Integrating Insights for Complex Problem Solving: Applications for Interdisciplinary Pedagogy and Water Governance

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ABSTRACT

The following three chapters are a product of four years of hard work and extensive growth toward my PhD in Environmental Science from the Joint Doctoral Program of the University of Idaho and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica. As a fellow in the Integrative Graduate Education and Research Traineeship (IGERT) I worked on an interdisciplinary team, which offered me a unique opportunity to explore many new disciplines, interdisciplinary areas and philosophical orientations. The angle that I took in my studies integrates insights from many disciplines and areas of practice, as I focused my studies on addressing complex problems, policy analysis, drinking water governance, and pedagogy. In each of the following three chapters I draw heavily from theoretical and philosophical discussions in the literature to develop an approach for analyzing and solving problems. Chapter one outlines my discovery of how personal practices in mindfulness and improvisation have profound insights for interdisciplinary education. Chapter two presents a policy analysis of rural drinking water management in the Turrialba region of Costa Rica, and is an example of the applied social science work that I aim to do. Chapter three is a reflection of four years of interdisciplinary teamwork, presenting an approach to identify and analyze issues of scale mis-fit in social-ecological systems. Together, these three chapters reflect my experiences in collaboration, interdisciplinarity, pedagogy and personal growth over the past four years.

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INTRODUCTION

The following three manuscripts are the product of four years of hard work and extensive growth toward my PhD in Environmental Science from the Joint Doctoral Program of the University of Idaho and the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica. I pursued a PhD because I truly love learning and exploring social phenomena around the world, but what most attracted me to this program was the unique design to work closely with a team. The most rewarding experiences in my life have been through close collaboration and connection with others and the teamwork in this program was indeed both challenging and enriching.

In addition to teamwork, the Integrative Graduate Education and Research Traineeship (IGERT) fellowship (NSF Award No. 0903479) offered me an opportunity to explore many new disciplines and interdisciplinary areas. With a background largely in international nutrition, public health and policy processes, I have never identified with any one *discipline*. The work that I have been involved in has been based on problems and solutions, rather than any one discipline or theoretical perspective. The angle that I took for my degree in Environmental Science integrates insights from many disciplines and areas of practice, as I focused on addressing complex problems, policy analysis, drinking water governance, and pedagogy. By interacting closely with people from very different scientific backgrounds throughout the PhD process, I have learned about many new disciplinary perspectives and insights. Prior to this experience I had never worked in the environmental sciences, or with ecologists, hydrologists or geologists. And to be honest, four years ago I could not define the term *watershed*.

This PhD process also allowed me the opportunity to continue growing as a teacher. During these four years I taught *Social Research Methods* at UI, co-taught *Law, Ethics and the Environment* with J.D. Wulfhorst at UI, and co-taught tenth grade *Accelerated Biology* at Moscow High School as an NSF-GK12 fellow (NSF Award No. 0841199). In all of these courses I was able to draw connections between multiple disciplines and epistemological orientations, as well as explore developing interactive, participatory pedagogy. In this process I have realized that I want high school and college level teaching to be an integral part of my career.

For me, the most important part of all of this hard work studying, investigating, thinking, and learning is the practical application of social science. I love learning about theories, reading proactive pieces, and getting deep into philosophical discussions. But what inspires and motivates me most is figuring out how to use my knowledge, understanding and experiences to contribute to the world in a meaningful way. My orientation toward applied science shines through in my dissertation. In each of my three manuscripts I draw heavily from theoretical and philosophical discussions in the literature to develop an approach for analyzing and solving problems. Together, these three chapters reflect my experiences in collaboration, interdisciplinarity, pedagogy and personal growth over the past four years. I hope you (whoever you are!) enjoy reading and thinking about the ideas presented in these chapters.

