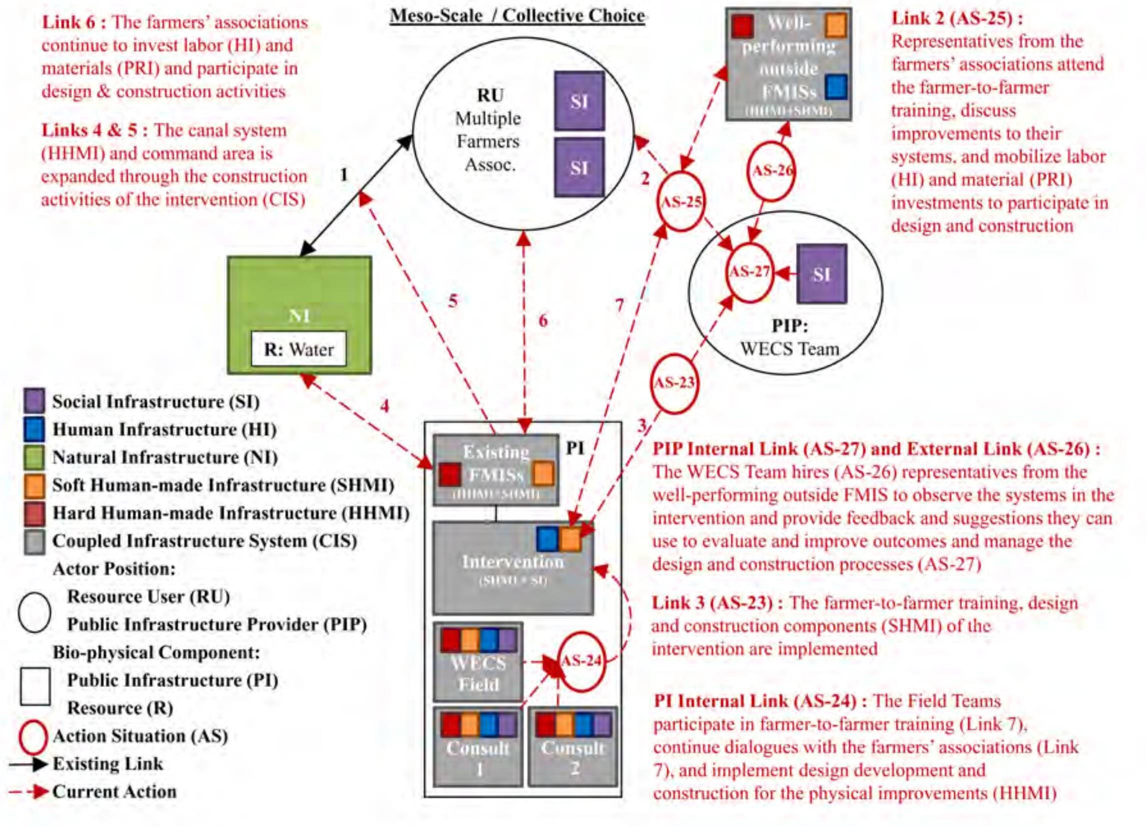


Figure 4.13: System Model During Farmer-to-Farmer Training, Design, and Construction

Kathmandu "away from the site without benefit of farmer input or re-inspection of the site" and "in the end, required substantial changes to comply with the project objectives, i.e., meet farmer approval" (WECS and IIMI 1990, p.20). The WECS and IIMI (1990), p.21) discuss this dilemma in their report on lessons learned:

> *Changing a design typically requires preparation of the new design and related drawings, a new cost estimate, and approval of both by higher authorities who are at a central office far from the work site. This must be understood in the context of an isolated work site where telephone and two-*

> *way radio communication are not available, and reaching the site requires considerable walking. Changes can cause long delays which are particularly annoying and expensive when a project has already mobilized labor and materials and is ready to build the structure. Because farmers frequently demand time-consuming design changes when they actually see what is to be constructed, project staff in government projects often prefer to use a contractor who will carry out the work according to the design regardless of objections from the farmers. To expedite construction in this project, the WECS Executive Director of Water Resources delegated authority to the two senior WECS engineers to approve design changes in the field if the request was made by a majority of the water users. This allowed a great deal of flexibility during implementation and a substantial number of design changes were made. However, even with a rapid, flexible process for changing and approving designs, it always caused delays for those supervising the field work.*

This example highlights the role of testing, evaluation, feedback and learning in the design-process, but also the need for flexibility and improvement or change during the process itself. The report states that "of the 150 first-priority structures designed for the 19 systems, 41 percent were redesigned as a result of farmer requests during construction, and seven percent were dropped in favor of using the money for modified priorities" (WECS/IIMI 190, p.21). However, the report also states that "through farmer participation and intensive construction supervision, enough money was saved in implementation of the first priority work to allow an additional 140 structures and activities to be completed" (WECS/IIMI 190, p.22). This highlights the trade-offs that must be weighed when planning a participatory intervention.

Implement/Create The design activities for the physical infrastructure (HHMI) improvements resulted in an expansion of the irrigated command area in the 19 FMIS by more than 50 percent. Almost all of the improvements identified by the farmers' associations were completed with the budgets originally allocated to cover only first-priority work (WECS and IIMI 1990, p.23):

> *More important than the low capital cost per hectare of the grant was the effect of intensive supervision and farmer training tours in motivating farmers to use the grant resource productively and to augment it with their own labor. This resulted in nearly all of the improvements identified by the farmers and consultant (including second- and third-priority work) being completed even though the budget was expected to cover only the improvements of first priority. ... farmer involvement in the construction resulted in a 38 percent saving over the estimated cost of the first-priority work. Although the project was not based on a mandatory contribution from the farmers, about half of the systems managed substantial labor mobilization from their own resources. One system contributed 30 percent of the total investment in their system. Averaged over all the systems, farmer participation can be credited with increasing the value of the grant by about 134 percent, where the volume of work completed is computed at the rates given in the national norms for rate analysis. Most of the increases in value of the work done can be credited to the efficiency of work accomplished by farmer participation over what would have been required if contractors had been used. Although a great deal of time and effort was required to bring about effective farmer participation and the project got off to a slow start with delays for design modifications, ultimately it resulted in an extraordinary farmer response during construction. Once farmers were convinced that they were getting what they needed from the project, they worked hard*

> *to gain the maximum benefits possible.*

The farmers themselves were heavily involved (Link 6) in the construction of the physical infrastructure (HHMI) (Fig. 4.13). First priority works were "such works which were beyond the capacity and the normal resources of the beneficiaries to improve them without a meaningful external support" (Acharya 1988, p.2). All of the first-priority work for all systems was completed in the project during construction. In addition, most of the second- and third-priority works were constructed as well. Second-priority works were "those works which were not necessary as critical as the first-priority works" and third-priority works "contained the earth work required to canal widening and canal expansion to expand command areas" which the farmers' typically construct through their own labor mobilization and labor investment (Acharya 1989, p.2). Some of these investments from the resource users did not result from collective decision-making processes (AS-24), but instead as a spillover effect of problems in the provisioning of tools for the construction work (Acharya 1989, p.19):

> *We required tools to be purchased sufficiently and of good quality at the beginning with our and beneficiary consultation. But we were not consulted. The tools supplied proved of ordinary quality. Also all the tools required were not supplied all at the same time. Provision of hiring locally available tools to mobilize required number of labours for work was also not considered by WECS upon our verbal request because the beneficiaries requested for their rental charge. However, when faced with no option, the beneficiaries utilized their own tools which is one of their significant local contributions.*

In addition, there were also some social dilemmas that arose during the construction process:

> *As the construction work requiring skilled labour also started side by side, we faced lack of workmanship and efficiency from the engaged labours. The beneficiaries were not identifying and clearly classifying more skilled ones with particular skills out of the lot, to avoid misunderstanding among themself that could spring out later on in course of their social interactions. Thus our field personnel had to select skilled hands like the masons from among the beneficiaries. This pleased some but at the same time brought sharp reactions from others who were displeased. We had to undertake this task on behalf of the beneficiaries because their management committee was not taking the responsibility in this matter. Due to ineffective management committee, it hampered the efficiency of work done.* (Acharya 1989, p.25)

> *Participation in work from all beneficiaries was satisfactory on an average. However, some of the members of the management committee never appeared in the system for working or helping for management to conduct the work.* (Acharya 1989, p.26)

> *In the beginning, progress and improvement in the quantity of work were not observed. Labourers showed laziness and were often found quite inefficient. The beneficiaries realized the problem and gave the reason to the low daily rates (local rates are higher) and the rejection of piece work demand*[12]

> *Due to the lack of sufficient adult labours, another problem cropped up was the presence of some labours from women and boys groups. Such labourers were separated from the male adult labours with the help of the*

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[12] The farmers' associations demanded competitive local rates for both labor and skilled piece work during construction but were rejected by the WECS team on this point in favor of using national standard rates (WECS and IIMI 1990).

> *management committee members and the daily wages rates of Rs 18/- and Rs. 14/- respectively [normally Rs. 22/- for adult male laborers] according to the district rate were fixed for them.*
>
> *During the early phase [of the project], some local politicians and other people dissatisfied with the approach undertaken, spread the rumours that (the consultants) we were the contractors entrusted to implement the proposed improvement works. Visit to the site and dialogue with the local people by officials of IIMI and WECS helped reduce this misinterpretation considerably. Even than being misguided, some local people found it difficult to understand our role in the delicate tripartiate arrangement for the work implementation. Thus beneficiaries continued to think that we were the contractors. However, with the tireless effort of our field personnel to make the beneficiaries understand our role, this situation improved completely at later stages, when they found us as facilitators helping transfer the government funds to the benefit of the beneficiaries.* (Acharya 1989, p.27-28)

These passages highlight several important findings about participatory processes like the one being analyzed here: 1) building trust and constantly communicating roles is critical; and 2) including mechanisms for recognizing and managing spillovers and wicked problems during the design-process are critical as well. The report from the secondary consultant, who did not build trust by participating in the earlier phases of the project, was seen as having a different role in the project than that of the other field teams, due to the timing of their entrance into the design-process. In addition, although the project funding and expenditures were transparent, the beneficiaries were not empowered in decision-making, responsibility, or authority when it came to negotiating monetary costs and payments to the beneficiaries for their labor "was never timely ... sometimes delayed by more than one and half months and so was often a source of friction between the various parties involved in the programme" (Acharya 1989, p.29). There may be well-founded explanations for why these spillovers occurred, such as mismatches between the speed of work at the micro-/operational level and the speed of invoicing, procuring, and delivering payment at the meso-/regional level of management. The aggregation of these spillovers and wicked problems, however, become negative affordances within the design-process in the form of mis-trust, conflict, and impotent efforts.

Sustain/Manage The WECS/IIMI reported (1990) that "In addition to effective construction output, the farmers gained confidence and pride in their own ability to organize and mobilize resources and gained skills in construction methods" which has "improved their ability to continue management of operation and maintenance of the systems" (p.26). They further iterate that "While the savings in cost of physical improvements attributable to farmer participation is valuable, the real payoff is in the sustainability of those improvements and better water delivery from improved management" (WECS and IIMI 1990, p.26). Following the completion of the construction activities, the WECS team and consultants removed (AS-28) themselves from the dynamics of the systems, at the meso-scale, and the day-to-day operation and management activities (AS-29) commenced on the micro-/operational level within each individual FMIS (Fig. 4.14). Each farmers' association created their own configurations for public infrastructure provider (PIP) positions who then made decisions (AS-28) and managed (AS-29) the systems. As part of the WECS action-research part of the intervention, however, the WECS team conducted (AS-30) a survey of the

19 FMIS after one monsoon season of operation following construction, to "determine if any of the management innovations introduced during the assistance were being used" (WECS and IIMI 1990, p.26). They found that leadership had changed in 11 of the systems, but that all systems were able to refer to an elected leader (WECS and IIMI 1990). They also found that there was evidence that all of the systems were more organized and more productive than prior to the intervention (WECS and IIMI 1990). Only one system reported that they were following all of the rules they had made collectively during the intervention, and 8 other systems indicated that the rules they had made were operational, but the remaining 10 systems "had nothing to report when asked about rules" (WECS and IIMI 1990, p.26). Conversely, it was reported that 16 of the farmers' associations continued to hold meetings following completion of construction, but records of these meetings were only kept in 9 of the systems and some reported attendance for the meetings was under 50 percent of the resource users in the system (WECS and IIMI 1990). The primary purpose for the majority of meetings was to mobilize labor for collective maintenance of the physical infrastructure (HHMI) but some meetings also discussed water allocation, distribution and/or conflict resolutions (WECS and IIMI 1990). No further investments into the canal systems (HHMI), the farmers' associations (SI), or their rules/management capacity (SHMI) were made for these systems at the meso-scale by the WECS. Some of the systems did receive additional funding for canal (HHMI) repairs by either local Village Development Committees (VDC), the national Department of Irrigation (DOI), or by the United Nations Development Program (Ostrom *et al.* 2011), but no dedicated effort to re-invest in the health of the farmers' associations was made again. Given that the WECS team considered those improvements to the capabilities of the

farmers' associations and their management capacity to be the most valuable outcomes of the intervention, it is somewhat surprising that no further effort or re-investment was put toward sustaining or maintaining any aspects of the farmer-to-farmer training or support network (SHMI) that was created during the intervention to strengthen these. This may be one noticeable strength of looking at these systems through the lens of the CIS Framework (Anderies *et al.* 2016), through which the farmers' associations (SI), their systems of management (SHMI) and even the intervention itself (SHMI) can be seen as part of the public infrastructure (PI) and important public assets that should be sustained, managed, and maintained alongside the physical infrastructure.

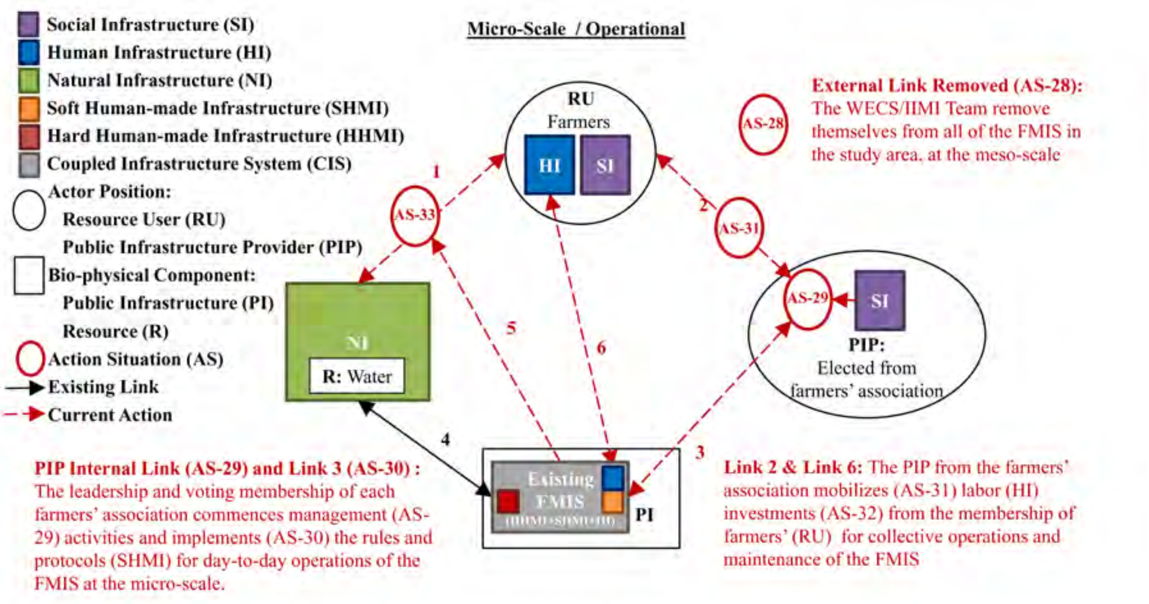

Figure 4.14: System Model During Operations and Maintenance

Change/Improve/Innovate It appears that the WECS intervention was not designed to innovate, improve or renew itself after its completion. From the PICs, it seems that it was intended as a pilot to be used as a model in other locations, but no evidence was found in this investigation that it was actually used in that way. The action-research including follow-ups and the thorough writing of reports for the project, however, did provide an interesting example for possible innovation in other areas and other times, so it is possible that the design-process and the lessons learned from it could be utilized as a model now or in the future.

4.5 Conclusions

This investigation of a participatory design-process for improving and expanding farmer-managed irrigation systems (FMIS) in Nepal has shown the potential for the using the theory and methodology proposed in Chapter 3 to understand design-processes in common-pool resource (CPR) systems. It shows that not only that the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016) useful for investigating these design-processes, but that when added to the CIS Framework, networks of linked action situations (NLAS) are useful in strengthening our ability to conduct institutional analysis with the CIS Framework. In addition, this investigation has shown that the design-process model (Fig. 4.4) proposed in Chapter 3 can be helpful in understanding the sequencing and outcomes of the NLAS at a variety of scales, providing a way to understand the structure and sequencing of NLAS within the CIS Framework. Finally, this investigation has demonstrated how these combined tools can be used to identify key leverage points in a system, and develop a theory of change in coupled infrastructure systems.

This investigation confirmed that the design-process is generally iterative between the two key phases of decision-making and development. The lines between the two phases and/or between different classes of design-activities in the process may be fuzzy, however, and these may be more like eddies in a river with mini-loops and repeats of various activities within each phase. At some points the design-process in the case study presented here circled back to decision-making or development activities that had already taken place and in other places a number of activities were combined in a single set of action situations or configurations. In addition, when social processes and protocols (e.g. the WECS intervention) are viewed as constructed infrastructures within the system that require both investments of resources (i.e. mass, energy, information) and face the same types of entropy and decay as physical infrastructure, the final activities within the development phase may take on increased significance within the design-process. Specific points of decision-making (i.e. action situations) about when, why, how, and by whom these infrastructures are sustained, improved, or removed from the coupled infrastructure system (CIS) become more important.

On top of these findings, there were a few interesting insights about the theoretical components included in the proposed synthesis that have come out of this investigation. First, there are a few new relationship links that should be considered for addition to the CIS Framework: 1) A new link (referred to as Link 7 in this document) between the public infrastructure (PI) holon and relationship link 2 (from resource users to public infrastructure providers) should be considered; and 2) links that are internal within each of the holons may justify further differentiation in the future when this case study may be compared to other similar case studies. Second, this study not only confirms McGinnis (2011b) hypothesis that the outcomes of one AS may affect the structure of another AS, but adds to this by showing how the position and sequencing of these AS within the system modeled by the CIS Framework become important to the structuring of other AS as well. The primary example of this is illustrated by the ways that different types of actors (e.g. resource users and public infrastructure providers) contribute different types of resources (i.e. mass, energy, and information), exercise different types of control, and view the costs and benefits of each AS differently based on their perspective and position within the system.

While this has been a successful and fruitful pilot for using these theoretical tools for the empirical investigation of design-processes in CPR systems, further investigation is still necessary to validate these findings and add precision to these tools. The following chapter investigates further into how each of the individual FMIS that took part in the WECS intervention progressed, by coding the development of these systems over time using the new machinery proposed in this chapter and the last. I specifically look deeper into developments in these systems related to wicked problems, robustness, and adaptability. Future research should include using the proposed theory and methodology presented here to investigate other design-processes in CPR systems.

Chapter 5

INVESTIGATING RESILIENCE TO WICKED PROBLEMS IN SMALL-SCALE, FARMER-MANAGED IRRIGATION SYSTEMS IN NEPAL

5.1 Introduction

Humanity currently faces a number of complex global issues which can have enormous impacts on human well-being, including issues such as climate change, food and water security, globalization and natural disasters (Brunckhorst 2002; Anderies *et al.* 2004; Liu *et al.* 2007; Ostrom and Cox 2010; Anderies *et al.* 2013; Hutt 2016; McGinnis and Ostrom 2014). These issues involve human-environment interactions at a variety of scales and our collective ability to design, develop and maintain systems that effectively produce, allocate, and distribute the resources on which we all depend (Anderies 2015). In addition, these are not isolated problems, but are instead complex and connected issues that are mutually dependent upon one another at multiple scales of interaction. Attempts to improve these types of issues must go beyond traditional modes of problem identification and solving to include approaches that account for problems involving deep uncertainties, social dilemmas, inequities, and trade-offs involving multiple feedback loops (Rittel and Webber 1973; Holland 1992; Anderies 2015).

One area where these issues can often come together is in our agricultural systems, existing at the nexus of other vital systems, such as land-use, water, energy, and economic systems. In the last chapter, I investigated a regional government-led intervention for the improvement of farmer-managed irrigation systems (FMIS) in the mid-hills of Nepal. Small-holder agricultural systems, like those in Nepal, are vitally important to global food security (Herrero *et al.* 2010; FAO *et al.* 2014). According to a 2014 report published by the Food and Agriculture Organization (FAO *et al.* 2014) on the State of World Food Insecurity (SOFI), there are still over 800 million people who are critically undernourished worldwide, equating to one in every nine people who go hungry each day (Anderson-Smith 2014). While smallholder farms (<2 ha) only work about 12% of the world's agricultural land they provide more than 70% of all food calories for people living in Asia and sub-Saharan Africa[1]. When combined with small farms (>20 but <50 ha) they produce 75% of all food commodities and nutritional value on the global scale (Lowder *et al.* 2016; Franzo 2018). Large farms (>50 ha), on the other hand, are predominantly found in North and South America and produce more than 75% of the world's cereal, livestock and fruit (Franzo 2018). Small-scale farms play a critical role in the global agricultural system, not only in maintaining the stock, genetic diversity and nutritional value of our global food supply, but also in contributing to our understanding and monitoring of ecosystem degradation, climate change, water security, and economic growth (Franzo 2018). In addition, small-scale, farmer-managed irrigation systems (FMIS) have been found to be prime exemplars of social-ecological systems (SES) dynamics with findings that are applicable across a broad range of sectors and geographical locations (Ostrom *et al.* 2011; Janssen and Anderies 2013).

People face a number of challenges when it comes to designing, maintaining and operating systems such as FMIS. Climate change, natural disasters, water scarcity, conflict, policy decisions, and market shifts are just a few of the problems with far reaching effects on these systems (Franzo 2018). Smaller systems, such as FMIS,

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[1] According to the definition provided by the World Bank, "sub-Saharan Africa" includes 48 of the 54 countries on the African continent, including all but two of the top ten hungriest countries on earth (World Bank, n.d.)

often have less control and capacity to deal with these types of issues, representing an on-going problem for coping with problems. Sometimes called "wicked problems", these issues often hamper attempts to meet resource needs through the attempted design and control of the complex systems in which we exist because they include deep uncertainties, social dilemmas, inequities, and complex trade-offs (Holland 1992; Walker *et al.* 2006; McGinnis 2011b; Anderies *et al.* 2013; Anderies 2014; Anderies 2015). In order to improve this situation, Franzo (2018) asserts that "it is crucial that we invest in smallholder farmers and their own rural transformation and human capital". In addition, Anderies (2014) suggests that approaches that incorporate concepts of resilience into our design processes may be the key to our ability to successfully cope with these types of issues in common-pool resource (CPR) systems like the FMIS studied here.

In the previous chapter, I showed that the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016), and the Network of Linked Action Situations (NLAS) are useful tools for integrating key concepts and empirically investigating design- and development-processes within actual CPR systems like these. In this chapter, I delve further into the relationships between design processes, wicked problems, and resilience by looking at the dynamics between these processes at the local level over the last three decades for each of the nineteen farmer-managed irrigation systems (FMIS) that participated in the government-led intervention. The intervention was designed to improve agricultural productivity through improvement of both physical and social infrastructures in these systems and the farmers who built the systems collectively decided whether or not to participate (WECS and IIMI 1990). I use a variety of data to investigate the types of problems that have occurred within these FMIS over time, including previously coded data, historical documentation, and new data obtained from interviews and group discussions. I also look at some of the ways that the people in these systems have tried to cope with different types of problems and how these actions affect on the structure and dynamics of the system. To do this I utilize structurally coded longitudinal data to investigate changes within these systems over time and how these changes relate to resilience (i.e. robustness and/or adaptability) over time.