Chapter 1- Zen and the Art of Interdisciplinary Team Maintenance: Insights for Interdisciplinary Pedagogy. The idea for this chapter organically emerged from discussions with my close friend, Irene Shaver. Our experiences in this PhD program led us to engage in

many conversations about the challenges we faced in our studies, on our teams and inside ourselves. One day we discovered that our personal practices in mindfulness and improvisation had profound insights for our interdisciplinary education, as well as the honest expression of how we make meaning and find inspiration in the world. These connections reflected a shift toward envisioning holistic development of ourselves, and marked the moment when we intentionally ceased to see our intellectual academic development as separate from our personal spiritual growth.

We have been developing this idea over the past two years. The concepts and ideas presented in this chapter reflect the major challenges, reflections, and insights that I have intimately experienced in this interdisciplinary, team-based PhD process while also undergoing deep transformations in my personal life. As they also reflect elements of a career path that I am dedicated to pursuing, I decided to include this chapter focused on literature review and the connections between major concepts in my dissertation. Irene and I are continuing to develop this pedagogical strategy, specific examples of lesson plans, and a training module for instructors interested in learning how to use our strategy. We are also preparing to facilitate workshops with students in grade 6-12 classrooms and at the University of Idaho. We plan to use feedback from these workshops and our lesson plans to prepare a manuscript for submission to the *Journal of Transformative Education*. We hope to continue to express what we learn from this exploratory journey through our intellectual, personal and artistic endeavors.

Chapter 2- Using Attributes of Good Governance to Advance the Common Interest for Rural Drinking Water Management in Costa Rica. This chapter reflects my contextual understanding of rural drinking water management in the Turrialba region of Costa Rica. I carried out a total of eight months of intensive fieldwork, primarily interviews and field site visits. I also facilitated five workshops, four about rural community development in the Turrialba and Sarapiquí regions (in collaboration with Irene Shaver), and one about rural drinking water management in the Turrialba region (in collaboration with my IGERT team). This chapter is a policy analysis based specifically on a sub-set of the interviews that I conducted, but drawing from my other experiences in the field. This policy analysis is an example of the applied social science work that I aim to do. I am currently working with my committee members to submit a manuscript based on this chapter to the *Policy Sciences* journal.

Chapter 3- Reconciling Resource Management with the Landscape: An Approach to Identify Scale Mis-fit in Social-ecological Systems. My team and I wrote this manuscript together. During our fieldwork in Costa Rica we discovered an issue of scale mis-fit with rural drinking water management. As we were processing our findings together in Taylor's living room at CATIE, we serendipitously came up with an approach to identify and analyze issues of scale mis-fit. Soon after this we realized that scale mis-fit is a topic of discussion in the literature, and a simple yet effective tool for this type of identification and analysis has not been published. Over the course of a year, our approach became the focus of our team manuscript. We are currently preparing to submit this paper to *Ecology and Society*.

CHAPTER 1

Zen and the Art of Interdisciplinary Team Maintenance: Insights for Interdisciplinary Pedagogy

Abstract

As the solutions to the complex problems we face globally are not bound by any one discipline or way of thinking, the need for creative, interdisciplinary, applied and collaborative approaches continues to grow. Interdisciplinary educational programs aim to prepare students to be successful interdisciplinarians professionally, by developing skills for complex systems thinking, higher order thinking, tolerance for ambiguity, epistemological development, metacognitive awareness, and collaboration. Although models for interdisciplinary teaching exist, there is still a need for pedagogical approaches specifically to develop these skills. Large bodies of evidence show that people who practice mindfulness develop these same skills desired among interdisciplinarians, although these bodies of literature rarely overlap. Moreover, improvisation exercises also provide a structure and process for practicing developing these same skills as a creative and collaborative team. In this chapter, I explain how insights from mindfulness and improvisation practices can inform the development of interdisciplinary pedagogy and maintenance of interdisciplinary teams. Connections between these areas of practice can inform a pedagogical strategy for developing interdisciplinary team science skills in higher education; however, this approach is applicable to a wide range of contexts including K-12 classrooms and formal and informal adult education settings.