5.2 Methodology

This investigation is a study of the complex problems that groups of people face in managing common-pool resources (CPRs) and the coping mechanisms that they use to deal with these problems. As asserted by Poteete *et al.* (2010), this field of research "utilizes multiple methods extensively" (p.3). When individual case studies are measured (i.e. coded) in a way that makes them comparable, key themes and patterns may emerge from the comparison that can then be more generally applied and tested through other methods such as systems modeling and human-subject experiments and the findings of these methods can then feed back into the process of new knowledge creation and contribute further to new rounds of comparative analysis against previous or new empirical evidence (Poteete *et al.* 2010). As with all methodological choices, however, there are trade-offs and drawbacks to this approach which have been criticized within the field (Agrawal 2014; Araral 2014; Cox 2016; Ratajczyk *et al.* 2016). Poteete *et al.* (2010) assert that it has been case studies and small-N comparisons which have primarily "facilitated ongoing efforts to disentangle interactions between complex social and ecological systems" (p.77), highlighting the value of the methodology and work collected using it. Most of the case studies in this area, however, have focused heavily on the social side of the SES equation: natural resource governance and how it affects the systems (Poteete *et al.* 2010; Agrawal 2014; Araral 2014). According to Araral (2014)), the first so-called "generation" of research in this area focused primarily on either the Market (privatization) or the State (regulation) as the solution to wicked problems in natural resource management, a reaction in response to articles such as Hardin's (1968) "Tragedy of the Commons". This was followed by a second "generation" of research which observed and recognized cases of collective action for resource management sought to understand the conditions under which collective management of natural resources can be successful. The Nobel prize winning work of Elinor Ostrom, which showed that collective action was often a better approach than State or market controls, was a seminal part of this new way of thinking (Araral 2014). Araral (2014) suggests that a third "generation" of research is now emerging in which the arguments of previous "generations" must be measured in better ways and made more generalizable. This has raised an important dialogue within the research community about future directions for this area and a number of other researchers (Agrawal 2014; Baggio *et al.* 2016; Cox 2016; Ratajczyk *et al.* 2016), support Araral (2014) suggestion that the way forward is to understand the strengths and weaknesses within the current state of this field and the call for "more nuanced, diagnostic, multi-disciplinary and empirical approaches (as cited in Cox 2016). I also support this movement and suggest that instead of measuring static structures and the snapshots of case studies at singular time points, more longitudinal studies with repeated measures like that of the data used in this study could be helpful. In addition, I also assert that while collective decision-making social activities are indeed important, they are not the only way that humans influence CPR systems. The work in Chapter 3 and 4 of this volume has shown that human intentions continue to work toward influencing CPR systems after the initial decisions and commitments have been made and that action situations extend well beyond governance and decision-making. In this study, I strive to understand both the patterns that emerge from the underlying dynamic processes of these systems, and the role of design as a key dynamic human process over time. I then try to relate this process to the development of resilience (i.e. robustness and adaptability) in the systems, as an approach for moving beyond binary measures of "success and failure". This represents a new step forward in the coding tradition for this field that was discussed in Chapter 2, offering a first step down a possibly more nuanced pathway toward understanding how change occurs within CIS and our role within it.

5.2.1 Data

A large portion of the data for this investigation is longitudinal data that has been collected by a variety of researchers over the past three decades, in three primary time-slices at each of the nineteen individual FMIS sites. Panel data, such as this, is somewhat rare in general terms (Stock and Watson 2015) and is quite rare among the case studies that have been collected within this field of study, making this dataset a valuable resource. This type of panel data can be used to help eliminate the effects of unobserved omitted variables by collecting repeated measures of the same observational units over time (Stock and Watson 2015). The nineteen systems included in this study are part of the larger Nepal Irrigation Institutions and Systems (NIIS) database which archives data on over 500 different variables for 274 total observations of irrigation systems in Nepal (Ostrom *et al.* 2011). The NIIS variables are organized into seven different meta-categories, as follows:

1. Agricultural production;
2. Location / Biophysical Resource;
3. Natural (Appropriation) Resource;
4. Operational Rules;
5. Operational Organization;

6. Operational Dynamics;
7. Subgroups

The NIIS database is a relational database originally created by researchers at the Workshop in Political Theory and Policy Analysis at Indiana University. Adapted from the previously established Common-Pool Resources (CPR) database and was intended as a corollary focused on a single resource sector (i.e. irrigation) in a single country (i.e. Nepal), rather than on the multiple sectors and geographic regions included in the CPR database (Poteete *et al.* 2010). Both databases share many of the same variables and protocols, making them highly comparable to one another[2]. Relational databases are the traditional row and column data organization of categorized data that includes a *database schema* (i.e. a structure of common variables and their range of possible answers), and the *relations* (i.e. values or observations) for each of these variables from a number of individual cases (Worboy 2005). The NIIS database contains 509 variable questions in the database schema and relations for 233 cases that were originally coded into database format by the researchers at Indiana University (Pokharel 2016).

For the nineteen systems for this investigation, the data in the NIIS database includes the following three primary observational time-slices:

1. A baseline measurement that took place in 1985-1987, prior to the government intervention
2. A measurement that took place in 1991, following the government intervention

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[2] The CPR and NIIS databases are now archived and accessible through the Social-Ecological Systems (SES) Library at the Center for Behavior, Institutions, and the Environment (CBIE) at Arizona State University (ASU), which was co-founded by Elinor Ostrom as the sister-center to the Workshop at Indiana.

3. A follow-up measurement that took place in 1999 to investigate the sustainability of the intervention

The observational unit for the NIIS is at the system level (i.e. one FMIS), so that the individuals within each system do not need to be the same individuals for all measurements at all periods. Additional, qualitative, community-level data was also collected at the study sites by previous researchers in 2001 and 2008, but these time-slices are not currently included in the NIIS database due to data losses and other issues. An additional site visit to each of the systems was conducted as part of a larger repeated measure of all of the systems in the NIIS database in 2013, but that data was not yet available during the research work presented here (Pokharel 2016). A visit to all but two[3] of the sites was conducted as part of this investigation with a local research team in November and December of 2016 to collect additional and updated data following the earthquakes that occurred in Nepal in the Spring of 2015. During these visits, geographic information was collected using a hand-held geographic positioning system (GPS) unit[4] while walking the length of each canal with a local user(s) who explained the history and problems associated with each physical infrastructure system. This coupled with hand drawn system representations that were drawn by the resource users for a participatory mapping approach that gathered more information on the spatial relationships and problem areas of each system. In addition, remote sensing techniques using satellite images were utilized to generate a digital elevation model of the study area and acquire data on land cover, usage,

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[3] Two of the most remote sites (Sites 1 & 3) in the study area were inaccessible to the research team during the field work due to landslides and washed out roads.

[4] GPS data was collected using the Bad Elf GNSS Surveyor model BE-GPS-3300 with up to 1 meter CEP positional accuracy using GPS+PPP+SBAS technology and up to 1.5 meter accuracy using DGPS and RTCM 2.3. More information and specifications can be found at www.bad-elf.com/pages/be-gps-3300.

and earthquake damage between October of 2009 and December of 2015[5]. Finally, historical documents pertaining to each of the systems were collected and digitized for content analysis along with transcripts of group discussions and individual interviews that were conducted with the users of each system to discuss the problems they have faced and methods utilized in coping with these problems. All of the new data collected for this investigation is being integrated into the NIIS database, along with current data being collected by other researchers as well.

The NIIS database is one of the largest accessible relational databases available that is dedicated to CPR systems and represents a valuable resource of data on small-scale locally managed irrigation systems. The database faces many of the methodological issues that were previously mentioned, however. There are many missing observations in the data, including the repeated measures for the nineteen FMIS included in this study. Out of the more than five hundred variables included in the NIIS database, there are only twenty-nine with full data across all three primary time-slices for all nineteen of the FMIS included in this study. In addition, because this data was collected by various researchers at different times, there are questions about the quality, consistency, and accuracy of this data which could be further confounded by language barriers and interpretation issues. While the NIIS variables and coding questions align almost perfectly with the variables and questions in the CPR Coding Manual (Ostrom *et al.* 1989), that was described in Chapter 2, the twenty-nine variables with full data in this dataset do not overlap well with the measures of success and failure utilized in that study (Chapter 2, this volume). This highlights some of the issues that have been raised by Araral (2014) and others for data collection and analysis in this field, and supports the need to go beyond the limitations of the data

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[5] Twelve high resolution satellite images were obtained through a digital imagery grant from the Digital Globe Foundation and include images from all seasons covering 100% of the study area

and coding schema. To supplement the panel data contained in the NIIS database, and learn more about how new problems have affected the system and how the farmers have coped with these problems, new qualitative data was collected at the study sites in 2016. Due to time and funding constraints, the research team for data collection, interpretation, and analysis was limited for this study to two researchers for data collection tasks and a single researcher for interpretation and analysis tasks. The investigation presented here, however, follows upon a number of well-founded studies using this data (Acharya 1989; Ansari 1990; Ostrom 1992; Joshi *et al.* 2000; Shivakoti and Ostrom 2002; Ostrom *et al.* 2011) and seeks to take another step forward in understanding how these systems both persist and change over time.

5.2.2 Background on Case Study Sites and Intervention

Nepal offers a plentiful resource for the study of locally managed small-scale irrigation systems. A tradition of local resource management that spans hundreds, if not thousands of years, and an estimated one hundred thousand (100,000) existing farmer-built and -managed irrigation systems in Nepal make an ample resource for the study of these types of systems (Hydro-engineering 1986; Benjamin *et al.* 1994). According to Janssen and Anderies (2013), small-scale irrigation systems are an important model system in the study of coupled infrastructure systems and the commons because they function in the same way that the fruit-fly functions in the study of evolutionary biology. In essence, they serve as a relatively simple system which is easier to study and manipulate than larger and more complex systems and yet exhibit some of the most complex dynamics, such as power dynamics between those at the head-end of a system and those at the tail-end (Janssen and Anderies 2013). Studies of farmer managed irrigation systems (FMIS) have been conducted in Nepal since the 1970's and have led to field investigations by numerous scholars since that time (Ansari 1990;

Ostrom 1992; Benjamin *et al.* 1994; Joshi *et al.* 2000; Shivakoti and Ostrom 2002; Ostrom *et al.* 2011; Janssen and Anderies 2013;Pokharel 2016). The case study sites for this investigation include nineteen FMIS located in the mid-hills of Nepal in the Indrawati River Basin. These systems participated in an innovative government-led intervention that was initiated by the Water Energy Commission Secretariat (WECS) of Nepal in 1985 with assistance from the International Irrigation Management Institute[6] (IIMI) and funding from the Ford Foundation (WECS and IIMI 1990). The Field Report for the initial phase of the WECS Intervention (Hydro-engineering 1986, p.1) states:

> *In spite of the problems and difficulties of the natural phenomena such as land sliding, flooding, gully crossing, drainage crossing, and steep slopes in the hilly region of Nepal, the farmers have been practicing for centuries to build irrigation facilities to increase their crops. Groups of farmers with common command area of an irrigation system worked together to divert water from the stream or river to their fields. They have their own rules and laws for running the system.*

The project was intended to utilize participatory design and construction activities to improve three primary functions of the nineteen FMIS, including (Yoder 2011, p.xv): 1) agricultural productivity; 2) capacity for self-support; and 3) capacity for self-governance. In addition to being included in the NIIS database, these case studies were also presented in the 2011 book by Ostrom et al., *Improving Irrigation in Asia.* The study by Ostrom *et al.* (2011) focused primarily on the variation of outcomes within each of the individual FMIS. The study presented here builds off of that previous study by applying the Coupled Infrastructure Systems (CIS) framework (Anderies *et al.* 2016) as a guide for understanding how key structures and dynamics within these systems are affected over time by human attempts to control (i.e. design-

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[6] Now known as the International Water Management Institute (IWMI) www.iwmi.cgiar.org/

and development-processes) the systems and the emergence of wicked problems within them (Rittel and Webber 1973).