Introduction

The nature of complex systems and problems necessitates interdisciplinary study (Newell 2001a; Wilson 2010). As the solutions to the complex problems we face globally are not bound by any one discipline or way of thinking, the need for creative, interdisciplinary, applied and collaborative approaches continues to grow (Manathunga et al. 2006; NRC 2004; Sawyer 2006). In response to this need, higher education institutions are creating degree programs that include interdisciplinary and collaborative efforts (Haynes and Brown Leonard 2010; Szostak 2013) and are increasingly supported by both federal and private funding (Rhoten and Pfirman 2007).

Despite the increase in interdisciplinary programs, a general lack of research about teaching and learning in interdisciplinary higher education exists (Lattuca et al. 2004). Literature about theory and practice of interdisciplinary higher education focuses on desired outcomes of programs, specifically preparing students to be successful interdisciplinarians professionally by developing skills for integration, critical thinking, problem solving and collaboration; however, specific approaches to achieve these outcomes as well as strategies to assess whether and how well they have been achieved are lacking (Friedow et al. 2012, Repko 2007). In this chapter, I present the intersections between interdisciplinary educational goals, mindfulness, and improvisation that can inform a pedagogical strategy to achieve desired goals for interdisciplinary higher education. I developed the ideas presented here in collaboration with Irene Shaver by drawing from both our experiences in an interdisciplinary PhD program and our personal experiences outside of academia.

As doctoral students in the Joint Doctoral program between the University of Idaho and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica, Irene and I are trainees in an Integrative Graduate Education and Research Traineeship (IGERT) program funded by the National Science Foundation. In this IGERT program, students carry out part of their doctoral research on collaborative teams with students with different disciplinary orientations and backgrounds. As the social science members of two different multi-disciplinary teams in this program, we have faced challenges such as gaining sufficient levels of proficiency in a variety of natural and social science disciplines, communicating clearly with scientists of different philosophical orientations, reconciling tensions between different approaches to scientific inquiry, developing team research projects that achieve interdisciplinary integration, and maintaining healthy team dynamics that foster learning and achievement of both disciplinary and interdisciplinary goals. While struggling with these challenges over the past four years, we found ourselves drawing from reflections about our personal experiences with mindfulness and improvisation practices. As we were fascinated by the parallels between these seemingly disparate parts of our lives, we began to explore these connections further.

Through this exploration, we found rich bodies of academic literature about both mindfulness and improvisation practices, as well as their explicit connections to teaching and learning. We discovered that people who practice mindfulness develop skills very similar to those desired by interdisciplinarians (i.e., complex systems thinking, higher order thinking, tolerance for ambiguity, epistemological development, metacognitive awareness, and collaboration). We also discovered that improvisation provides a structure and process for

learning how to become a creative and collaborative team, and offers problem-based exercises based on ground rules that are critical for teamwork and fostering creativity. While examples of using mindfulness and improvisation practices in education exist in academic and practitioner oriented bodies of literature, we found that despite these natural connections, bodies of literature about mindfulness, improvisation and interdisciplinary higher education barely overlap.

These discoveries led us to begin developing a pedagogical strategy for cultivating interdisciplinary team science skills by combining insights from multiple bodies of academic literature, our experiences in a team-based PhD program, and our personal practices in mindfulness and improvisation. This strategy uses mindfulness practices to develop characteristics desired for interdisciplinary team members, and improvisation as a way to practice mindfulness as a collaborative team. In this process, the individual practice of mindfulness and group practice of improvisation stimulate reflection and discussion about these experiences and insights gained for interdisciplinary teaching and learning and working in collaborative environments. We believe that this pedagogical strategy can help inform the development and maintenance of interdisciplinary teams and enhance their intellectual, creative and collaborative potentials. Although the focus is on higher education, we believe that these insights are applicable to other contexts, such as K-12 classrooms and many formal and informal adult education settings.