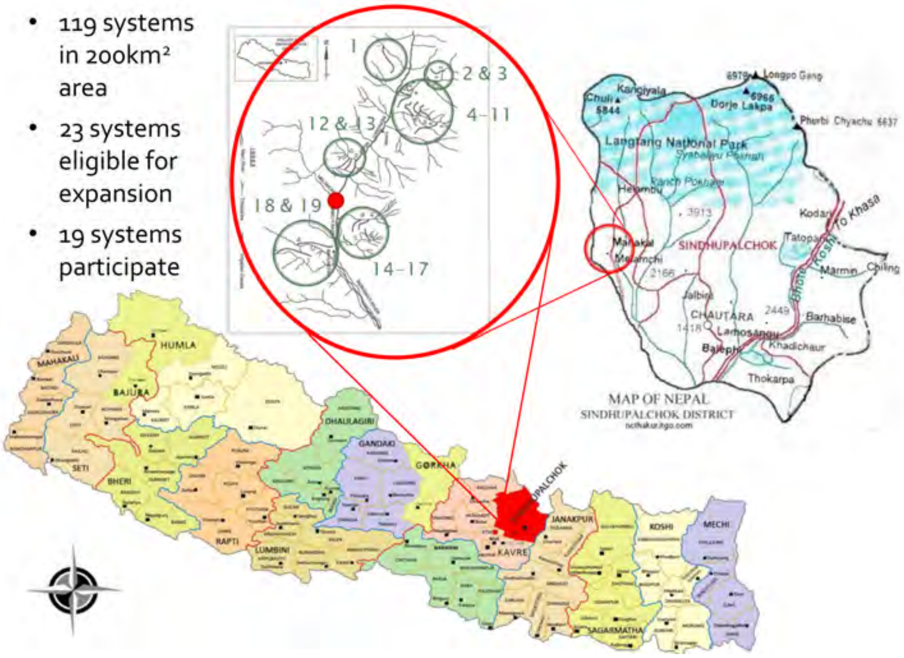

Figure 5.1: Map of irrigation systems in the Indrawati River Basin of Nepal

An additional strength of this dataset is that all nineteen of the systems are located within a relatively small geographical area (200 km^2) in the Indrawati River valley (Fig. 5.1), minimizing potential variances between systems across space and time in the broader ecological and social contexts. While this increases internal validity through the ability to control for confounding effects via within-case comparisons, it also decreases the external validity of the study (Poteete *et al.* 2010). Irrigation canals for each system are diverted from tributary streams (i.e. kholas) that come down the steep slopes and gullies of the Himalayas to the Indrawati River. The study area was originally found to contain at least one hundred and nineteen (119) FMIS of more than half km in length, according to an inventory conducted by the WECS prior to the intervention (Hydro-engineering 1986). The selection criteria for participation in the intervention was originally narrowed to only those systems that were at least two kilometers in length. Twenty-three of those systems were then found to be eligible for expansion (Ostrom *et al.* 2011) based on the following criteria:

1. water availability
2. need for physical improvement
3. the potential for expansion of the command area, crop intensification, and/or improved ease of maintenance

Most of the systems were established by the farmers in the 1960's and 70's, but one dates back to 1946 and six are more than a century old (Table 5.1). The farmers in these twenty-three systems were asked to collectively decide if they wanted to participate in the intervention and would accept new members into their associations. Nineteen of the twenty-three systems agreed to participate in the intervention process (WECS and IIMI 1990; Ostrom *et al.* 2011). Each of the nineteen FMIS that participated in the WECS intervention share the source with at least two other systems, although some of these other systems were deemed ineligible and/or chose not to participate in the intervention. Portions of many systems cut across vertical rock cliffs, requiring dangerous construction, repair and maintenance activities (Benjamin *et al.* 1994). Up to three irrigated crops may be grown each year at lower elevations, but lower temperatures at higher elevations limit crop intensity to two irrigated crops per year. Crops grown in the systems include paddy rice, wheat, maize, and millet (Hydro-engineering 1986). The total cultivated land in the study area was estimated to be about 90 sq. km., prior to the intervention, with the remaining land consisting of residential areas and uncultivated forest and/or grazing land (Hydro-engineering 1986). The dominant ethnic groups in the study area include Tamangs, Brahmins, Chhetris and Majhis and the primary economic sources include agriculture, carpet weaving, and a small amount of work at local water-powered mills (Hydro-engineering 1986).

Table 5.1: Basic information about the case study irrigation systems (adapted from Ostrom et al. 2011, p.86 and Hydro-engineering 1986)

System Number	**Name of System**	**Year Established**	**Source**
1	Chhahare Kulo*	1971	Chhahare Khola
2	Naya Dhara Ko Kulo	1973	Handi Kholo
3	Besi Kulo	1946	Handi Kholo
4	Dhap Kulo**	1897	Handi Kholo
5	Subedar Ko Kulo**	1897	Handi Kholo
6	Soti Bagar Ko Kulo	1974	Handi Kholo
7	Dovaneswar	1979	Handi Kholo
8	Magar Kulo	1895	Mahadev Kholo
9	Siran, Tar Ko Kulo	1974	Mahadev Kholo
10	Majha, Tar Ko Kulo	1974	Mahadev Kholo
11	Ghatta Muhan Ko Kulo	1960-61	Mahadev Kholo
12	Jhankri Ko Kulo	1802	Pangsing Kholo
13	Chholong Khet Ko Kulo	1895	Pangsing Kholo
14	Siran, Baguwa Ko Kulo	1980	Sahare Kholo
15	Majha, Baguwa Ko Kulo	1965	Sahare Kholo
16	Chapleti Ko Kulo	1973	Baghmara Kholo
17	Baghmara Ko Kulo	1960	Baghmara Kholo
18	Chap Bot Ko Kulo	1969	Sindhu Kholo
19	Bhanjyang Tar Ko Kulo	1969	Jarke Kholo

* Several systems (number 1, 18 & 19) appear to be isolated to their own source but actually share these sources with at least two other systems that did not participate in the WECS intervention.
** Dhap Kulo and Subedar Ko Kulo (numbers 4 & 5) share the same source and serve an overlapping command area (Ostrom et al. 2011, p.86).

The WECS intervention was conceived as an innovative experiment in how to help small-scale FMIS by utilizing participatory design and construction activities to simultaneously strengthen the self-governance and self-support capacities of the farmers' organizations (WECS and IIMI 1990). The design-process started with an inventory and selection of systems that were eligible to participate in the intervention, as well as the establishment of dialogues and relationships with the farmers' associations for each system (WECS and IIMI 1990). A second, more intensive, rapid appraisal was conducted for the twenty-three systems deemed eligible to participate in the intervention and farmers were asked to identify and prioritize the work that they needed to improve their systems and collectively decide whether or not to participate (WECS and IIMI 1990). The rapid appraisal found that there was more work to be done on the physical infrastructure in the systems than could be covered by the total project budget and so a system in which first-priority work was deemed as that which is “essential for expansion but difficult for farmers to do without assistance”, second-priority work as “work desirable for improved system operation and maintenance”, and third-priority work as “improvements farmers could accomplish with their own resources - skills, labor, and materials” was implemented (WECS and IIMI 1990, p.19). An incentive for the farmers to invest their time, energy, and materials to the project was offered, stating that a fixed amount of money would be available to each system and that this money would initially be applied to the first-priority works but could then be extended to second- and even third-priorities through the farmers’ efforts at working efficiently, paying themselves lower wages, or by donating labor and/or materials to the project (WECS and IIMI 1990). Another major factor identified by the rapid appraisal as important in achieving success was the strength of their users’ groups (WECS and IIMI 1990). Because of this, the intervention mandated that the farmers’ participate in the design and implementation of the physical improvements but also that each system elect a strong management committee that would be responsible for the construction activities and continued day-to-day management of their system (WECS and IIMI 1990). In addition, the farmers’ associations were required to participate in a farmer-to-farmer training program in which they would visit and receive training in effective management practices from other well-performing FMIS and establish their own rules for the on-going operation and maintenance of their systems (WECS and IIMI 1990).

These systems have experienced many different types of problems over the last three decades, but have shown remarkable resilience in most cases. They regularly cope with problems such as flooding and landslides that damage the canals as well as any internal conflicts (Ostrom *et al.* 2011). However, disturbances such as larger natural disasters, political/policy changes, and market pressures may be more difficult, or sometimes even impossible, for the farmers to cope with on their own (Bastakoti *et al.* 2010). The Maoist conflict, for example, has been difficult for all of the systems in the study area (Karna *et al.* 2010), even cited as the reason for the failure of one system included in this study. In addition, all of the systems in the study area suffered badly from the earthquakes that struck Nepal in the spring of 2015. While the initial 7.8 magnitude earthquake (Fig. 5.2) that struck on April 25th was centered in the Gorkha District to the west of the study area, it still had major impacts in the Sindhupalchok District where the study area is located (Shrestha *et al.* 2015). A subsequent 7.3 magnitude quake and 6.3 magnitude aftershock struck the Sindhupalchok District within minutes of one another on May 12, 2015 causing further panic and devastation (BBC News 2015). Because the secondary quakes struck during mid-day however, a time in which many people were outdoors working, many lives were spared (BBC News 2015). More than 153 people were killed by the quakes, however, and more than 3,000 were injured with tolls especially high in mountain regions such as our study area (Shrestha *et al.* 2015). It was reported that between the two earthquakes, more than 95% of the houses in these areas of the Sindhupalchok District were destroyed (Shrestha *et al.* 2015). In addition, most of the irrigation systems in the Sindhupalchok District were also damaged in the earthquakes, causing severely reduced agricultural capacity for all of the systems included in this study.

Figure 5.2: Map of Major 2015 Nepal Earthquakes

5.3 Analyses and Discussion

The analysis for each case study FMIS was completed using the Coupled Infrastructure Systems (CIS) framework (Anderies *et al.* 2016) as a guide. The CIS framework (Fig. 5.3) provides a useful and implementable framework for bringing together concepts from social-ecological systems (SES) science such as collective action, common-pool resource systems, institutional analysis, and resiliency (Anderies 2015; Anderies *et al.* 2016). The CIS Framework is divided into four major components (i.e. holons[7]) including, the Resource (R), the Resource Users (RU), the Public Infrastructure Providers (PIP), and the Public Infrastructure (PI), as well as the relationships between them (i.e. Links 1-7). Each of the holons is composed of different types of infrastructure[8]. Each holon may include any of five different pri-

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[7] *Holons* are subassemblies that are nested within complex adaptive systems (Ostrom 2005, p.11) and the term can be applied to "any stable sub-whole in an organismic or social hierarchy, which displays rule-governed behavior and/or structural Gestalt constancy" (Koestler, 173, p.291).

[8] Infrastructure is defined here as any coherent structure that can manipulate resources (i.e. mass, energy, and information); requires investment; and can be combined with other classes of infrastructure to provide affordances for flows of resources valued by humans (Anderies *et al.* 2016).

mary classes of infrastructure, including: Social Infrastructure (SI); Human Infrastructure (HI); Natural Infrastructure (NI); Soft Human-Made Infrastructure (SHMI); and Hard Human-Made Infrastructure (HHMI). These five classes of infrastructure are derived through trans-disciplinary approaches from various fields including economics, political science, sociology, anthropology, psychology, geography, planning, engineering, and ecology.