Interdisciplinarity in higher education

There has been a surge in interdisciplinary programs, projects, courses and educational opportunities in higher education in recent decades (Haynes and Brown Leonard 2010; Klein 1999; Lindhom et al. 2002; Rhoten et al. 2007). This steady growth in interdisciplinarity has largely been a response to the growing recognition that addressing the socially relevant and interconnected problems the world faces, such as global climate change, food insecurity and economic poverty, requires approaches that extend beyond the knowledge and practices of a single discipline or area of research (NRC 2004; Hubenthal 1994). Traditional academic disciplines alone have shown to be insufficient to address this complexity, thereby emphasizing the need for applied, interdisciplinary approaches that combine and integrate the knowledge, tools and perspectives of multiple disciplines to study problems and potential solutions (Szostak 2007). Problem-based education has been promoted as early as four decades ago as a means to make education more emancipatory, liberating and focused on problem solving for social justice (Freire 1970). Scholars at universities have designed doctoral programs focused on developing interdisciplinary knowledge, skills, and attitudes to produce future leaders capable of dealing with complex problems (Manathunga et al. 2006; Roehler et al. 1998; Spelt et al. 2009; Palmer and Zajonc 2010; Sawyer 2006), as this type of interdisciplinary study prepares them to confront the complexities they will encounter throughout their careers (Newell 2001a).

Despite growth in interdisciplinary programs and experiences, the concept of interdisciplinarity has often been elusive (Repko 2007). While disciplines are defined as their own domains with particular phenomena of focus, theories, methods, and rules (Szostak

2007), interdisciplinarity is seen more as a process of integration rather than its own domain (Youngblood 2007). Although many definitions for the term exist, there is a general consensus that interdisciplinarity is focused on addressing complex problems, drawing from multiple disciplines, and integration (Szostak 2013). Klein and Newell (1997) incorporate these themes in their definition of interdisciplinarity as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession and drawing on disciplinary perspectives and integrating their insights by producing a more comprehensive understanding" (393-4). In other words, interdisciplinarity is not an end goal in itself, but rather a process that can be used as a means to better achieve goals of addressing problems. While distinctions between multi-, inter-, and trans-disciplinarity have been discussed (Klein 2014), I use the term *interdisciplinary* throughout this chapter as it is broadly used to describe integration of insights from more than one discipline for problem-solving.

Integration is widely considered the defining characteristic of interdisciplinarity (Rhoten and Pfirman 2007; Spelt et al. 2009; Szostak 2007), although it has shown to be poorly understood and difficult to define concretely among interdisciplinarians (Newell 2001a). Despite a lack of consensus on the meaning of integration and its role in interdisciplinarity, developments in interdisciplinary theory and practice over recent decades have contributed to increasing clarity (Repko 2007). The concept of integration has been used to refer to the synthesis of knowledge, theories and methods from two or more disciplines. However, interdisciplinarity involves integrating and critiquing insights that disciplines have about a phenomenon, which are a product of the application of knowledge, theories and methods

(Repko 2008; Szostak 2007). Discovering common ground among these insights makes achieving integration possible (Boix Mansilla 2005; Haynes 2002; Klein 1996; Newell 2001a; Repko 2007). Despite distinguishing features, interdisciplinary and disciplinary approaches to scientific inquiry complement each other in a symbiotic relationship (Friedow et al. 2012; Szostak 2007), as insights from each can contribute to intellectual development in the other.

Integration is also a key outcome for student learning in interdisciplinary higher education programs. Teaching and promoting integration in learning processes prepares students to confront complexities they will face in their future professions by enhancing capacities for complex problem solving and discovery of novel solutions and insights (Szostak 2007; Newell 2001a). Comparing and contrasting the unique perspectives of each discipline promotes the intellectual maturation desired in these programs (Ivanitskaya et al. 2002) and learning how, why and what to integrate is much more useful for addressing complex problems than just learning about many different theories or disciplines (Szostak 2007). Integration of disciplinary insights allows for creative synthesis, transformative changes for disciplinary perspectives, and a unique potential for understanding beyond what is possible within the domain of a single discipline (Boix Mansilla 2000; Ivanitskaya et al. 2002; Manathunga et al. 2006). Boix Mansilla et al. (2000) emphasize the power of these possibilities in their definition of interdisciplinary understanding as “the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement – such as explaining a phenomenon, solving a problem,

or creating a product – in ways that would have been impossible or unlikely through single disciplinary means" (219).