In addition to the data archived in the NIIS database, new data was generated for this investigation through content analysis techniques using historical reports and documents that detail the original WECS intervention. These were collected through contact with previous researchers, practitioners and government authorities that had been involved with either the original intervention or the subsequent longitudinal study. All previously un-digitized documents were scanned and converted to searchable PDF files using a high-resolution book scanner. Furthermore, other new data was derived from oral and visual information gathered while walking the length of each canal with representatives of the famers' association, focus group discussions, interviews, and hand-drawn maps from the local resource users that were transcribed and then translated into English. All historical documents and transcriptions were digitized and then imported and coded using qualitative data analysis software, MaxQDA v.12. While more than one coder is always preferable (Bernard 2011), these documents were translated by one researcher and then coded by a single coder due to time and funding constraints. They were then compared to the previous NIIS data for logical consistency. Coding was completed for each of the twenty-nine questions in the NIIS data schema that contained full data through the 1999 time-slice. Some additional variables were also created to correlate with the working parts of CIS

Affordances are the possible outcomes (i.e. functional dynamics) that are accessible to individuals or groups, independent of their ability to perceive these possibilities (Anderies *et al.* 2016).

Framework (Anderies *et al.* 2016), problems that were experienced in each system as well as any changes and/or coping mechanisms found within each system.

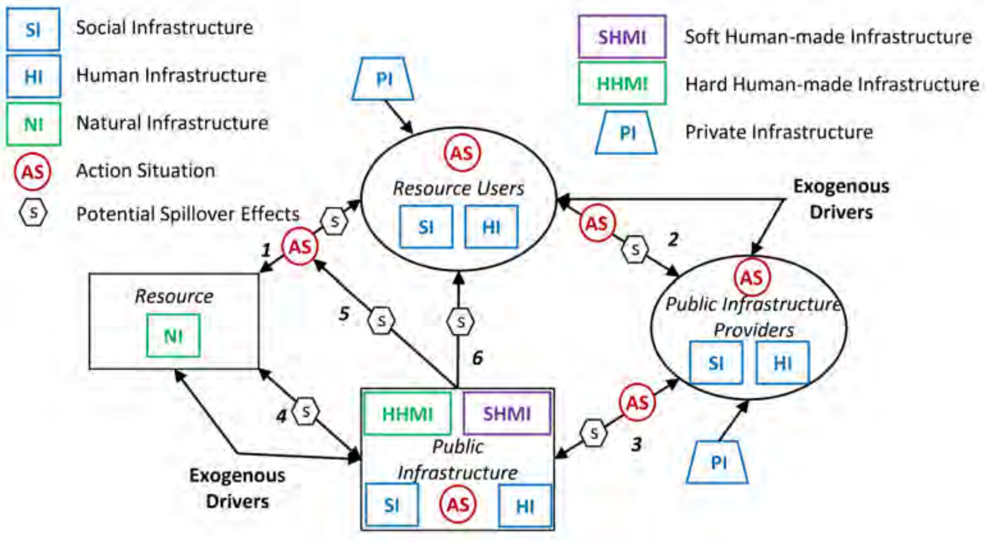

Figure 5.3: Coupled Infrastructure Systems (CIS) Framework (adapted from Anderies *et al.* 2016)

A system representation and narrative was created for each of the nineteen FMIS, by mapping the data to various working parts of the CIS Framework (Fig. 5.3). Protocols for this process were developed and tested by a group of researchers at the Center for Behavior, Institutions, and the Environment (CBIE) at Arizona State University (ASU) and are available through the Social-Ecological Systems (SES) Library[9]. The coded data for each system was mapped onto the CIS Framework, thus creating a system representation for each system, taking into account how the system representation changes for each system over time. These system representations and narratives (see Appendix) were then utilized to analyze the resilience of each system

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[9] The Social-Ecological Systems (SES) Library contains many case studies, models, and system representations of social-ecological systems and coupled infrastructure systems (CIS) from a variety of sectors and geographic areas around the world which are available at www.seslibrary.asu.edu.

over time. As detailed in the previous chapter, *resilience* is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.* 2004, p.2). This definition of resilience is operationalized by the concepts of *robustness* and *adaptability*. Robustness is the capacity of a system to absorb disturbance and yet retain it's essential functions, and adaptability is the capacity of a system to reorganize while undergoing change (Walker *et al.* 2004; Husdal 2008; Anderies 2015). Together, robustness and adaptability define the resilience of the system (Fig. 5.4).

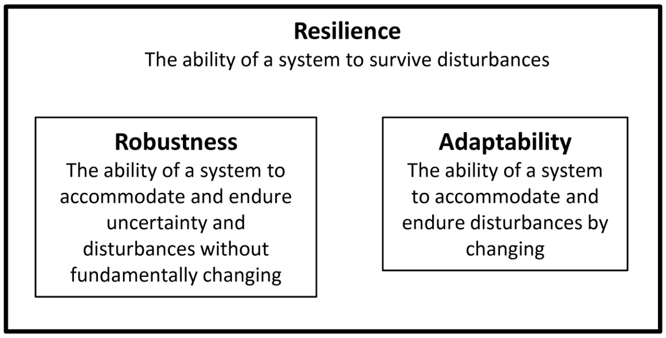

Figure 5.4: Resilience, Robustness, and Adaptability (adapted from Husdal 2008)

5.3.1 Problems

Problems types that were found within the data were categorized according the type of infrastructure that they affect and whether they represent a type of wicked problem (Table 5.2). *Wicked problems* are defined as those issues that prevent the design and development of idealized and replicable solutions because these problems involve inherent *uncertainties, social dilemmas, inequities, and trade-offs involving multiple feedback loops* (Rittel and Webber 1973). Wicked problems and their possible solutions are difficult to define because both the problems and solutions may evolve and shift together when trying to affect complex and dynamic systems, resulting in new problems or emergent features at the system level (Rittel and Webber 1973). Problems were also coded for how frequently the problem is reported to have occurred (low, moderate, high) and the relative magnitude of the problem within the FMIS (low, moderate, high). Floods, for example, are reported to happen nearly every year during the monsoon season, in every system representing a high frequency problem. The farmers also report, however, that while floods are a fairly serious threat to the system because they can cause damage or washouts or fill the canal with mud and debris so that it cannot function; this is a problem that they regularly cope with on their own without much, if any, outside help. Earthquakes, on the other hand, happen very infrequently, with 80-100 or more years between events, therefore low frequency. They are a very high magnitude problem, however, that caused serious damaged all of the systems within the study in 2015. The farmers within these systems did not have the capacity to cope with the damages to both the physical and social structures that occurred because of the earthquakes in the Spring of 2015. During the research team's visits to the sites in 2016, a full 18 months after the earthquakes happened, the systems were functioning at 60% or less of their previous productivity and continued to struggle in their efforts to secure the equipment and materials necessary to repair or rebuild the canals where they were damaged by the earthquakes or subsequent landslides.

Table 5.2: Types of Problems Found within Farmer-managed Irrigation Systems

Problem Type	**Freq.***	**Mag.****	**Inf. Type†**	**Wicked Prob.‡**	**Coping Mechanisms**
Capacity	Mod.	Low	HI, SI, HHMI	U, SD	Changes in the size and make-up of the system (HI, SI, HHMI); seek outside support (SI)
Champions/Support (Lack)	High	Mod.	SI, SHMI	I, T	Communicate more frequently with officials (SI)
Collective Action (Lack)/Coordination	Mod.	Mod.	HI, SI, SHMI	U, SD	Meetings, change rules (SI, SHMI)
Conflict	Low	Mod.	SI	I, T	Meetings (SI)
Earthquakes	Low	High	NI, HHMI	U	Ask for help (SI), repair what they can (HI, HHMI)
Elite Capture	Low	Mod.	HI, SI, SHMI	I	Meetings, change rules (SI, SHMI)
Flooding/drought	High	Mod.	NI, HHMI	U	Improvement (HHMI); rules (SHMI)
Gully/Drainage Crossing	High	Low	Hi, HHMI		Pipes and culverts (HHMI)
Information (Lack)	Mod.	Mod.	HI, SI	U	Meetings (SI)
Landslides	Mod.	HIgh	NI, HI, HHMI	U	Member labor (HI) or borrow heavy equip. (HHMI)
Leaks/Seepage	Mod.	Low	HI, HHMI		Require labor investment from members (HI)
Maintenance	Mod.	Mod.	HI, SI, HHMI		Require labor investment from members (HI)
Materials (Lack)	Mod.	Mod.	HI, HHMI	I	Seek donors (SI)
Management	Low	Low	HI, SI, SHMI		Change rules (SHMI)
Market changes	Low	High	HI, SI	U, I, T	Change crops (HHMI)
Monitoring	Low	Low	HI, SI, SHMI, HHMI		Install guards (HI, SHMI)
Monkeys/Wildlife	Mod.	Mod.	HI, SI, HHMI		Install guards (HI, SHMI)
Out migration	Mod.	Low	HI, SI	T	Change to cash economy (SHMI)
Participation	Mod.	Mod.	HI, SI, HHMI	U, I	Impose sanctions (SHMI)
Productivity	Mod.	Mod.	HHMI		Improvements (HHMI)
Repair/Maint.	High	Mod.	HI, HHMI		Collective Action (SI); sanctions (SHMI)
Rules-following	Mod.	Low	SI, SHMI		Monitoring (HI) and sanctioning (SHMI)
Trust	Low	Mod.	SI	U, SD	Meetings (SI) and fair governance (SHMI)

* Freq. refers to the frequency of encountering this problem in the systems.
** Mag. refers to the magnitude of the problem within the systems.
†This indicates the types of infrastructure affected: Natural (NI), Human (HI), Social (SI), Soft Human-made (SHMI), or Hard Human-made (HHMI).
‡This indicates the types of "Wicked Problems" invoked: Uncertainty (U); Social Dilemma (SD); Inequity (I); and Trade-off (T) (Rittel and Webber 1973).

The differences between annual flooding and rarely occurring earthquakes is a good example of why some of the problems that the farmers face in these systems can be considered “wicked problems” that are interdependent with other problems. Some problems, such as capacity for example, are dependent upon many other variables, including other types of problems. A group of farmers may have more capacity and experience in coping with relatively frequent but low magnitude problems, such as annual flooding during the monsoon season. They do not have the capacity and experience to cope with something like the earthquakes, however. Neither earthquakes, nor flooding, are simple and singular problems and the resiliency of the system to either of these events are dependent on the design and resilience of the overall coupled infrastructure system (CIS). The physical hard-human made infrastructure may be designed to be more robust to one or the other type of event, but designing for robustness to one type of problem sometimes leads to fragility to other types of problems (Anderies 2014). Both of these types of events may also beget other problems. Both the flooding and earthquakes incur a collective action problem on the social side of the system, in which the group of farmers must somehow mobilize the labor, materials, and equipment necessary to repair the damages. This, then, becomes the problem of capacity. Do they have the capacity within their ranks to mobilize what is necessary for the problem at hand or will they have to look for outside assistance? If it becomes necessary to seek outside support, do they have the knowledge, connections, and influence to find and garner the support they need? Is the support there to be found? Then, these are the problems when only looking at a single FMIS that is experiencing these types of problems, most of the time it is multiple or all of the systems that are dealing with the same type of root problem (flood/earthquake) at the same time. This is where problems begin to escalate across scales, becoming disasters at the regional or national level, in turn producing higher level wicked problems in which support garnered for one system leaves less available support for other systems. Coupled social-ecological systems (SES) are inherent when thinking about natural disasters, like floods, landslides, and earthquakes. These types of events within the natural system only become "disasters" when they cause "serious negative impact on people in the absence of adequate mitigating measures" (Wilhite and Pulwarty 2017, p.18).