Skills as key learning goals in interdisciplinary higher education

Interdisciplinary higher education programs aim to support students in developing skills to be successful professional interdisciplinarians. Key skills promoted in literature about interdisciplinary higher education include complex systems thinking, higher order thinking, tolerance for ambiguity, epistemological sophistication, metacognitive awareness, and collaboration. The literature cited in the following sections describes these skills as key learning goals of an interdisciplinary approach to education.

Complex systems thinking

Problems that occur in complex systems require interdisciplinary study, as system components are connected through nonlinear relationships and can only be holistically observed from many different angles or perspectives (Newell 2001a). Therefore, interdisciplinary learning should aim to create meaningful connections between and among disciplines and result in knowledge that is more holistic than discipline-specific (Ivanitskaya et al. 2002). These desired connections emphasize the role of integration in the interdisciplinary learning process. Complex systems theory literature provides insights about system components, nonlinear relationships and system behaviors to improve how we conceptualize the interdisciplinary process and evaluate the types and extent of interdisciplinary integration that are achieved in this process (Newell 2001a). Although research shows that interdisciplinary learning requires and promotes these types of cognitive

complexity, how students develop cognitive complexity over time is less understood (Haynes and Brown Leonard 2010), leaving much room for future research and development for interdisciplinary programs.

Higher order thinking

Capacities for complex systems thinking can be heightened by development of higher order thinking skills. Interdisciplinary approaches to learning emphasize higher order thinking (i.e., analyzing, applying and generalizing), which helps students draw connections between varied concepts and develop their own processes for organizing knowledge, thereby facilitating problem-solving abilities (Ivanitskaya et al. 2002). Studies have shown that students in interdisciplinary courses or programs develop skills in synthesis and higher order thinking (Boix Mansilla et al. 2000; Lattuca et al. 2004). In their literature review about teaching and learning in interdisciplinary higher education, Spelt et al. (2009) found that higher-order cognitive skills were important to become capable of interdisciplinary thinking. The authors describe higher-order thinking skills as the ability to "search, identify, understand, critically appraise, connect and integrate theories and methods of different disciplines and to apply the resulting cognitive advancement together with continuous evaluation" and "the ability to change disciplinary perspectives, to switch between depth and breadth, and to transfer new knowledge structures to other appropriate contexts" (Spelt et al. 2009:373). Curricula that balance focus on practicing thinking processes with learning specific content enables the development of these types of complex thinking skills (Baxter Magolda 1992; Ivanitskaya et al. 2002).

Tolerance for ambiguity

Both complex systems thinking and higher order thinking require a tolerance for ambiguity. Tolerating ambiguity means having a certain level of comfort with complexity, recognizing existing paradoxes and embracing the value of multiple points of view. As interdisciplinary higher education aims to develop students with the ability to cope with complexity (Spelt et al. 2009), developing cognitive flexibility to increase one's ability to handle large amounts of information and tolerate the ambiguity inherent in drawing meaningful connections can contribute to the interdisciplinary learning process. Newell (2001) reiterates the need for tolerance of ambiguity suggesting that "the recognition of complexity should not lead us to throw up our hands, but to develop humility as well as interdisciplinarity" (22). Our epistemological and intellectual development "requires us to embrace the mess, since growth requires some discomfort" (Stenberg 2005:148). Becoming comfortable with ambiguity and complexity in interdisciplinarity is about seeing beauty in the diversity of existing perspectives that makes integration necessary, possible, interesting, and incredibly challenging.

Epistemological development

Epistemological beliefs are what individuals implicitly believe about the nature of knowledge and learning (Schommer 1994), including "perspectives on the difficulty of knowledge acquisition, learners' control over learning, the nature of knowledge authority, relativism, uncertainty, and subjectivity" (Ivanitskaya et al. 2002:103). Epistemological development is a process of gaining awareness and understanding of one's own beliefs, philosophical orientations and reflection that contributes to deeper awareness and understanding of others'

beliefs. This type of cognitive development is a key component of interdisciplinary learning because these beliefs heavily influence a student's disciplinary orientations toward knowledge and ability to integrate with others at a philosophical level (Eigenbrode et al. 2007). Interdisciplinary learning facilitates epistemological development by challenging students to recognize and reconcile inherent contradictions in the process of integration and application of different types of knowledge to a phenomenon of study (Ivanitskaya et al. 2002).