5.3.2 Coping Mechanisms

There were a number of different types of coping mechanisms found within the data that correlate with different types of problems. An interesting and creative example found, showing the farmers ongoing activity in design-processes, was one case where the canal system itself was created to capture and use the ongoing leakage from another system. This shows the recognition of both an existing and persistent problem, but also an affordance. In this case, the farmers could have decided upon rules that would better mobilize labor for fixing the problem when it occurred annually. They might also have decided to, instead, line the canal with concrete at that point in the system, making the hard infrastructure more resilient to the annual flooding and leakage. This choice, however, might have made the system more vulnerable to conflict with the resource users who saw an opportunity to utilize the leaking water in other locations. This exact situation was found in one system, where the leaders in one farmers association made a decision to replace a portion of dirt and stone canal with a PVC pipe, thereby cutting the use of the water off from several areas where more water was wanted, thereby creating some conflict in the system. This problem, however, is also connected to the larger ecosystem in which there is a lot of variation between having too much water (i.e. flooding) during the monsoon season and too little water (i.e. scarcity) during the dry season. All of the coping mechanisms found in the data were also able to be mapped to different types of infrastructure (Table 5.2). While the coping mechanisms that the farmers have come up with for different types of problems are diverse, they typically involve some form of configuring or reconfiguring other coupled infrastructures to bolster other infrastructure, mitigate problems, and sometimes prevent problems. One system was able to cope with the variability of flooding and drought by creating storage structures (HHMI), while others cope with these problems through institutional rules (SHMI) such as rotational schedules for watering. This perspective on small-scale irrigation systems not only shows the value of the Coupled Infrastructure Systems (CIS) approach to viewing the dynamics of these systems as problems occur and are dealt with by the people in the systems, but also shows the capacities for engaging in design-processes (i.e. decision-making and development) within these systems without any input from government officials, engineers, and other professional policy and system “designers”. The investigation also shows how much the resource users might engage in the on-going process of dynamic design and how sensitive they can be in terms of recognizing both problems and affordances within the system. This occurs most successfully, however, when the resource users have the right and capacity to make decisions and act on the system.

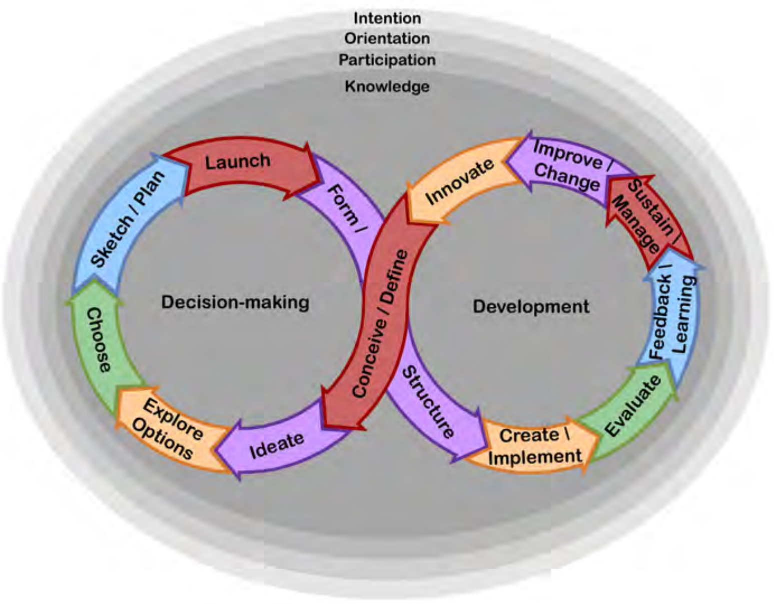

Figure 5.5: Conceptual Landscape of Design-Processes for Complex Adaptive Systems

5.3.3 Discussion: Resiliency vs. "Success"

The ability to engage in these design-processes within the dynamic system, as problems or affordances present themselves, may be at the heart of resiliency. If a natural event only becomes a "disaster" by its affect upon people "in the absence of adequate mitigating measures" (Wilhite and Pulwarty 2017, p.18), then resilience for social-ecological systems may very well have something to do with the ability of the humans within the systems to contribute to robustness and adaptability by designing and developing these so-called "mitigating measures". The intentional actions of humans that contribute to robustness and adaptability can be viewed as occurring through design-processes (Fig. 5.5). Because these are complex adaptive systems, however, design-processes and the changes they produce in the system cannot be assumed to be isolated to the individual FMIS at the micro-level. These systems exist in a panarchy, in which there are interdependent "relationships among a nested set of adaptive cycles as a dynamic hierarchy in space and time" (Holling *et al.* 2001, p.101). Iterative design-processes continuously occur within and across these nested scales at different speeds, involving various actors, problems, and coping mechanisms, as groups of people perceive problems or affordances and respond to them. Design, through the intentional configuring of coupled infrastructures, may be considered as the ultimate human activity aimed at our own sustainability and resilience (Papanek 1971).

The measurement of outcomes and so-called "success" may be one of the biggest issues which researchers in the study of CIS and the commons may be facing (Young *et al.* 2006; Agrawal 2014; Araral 2014; Baggio *et al.* 2016; Ratajczyk *et al.* 2016; Cox *et al.* 2016). Cox *et al.* (2016) state that difficulty "arises in part because of the potential multiplicity of outcomes that analysts might focus on in studies of the commons" (p.342). Agrawal (2014, p.89) states, “For too long, scholars of the commons have not differentiated clearly between the different measures and dimensions of the commons outcomes in which they are interested, often remaining satisfied with relatively vague terms such as sustainability of the commons, long-term viability of the commons, or conditions of the commons.” The study presented in Chapter 2 of this volume defined “success” in a more nuanced way by defining it according to a number of dimensions of social and ecological outcomes which include: 1) resource sustainability; 2) process of collective choice arrangements; 3) equity among users; and 4) overall assessment of success or failure for the case (Ratajczyk *et al.* 2016). This is similar to Agrawal’s (2014, p.89) assertion that “If it is necessary to distinguish between the many different outcomes of the governance of common-pool resource systems – among them, livelihoods benefits from the resource, equity in the distribution of benefits, diversity of biological systems, and long-term sustainability of the resource system – and that these outcomes may not be tightly correlated, then the task facing scholars of the commons is only starting.” Both of these definitions overlap each other in identifying indicators of success that fall within the purview of the four holons included in the CIS Framework (Anderies *et al.* 2016). Where they differ, however, is in the still ambiguous inclusion of “long-term sustainability” (Cox 2010). Ratajczyk et al. (2016, p.10) point out the problem, stating: “While the idea of long-enduring CPR institutions is well founded within the literature (Anderies *et al.* 2004; Cox 2010; Ostrom 1990; Ostrom 2005 ; Poteete *et al.* 2010), we found this to be a difficult concept to assess within the meta-analysis of secondary data. Most of the cases in the dataset only captured a limited snapshot in time and did not include adequate longitudinal data to indicate the longevity of success within the case.”This illustrates why panel data, such as the dataset being analyzed here, is critically important in potentially pushing the measurements of outcomes forward. This is, again, a product of improved research design but requires the repeated collection of measures on systems rather than the focused case-study approach, which can be costly and time consuming. Approaches of this nature might be significantly improved through the collaboration of researchers in order to build up panel data sets over time, as has been done in the study being examined here.

Although the NIIS and the Indrawati panel data includes an open-ended, qualitative variable for the overall assessment of “success” in the system at the time period in which the observation was collected, and all except one of the systems was still in operation during the field work for this study, I assert that there is not a point at which either “success or failure” can actually be measured and that gaining some sense of resiliency in a system is a more dynamic way to assess these systems at any given time. Chapter 4 discussed using Robustness Analysis (RA) techniques to discern qualities of resilience, which generally attempts to measure whether the robustness and/or adaptability of a system is increased or decreased by decisions and commitments at various points in the sequencing of a design-process in a system (Wong and Rosenhead 2000). I analyzed the longitudinal data to try and trace changes within these systems that pointed to the presence of problems and/or coping mechanisms within the lifespan of these systems, but could not adequately correlate changes with either problems or coping mechanisms because these were not tracked throughout the entire longitudinal study. There is an open-ended qualitative question concerning problems in the NIIS coding schema, but this was not consistently tracked for all of these systems across all of the time slices. Table 5.3 represents a tracking of different types of changes that occurred within these systems over the past three decades as reported in the NIIS database. The changes could only be tracked consistently across the twenty-nine variables that have full data within the NIIS database, but crossed all of the major holons and included the measures shown.

Table 5.3: Measures of Change within Farmer-Managed Irrigation Systems in the Sindhupalchok District of Nepal

Holon	**Measures**	**Possible Values**	**Findings***
R	Cropping intensity across system (measures both land and water productivity)	1 (worst) to 3 (best) indicating the number of crops produced across the system per growing season	Most systems (9/19) stayed the same; some increased (6/9); and a few decreased (4/9)
RU	Access to resource (are some consistently disadvantaged and/or are the worst off cut out?)	-2 (yes to both questions); (-1) yes to one question but no to other; (0) no to both questions	A few systems (3/19) initially declined but then improved; the majority of the systems (9/19) reported no problem in this area; and some systems (4/19) reported continuous improvement
RU	Relative equity among users	(-1) getting worse; (0) staying the same; (1) getting better	Equity continually worsened in 3/19 systems; stayed the same in 9/19 systems; gradually improved in 6/19 systems; and continuously improved in one system
RU	Asymmetric power dynamics (do tailenders receive adequate and predictable supply?)	(-2) inadequate and unpredictable; (-1) inadequate but predictable; (0) adequate but unpredictable; (1) adequate and predictable	One system continually worsened; 3/19 systems gradually worsened; 8/19 remained the same; 5/19 gradually improved; and 2/19 continuously improved
PIP	Technical effectiveness of the system	(-1) highly ineffective; (0) moderately ineffective; (1) moderately effective; (2) highly effective	3/19 systems gradually declined; one system initially declined and then improved; one system stayed the same; the majority (12/19) initially improved and then declined; 2/19 systems improved and maintained that improvement
PIP	Economic efficiency of the system (short-run)	(-1) highly inefficient; (0) moderately inefficient; (1) moderately efficient; (2) highly efficient	One system reported no initial improvement and then gradually declined; the majority of the systems (16/19) initially improved and then declined; 2/19 systems improved and maintained that improvement;
PI	Condition (condition and maintenance of the public infrastructure)	(-1) very bad; (0) moderately poor; (1) moderately good; (2) excellent	one system reported no initial improvement and then gradually declined; the majority (14/19) initially improved but then declined; 3/19 systems initially improved and maintained that improvement; one system reported continuous improvement
PI	Length of the system	Measured in meters	3/19 systems gradually declined; 5/19 systems stayed the same; 5/19 systems gradually lengthened; 4/19 systems initially lengthened and then declined; 2/19 systems continually lengthened
PI	System area	Measured in hectares	2/19 systems continually declined; 2/19 systems gradually declined; one area remained the same; 7/19 systems initially grew and then declined; 3/19 systems gradually grew; 4/19 systems continuously grew

Holon categories in the CIS Framework (Anderies *et al.* 2016) are Resource (R), Resource Users (RU), Public Infrastructure Providers (PIP), and Public Infrastructure (PI)
* These findings do not take into account the effects of the earthquake as this event reduced capacity and functionality in all systems.

Changes in these measures can give some qualitative indication of both the health of the system in different key areas (i.e. holons) and the employment of different types of coping mechanisms, such as reducing the length of the canal being used, reduced system area and/or cropping intensities, or changes in the number of resource users, for example. Some of these changes, such as negative changes in equity or condition can indicate problems in the social structure and management of the systems over time. The findings show that both the condition of the physical infrastructure and the condition of the social infrastructure tend to decline and decay over time, as evidenced by the condition as well as technical and economic efficiency. Condition, in particular is a direct indicator of the working condition of both hard and soft human-made infrastructure because the physical condition is dependent on the ability of the farmers' association to mobilize commitment and labor for maintenance and repairs when necessary. All of these indicators may point to some kind of increased or decreased resiliency, depending on which type of problem lens they are being looked at through. It is my assessment that certain coping mechanisms may be more tied to resiliency than changes over time.