Metacognitive awareness

Having metacognitive awareness means being consciously aware of one's own thinking processes and patterns (Flavell 1976; Wenden 1998). Such awareness includes having an ability to manage, evaluate, and improve one's own cognitive processes (Gourgey 1998; Hacker 1998; Nelson 1996). Metacognitive awareness allows a student to gain understanding about how they learn, develop strategies for processing and storing new information, improve performance, develop emotional maturity and deepened cognitive functioning (Anderson 1991; Anderson 2003; Goh 2002; Hart 2004; Vandergrift et al. 2006). Interdisciplinary programs facilitate the development of metacognitive skills when, in the process of applying tools from many disciplines, students deliberately reflect on their own ways of thinking and face their own "internal set of implicit theories, assumptions, beliefs, and prejudices" (Ivanitskaya et al. 2002:103). In turn, metacognitive- and self-awareness are great assets for interdisciplinary interactions that challenge participants to be reflective about their own values and critique the claims and assumptions of their disciplinary backgrounds (Friedow et al. 2012; Qualley 2004). Awareness and ability to acknowledge and critically examine the

ways that disciplinary conventions influence oneself has contributed to successful pedagogical interactions among faculty and students in collaborative interdisciplinary work (Friedow et al. 2012). Interdisciplinary courses or programs that promote self-reflection and self-awareness in this way contribute to students' development of metacognitive awareness (Haynes and Brown Leonard 2010). Interdisciplinarians would greatly benefit from engaging more in processes that enhance metacognitive awareness such as reflection and contemplation about one's own tendencies and biases (Szostak 2007).

Collaboration

Cross-disciplinary, collaborative team science initiatives have become increasingly common in recent decades (Falk-Krzesinski 2011). Although teamwork is not a requirement for interdisciplinarity (Szostak 2013), the increase in collaborative teams is due to the limitations of any individual or their knowledge based in any single discipline to research complex problems (Hubenthal 1994; Newell 2001a). For this reason, interdisciplinary integration often requires coordination of efforts among a diverse range of participants with different disciplinary knowledge and experiences (Stokols et al. 2008; Fiore 2008). Therefore, skills for engaging in collaborative teamwork and maintaining healthy relationships in diverse groups are key to interdisciplinary learning and practice (Crowley et al. 2014). Interdisciplinary higher education programs aim to train students in the development of collaboration skills, including active speaking and listening, respectful communication, open epistemological analysis, conflict resolution, creativity, and adaptive flexibility (Benda et al. 2002; Burgett et al. 2011; Morse et al. 2007; Sawyer 2006; Stokols 2014; Stone 2014). Interdisciplinary pedagogy is also a collaborative process where faculty and students learn

together; however, interdisciplinary higher education programs often do not conceive of the student-teacher relationship this way (Friedow et al. 2012; Manathunga et al. 2006). Despite growing interest in collaboration, how and when collaborative efforts truly enhance scientific processes is not well understood (Falk-Krzesinski 2011). Moreover, breakdown of interdisciplinary collaborations due to interpersonal conflicts and communication challenges are common (Rhoten and Parker 2004; Graybill et al. 2006; Morse et al. 2007). Despite recent advances, there is room for the continued development of research and practice to support successful collaboration in interdisciplinary higher education. I aim to contribute to this development with the following insights for interdisciplinary pedagogy.