5.4 Conclusions

This investigation of problems, coping mechanisms and resiliency for the nineteen farmer-managed irrigation systems (FMIS) over the past thirty years has relied heavily upon the longitudinal data captured in the Nepal Irrigation Institutions and Systems (NIIS) database. The longitudinal data in the NIIS database for these systems was collected and coded by a number of researchers over the last three decades, using common coding questions and variable options (i.e. coding schema). Some additional variables were added for this investigation that were specific to identifying problems, designed coping mechanisms, and resiliency. Poteete *et al.* (2010) summarized some of the major contributions of the NIIS database as follows (p.105):

> Studies conducted with the NIIS database have evaluated three types of factors thought to influence the performance of irrigation systems: owner-

> ship and management rights, investments in physical infrastructure, and characteristics of the group of irrigators. These findings raised policy-relevant questions about the value of centralized and capital-intensive strategies for providing irrigation. They also confirmed the importance of two design principles identified by Ostrom (1990): proportionality in benefits and costs, and collective-choice arrangements that involve individuals affected by the resource system.

While this study confirms these findings, it also expands upon them in some important ways. First, allowing for local ownership and management rights has been proven to be generally more effectively resilient than agency management but there are some types of problems that local users cannot cope with on their own. This highlights the need for some kind of support infrastructure that recognizes and provides support for those problems that are beyond the capacity of the individual local farmers' associations. Damages to the canal systems (HHMI) and, in some cases, the loss of knowledge and leadership within their farmers' association (HI/SI), due to the earthquakes in the spring of 2015 badly incapacitated all of the systems in the study area. This is an example of a low frequency/high magnitude problem that affected the whole region of the study area. For a problem of this type, additional exogenous support for all of the systems becomes necessary but would vary in what types of assistance are necessary from system to system.

Secondly, all types of infrastructure require on-going investment, maintenance, and sometimes repair. This includes the social infrastructure. While the original intervention was intended to establish strong and resilient farmers associations that would then be more successful in managing and sustaining the systems, the improvements were not ever re-invested in as an act of maintenance. The farmer-to-farmer training network that was established during the intervention, for example, could have been held in place as a maintained social infrastructure that could provide increased support and capacity for the FMIS when they experienced a problem that they struggled to cope with. Characteristics of the group of irrigators are key in the success of the system but, when they, themselves, are viewed as a type of infrastructure, it becomes clear that we must continue to re-invest in maintaining and repairing their infrastructure when necessary, if we expect them to persist and become resilient. Farmers' organizations are sometimes prone to internal and external disturbances that can affect their structure and performance. Relationships may change, memories may falter, and effective leadership may not last.

In addition to these points, I would also add problem types as a key factor influencing the effective performance of these coupled infrastructure systems (CIS). The resilience, and therefore long-term success, of these systems depends on the types of problems that they encounter and the ability of the farmers to utilize and sometimes re-arrange the infrastructures in the system to cope with those problems. There are, however, some problems that are beyond the capacity of the system to cope with, and in these instances there must be support mechanisms in place to increase their capacity. Investment of resources (i.e. mass, energy, and information) is important to the development and maintenance of all types of infrastructure.

Resiliency depends on the ability of actors in the system to mobilize the resources they need that allow for robustness or adaptability to different types of problems. While a FMIS may be robust to a certain type of disturbance, such as the uncertainty of water flow, they may be very fragile to another type of problem such as political conflict or natural disaster. Resiliency has to do with having options for dealing with unpredictable disturbances when they arise, e.g. bandwidth. This study provides proof that the CIS Framework is useful in understanding the problems that people are facing in social-ecological systems (SES) as well as the ways that they find to connect coping mechanisms with different types of problems through design-processes. More research is warranted in this area, however, and there is a need to understand how the different roles and structures of individuals and teams involved in design-processes within shared resource systems work through the dynamics of the systems. The ability of different types of actors to invest different types of resources to a given action situation depends on what type of actor is investing and their access to the necessary resources, for example. Different actors have access to different types of resources that could bear on a situation depending on their position within the system and relationships to other components. Further research in this area may result in the identification of patterns that show what the most beneficial actions of a professional design teams, like that of the WECS/IIMI team, can do to help achieve the goal of making groups of local farmers more successful during their long-term engagement in design-processes for resiliency in these types of systems.

Chapter 6

SYNTHESIS AND CONCLUSIONS

In this dissertation I address a gap in understanding about the meaning and role of design within complex adaptive systems (CAS) involving common-pool resources (CPRs). Through this investigation, I utilized and extended the strong tradition of structural coding methodology utilized in this field to map out the conceptual landscape of design for CAS and develop a theoretical synthesis for use as a foundation for investigating design-processes in CPR systems. This effort was aimed at connecting the coding tradition more clearly within the CIS Framework (Anderies *et al.* 2016) by moving beyond the coding of static attributes to the coding of processes in dynamic systems. This represents a step forward in actualizing the goal of understanding what is designed and what is emergent in CAS involving CPRs. By utilizing this theoretical foundation in the empirical investigation of longitudinal data, spanning three decades, on a government-led intervention (i.e. design-process) for the improvement of farmer-managed irrigation systems (FMIS) in Nepal, I was able to both show that the theory is functional for helping to understand design-processes in CPR systems and also take a few incremental steps forward in improving the theory for these purposes. CPR systems are the complex adaptive systems from which we derive our most valuable shared resources. These systems are difficult to understand and control, however, and our efforts to design coupled infrastructure systems (CIS) and create the flows of the resources (mass, energy and information) that we need are sometimes thwarted by wicked problems, including: uncertainty, social dilemmas, inequities, and trade-offs. In addition, because interdependent dynamics occur across multiple levels of the system, our design efforts must become complex enough to be effective within the complexity of the system.

In Chapter 2, I established the background knowledge and foundational concepts for the state of the coding methodology in this field of research. This information came from a previously published study that I was a part of, but served to introduce the key concepts and considerations necessary for understanding the methodology and it's use, importance, and tradition in the study of common-pool resources.

In Chapter 3, I utilized an inductive approach to coding to define "design" within the concept of complex adaptive systems (CAS). I found that the concept of design as applied to CAS includes a number of linked activities and products that work across multiple parts of a system through design-processes. Because of the dynamic nature of CAS, design-processes for these systems must include the capacity for change, calibration, learning, improvement, and innovation. It is, perhaps, more about navigating a continual flow of design activities that never end, and less about finding "the solution" to a problem or "the answer" to the question. Akin to the assertions of Papanek (1971), design may be the very stuff of human life and well-being. Common-pool resources (CPRs) are, by definition, shared resources, meaning that design for these special types of systems cannot be done by elite professional alone, but must include many different participants in the system at many different levels of the system and many different phases of the design-process. Human action in CPR systems is, therefore, collective action which Ostrom (1990) showed us occurs within action situations (AS). The CIS Framework (Anderies *et al.* 2016) is an important iteration in the legacy of Elinor Ostrom's work, allowing for CPR systems to be viewed as configurations of coupled infrastructures (i.e. natural, human, social, hard human-made, and soft human-made) which work together to provide the affordances within these systems for human survival and thrival. The creation of infrastructure, however, requires the investment of resources (i.e. mass, energy, and information). It becomes clear, from this perspective, why it is important to include user participation and the collaboration of a variety of stakeholders within design-processes in order to bring the fullest amount of resources to bear on each action situation.

My investigation, in Chapter 4, of the participatory design-process for improving farmer-managed irrigation systems (FMIS) in Nepal found that the proposed synthesized theory does help to broaden our understanding of how design-processes in common-pool resource systems work. I not only showed that the Coupled Infrastructure Systems (CIS) Framework (Anderies *et al.* 2016) is useful for empirically investigating design-processes in CPR systems, but that networks of linked action situations (NLAS) is a useful addition to the CIS Framework which more strongly links the CIS Framework to the foundational machinery of Ostrom's (1990) IAD Framework. In addition, the coupling of the design-process model with McGinnis (2011b) network of adjacent action situations (NAAS), forms the structure for NLAS and a theory of how change happens within CIS. The methodology that I proposed in Chapter 3 was found to be useful in understanding the sequencing and outcomes of the NLAS at a variety of scales. In addition, I was able to demonstrate how these combined tools can be used to identify the action situations that are key leverage points in generating or mitigating both unintended consequences (i.e. spillovers and wicked problems) and resilience (i.e. robustness and adaptability) trade-offs within the design-processes of CPR systems. The investigation in Chapter 4 also confirmed that the design-process is generally iterative between the two key phases of decision-making and development, perhaps functioning more like eddies in a river.

In Chapter 5, I investigated problems, coping mechanisms and resiliency at the local level and further confirmed that all types of infrastructure require on-going investment, maintenance, and repair. When social processes and protocols (e.g. the WECS intervention) are viewed as constructed infrastructures within the system, they face the same types of entropy and decay as physical infrastructure and require similar levels of re-investment of resources (i.e. mass, energy, information) and maintenance to remain in good working order. From this perspective, certain points of decision-making (i.e. action situations) about when, why, how, and by whom these infrastructures are sustained, improved, or removed from the coupled infrastructure system (CIS) become more important. In addition to this, I found that problem types may be a key factor that influences the effective performance of coupled infrastructure systems (CIS). Resilience within CPR systems depends upon the types of problems encountered and ability of actors within various levels of the system to mobilize the resources they need to cope with different types of problems.

This study has also shown that the CIS Framework provides a useful framework that helps to integrate the necessary theories for understanding design-processes in CPR systems. The CIS Framework not only allows for a systematic mapping of the key system components and their dynamic relationships to one another but also provides the space to map out the networks of linked action situations (NLAS) that make up a design-process and the affects of the human activities occurring within them. In addition, The CIS Framework and NLAS provide a systematic way of identifying the key leverage points for resilience, robustness, and adaptability within a system. When brought together for a unified theory that includes collective action, design-processes, and resilience theory, my findings suggest that action situations (AS) produce *commitments to intended actions (i.e. intention)* that then produces *potential outcomes (i.e. affordances)* through the creation, configuring, and use of coupled infrastructures. Sometimes, however, these same action situations can also generate unintended consequences in the form of *spillovers* (Anderies *et al.* 2016) and *wicked problems.* These unintended consequences account for, at least in part, the *emergence* of patterns at the system level that are difficult or impossible to predict by the behavior of the system's individual components or sub-systems (Holland 1992; Miller and Page 2009). *Wicked problems* are the inherent *uncertainties, social dilemmas, inequities, and trade-offs* that plague us in our attempts to manipulate CPR systems, causing action situations to become moving targets where there are neither clear problems nor solutions and also cause the interdependent dynamics that operate at different speeds and across multiple levels of the system (Holland 1992; Walker *et al.* 2006; McGinnis 2011b; Anderies *et al.* 2013; Anderies 2014; Anderies 2015).

A few interesting insights about the theoretical components included in the proposed synthesis have come out of this investigation. First, there are a few new relationship links that should be considered for addition to the CIS Framework: 1) A new link (referred to as Link 7 in this document) between the public infrastructure (PI) holon and relationship link 2 (from resource users to public infrastructure providers) should be added; and 2) links that are internal within each of the holons may justify further differentiation in the future when this case study may be compared to other similar case studies. Second, this study not only confirms McGinnis (2011b) hypothesis that the outcomes of one AS may affect the structure of another AS, but adds to this by showing how the position and sequencing of these AS within the system modeled by the CIS Framework become important to the structuring of other AS as well. The primary example of this is illustrated by the ways that different types of actors (e.g. resource users and public infrastructure providers) contribute different types of resources (i.e. mass, energy, and information), exercise different types of control, and view the costs and benefits of each AS differently based on their perspective and position within the system.

I conclude this dissertation with the hope that this trajectory of research will lead to further dialogue and conversations concerning our collective ability to effectively engage in design-processes within CPR systems. I believe that there are many future directions that this research may lead to, as more research is needed to better understand the different types of roles through which different types of stakeholders can engage in design-processes and how the resources that they bring with them into the NLAS affect the resilience of these systems. I thank you for your time and consideration of these ideas, and hope that curiosity will continue to drive us ever forward.

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APPENDIX A

APPENDIX

A.1 Chapter 3 Supplementary Materials

A.1.1 Design Definitions

Table A.1: Definitions of ”design”

	Noun-form Definitions: Design is a Thing	
1	Cambridge	A purpose or intention
2	Cambridge	A plan or drawing
3	dictionary.com	A conception or intention
4	dictionary.com	An outline, sketch, draft or plan
5	dictionary.com	An organization or structure
6	Fuller (1971)	Design is either a mental conception or a pattern, the opposite of design is chaos
7	Hevner et al. (2004)	A purposeful organization of resources to accomplish a goal
8	Love, T. (2002)	A specification or plan for making a particular artifact or for undertaking a particular activity
9	Macmillan Dictionary	A drawing that shows what something will look like when it’s made
10	Macmillan Dictionary	The way that something is made so that it works in a certain way or has a certain appearance
11	Oxford	A purpose or planning that exists behind an action or object
12	Oxford	A plan or drawing
13	Oxford	The arrangement of the features of an artefact
	Verb-form Definitions: Design is an Activity	
14	Alexander, C. (1964)	the process of inventing physical things which display new physical order, organization, form, in response to function

15	Brown, T. (2011)	Design thinking is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success
16	Bjögvinsson, Ehn, and Hillgren (2012)	That designers should be more involved in the big picture of socially innovative design, beyond the economic bottom line
17	Buchanan, R. (2001)	Design is the human power to conceive, plan, and realise products that serve human beings in the accomplishment of any individual or collective purpose
18	Cross, N. (1990)	Designers produce novel unexpected solutions, tolerate uncertainty, work with incomplete information, apply imagination and forethought to practical problems and use drawings and other modeling media as a means of problem solving
19	Gero, J. (1990)	Designers are change agents in society. Their goal is to improve the human condition in all its aspects through physical change. ... Design exists because the world around us does not suit us, and the goal of designers is to change the world through the creation of artifacts. ... design is to transform requirements, generally termed as functions, which embody the expectations of the purposes of the resulting artifact, into design descriptions
20	Mau (2007)	No longer associated simply with objects and appearances, design is increasingly understood in a much wider sense as the human capacity to plan and produce desired outcomes
21	Papanek, V. (1971)	All men are designers. All that we do, almost all of the time, is design, for design is basic to all human activity. The planning and patterning of any act towards a desired, foreseeable end constitutes the design process. Any attempt to separate design, to make it a thing-by-itself, works counter to the fact that design is the primary underlying matrix of life. Design is composing an epic poem, executing a mural, painting a master-piece, writing a concerto. But design is also cleaning and reorganizing a desk drawer, pulling an impacted tooth, baking an apple pie, choosing sides for a backlot baseball game, and educating a child
22	Pourdehnad, Wexler, and Wilson (2011)	In systems thinking, design is a creative act which attempts to estimate how alternative sets of behavior patterns would serve specified sets of goals

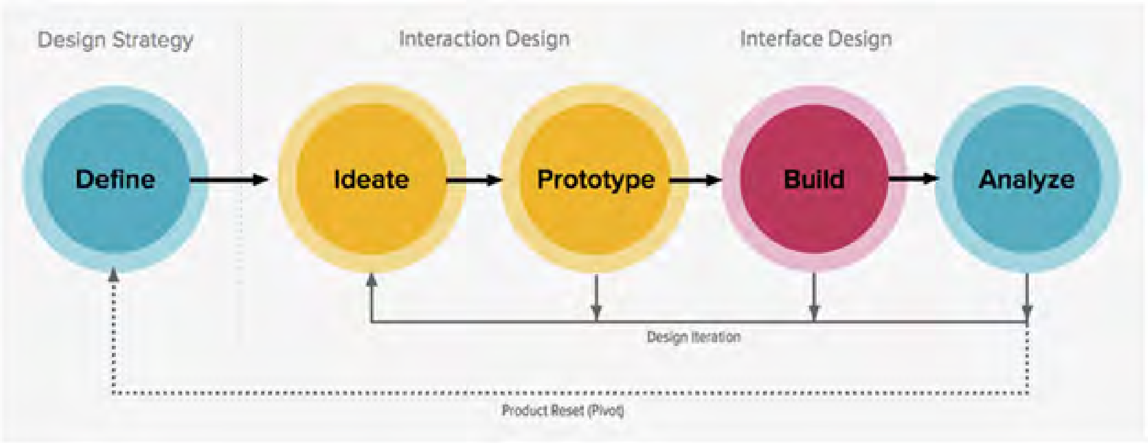
23	Simon, H. (1969)	Design is devising courses of action aimed at changing existing situations into preferred ones
	Process-form Definitions: Design is a Process	
24	Bausch (2002)	To accomplish its goals, systems design cannot be a top-down operation nor can it be expert driven. It must actively involve the stakeholders of the design in shaping a shared vision that represents their ideas, aspirations, values and ideals
25	Bjögvinsson, Ehn, and Hillgren (2012)	That design is a collaborative effort where the design process is spread among diverse participating stakeholders and competences
26	Bjögvinsson, Ehn, and Hillgren (2012)	That ideas have to be envisioned, prototyped, and explored in a hands-on way, tried out early in the design process in ways characterized by human-centeredness, empathy, and optimism
27	Cambridge	The way in which something is arranged or shaped
28	Cambridge	To make or draw plans
29	Cambridge	To intend as a result
30	Charnley, F. and Lemon, M. (2010)	Whole system design is one such approach that aims to integrate social, economic and environmental phenomena into a comprehensive design solution. The approach encourages the development of partnerships between actors from a variety of different backgrounds, disciplines and sectors to develop an innovative, sustainable and optimised solution at a whole system level. However, there is limited research concerning the integrative process that actors are required to follow in order to reach such a solution.
31	dictionary.com	To plan or outline
32	dictionary.com	To create or conceive
33	dictionary.com	To devise or choose
34	dictionary.com	To intend

35	Dorst and Dijkhuis (1995)	Describing design as a rational problem solving process is particularly apt in situations where the problem is fairly clear-cut, and the designer has strategies that he/she can follow while solving them … Describing design as a process of reflection-in-action works particularly well in the conceptual stage of the design process, where the designer has no standard strategies to follow and is proposing and trying out problem/solution structures. Seeing design as reflection-in-action manages to describe the design activity without totally severing the close link between the content and the process components of design decisions
36	Macmillan Dictionary	To decide how something will be made
37	Macmillan Dictionary	The process of deciding how something will be made, including how it will work and what it will look like
38	Mang, P. and Reed, B. (2012)	Regenerative design is a system of technologies and strategies, based on an understanding of the inner working of ecosystems that generate designs to regenerate rather than deplete underlying life support systems and resources within socio-ecological wholes
39	Merriam-Webster Dictionary	To create, fashion, execute or construct according to a plan
40	Merriam-Webster Dictionary	To conceive or plan out in the mind
41	Merriam-Webster Dictionary	To make a drawing, pattern, or sketch
42	Merriam-Webster Dictionary	To conceive or execute a plan
43	Merriam-Webster Dictionary	To devise for a specific function or end
44	Merriam-Webster Dictionary	To intend or have as a purpose
45	Oxford	The art or action of conceiving of and producing a plan or drawing of something before it is made
46	Oxford	To decide upon the look and functioning of
47	Oxford	Do or plan with a specific purpose in mind

48	Van Gigh (1978)	Design is to the systems approach as continuous improvement is to the scientific approach

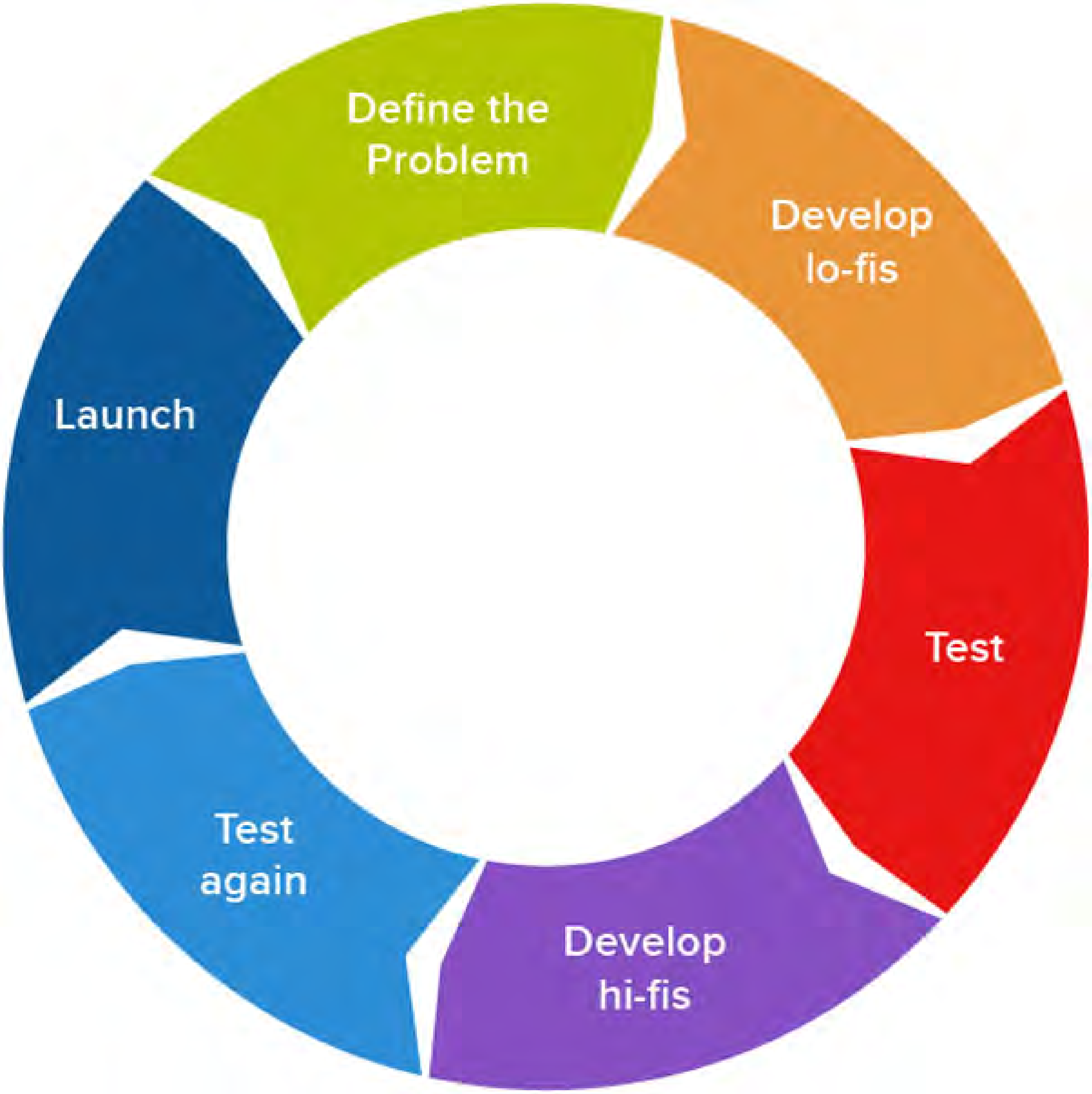
A.1.2 Design Diagrams

Figure A.1: Design Diagram: Zurb



ZURB is a product design company. We help companies design incredible digital products (things like desktop software, mobile apps, etc), websites, and integrated services. For us at ZURB, the process includes, but not limited to: identifying opportunities, creating lo-fi sketches, determining requirements of your product, developing a style guide, and then identifying and rectifying any problems your product may have. http://s3.amazonaws.com/prod.word/images/562/original.png?1358213619

Figure A.2: Design Diagram: UX Design



Jerr Cap. UX Design. Designmodo Blog A design process empowers you to confidently innovate because you can map the inception of an idea to its evolution. 1. Define the problem before hunting for solutions; 2. Know your user like the back of your hand. 3. Consider extreme solutions to the problem. 4. Establish a hypothesis to test before you design. 5. Collaborate with a diverse group on the best solution. 6. Create a story with documentation. 7. Design and test on paper. 8. Post artifacts on a wall. 9. Create a lo-fi prototype to test. 10. Build collaboratively. https://designmodo.com/wp-content/uploads/2015/09/image00.jpg