Achieving and assessing skills in interdisciplinary higher education

The skills introduced above - complex systems thinking, higher order thinking, tolerance for ambiguity, epistemological development, metacognitive awareness, and collaboration - are discussed in the interdisciplinary education literature cited above as existing or proposed learning goals for interdisciplinary higher education programs. However, there is still a lack of understanding about how students develop these skills over time and a need for pedagogical strategies to achieve them (Haynes and Brown Leonard 2010). There is more discussion in interdisciplinary education literature about desired outcomes of programs than on specific strategies for achieving them. For example, although integration is a defining element of interdisciplinary practice, the concept is used frequently with very little discussion about what is meant by the term or how to achieve it (Newell 2001a; Repko 2007). The difficulty of defining the ‘black box of integration’ (Repko 2008) has presented major challenges for developing interdisciplinary curriculum and pedagogical strategies to teach

and practice integration in interdisciplinary higher education. Although curricula are commonly called interdisciplinary, they are often more multidisciplinary in nature as they present multiple perspectives without offering true support for integration of disciplinary insights (Spelt et al. 2009). Interdisciplinary higher education programs would be more successful if integration were clearly conceptualized and made an explicit goal (Szostak 2007).

Just as it is difficult to design pedagogical strategies to achieve interdisciplinary learning goals, it is also difficult to assess whether and to what extent these goals have been achieved. Since adequate assessment of interdisciplinary work, programs and learning goals is a persistent problem (Repko 2007), interdisciplinary higher education is often defined by its own pedagogical characteristics rather than what students actually gain from it (Spelt et al. 2009). Traditional assessment techniques (i.e., exams, papers, and end-of-course surveys) are often insufficient to address desired interdisciplinary learning outcomes such as skills for critical thinking and metacognition (Ivanitskaya et al. 2002) described above. Moreover, uncertainty about criteria for assessment has been identified as a source of anxiety among students (Burgett et al. 2011). Boix Mansilla (2005) suggested a strategy for assessing interdisciplinary student work using criteria that balances how well the product is deeply grounded in disciplinary insights, clearly integrates disciplinary views to lead to cognitive advancement, and exhibits a clear sense of self-reflection. More research is needed to identify criteria and evaluative strategies to assess and enhance students' cognitive development throughout interdisciplinary learning processes (Ivanitskaya et al. 2002).

The skills discussed here are promoted widely in education literature, as they are beneficial for holistic development of the whole individual both personally and academically (Shapiro et al. 2011). There is a contemporary movement toward promoting experiential and transformative learning experiences in higher education (Baxter Magolda 2001; Mahani 2012; Palmer and Zajonc 2010; Smith and McCann 2001; Wilson 2010), which is contributing to improving understanding about how students develop these skills and effective pedagogical strategies for achieving them. This movement promotes the transformation of educational models that treat knowledge acquisition like a passive, one-way transfer from teacher to student to models that emphasize the active role of students in their own learning processes (Newell 2001b; Smith 2001).

Through their review of literature about interdisciplinary learning and epistemologies, Manathunga et al. (2006) proposed an interdisciplinary doctoral pedagogy to develop higher order thinking and metacognitive skills through transformative learning experiences that promote explicit exploration of epistemological understandings of disciplinary and interdisciplinary knowledge. These authors call for more research about the efficacy of such pedagogical strategies for interdisciplinary learning (Manathunga et al. 2006). In addition, Friedow et al. (2012) drew from their experiences collaborating with university faculty and students to design and implement an interdisciplinary program. Their interdisciplinary pedagogy promotes close interactions among faculty and students in designing and engaging in teaching and learning experiences, reflective habits, intentional framing of difficulty and discomfort as opportunities, and humility so both faculty and students see themselves as learners in the process. These authors stated that interdisciplinary pedagogy is never entirely

completed, but rather requires continual attention and reflection. A shared, reflective learning process among teachers and students is widely considered a key element of transformative education (Holland 2004; Schon 1983; Tremmel 1993). These movements toward transformative educational experiences extend beyond higher education and are also gaining momentum as priorities for pedagogical development in K-12 education (Garrison Institute 2005; Roeser and Peck 2009).

Developing an interdisciplinary pedagogy for higher education

As doctoral students working on multi-disciplinary teams over the past four years, Irene and I have faced challenges in developing the skills described above. Through many reflective discussions about these challenges, we began to gain insights from our personal practices in mindfulness and improvisation. As we explored bodies of literature about both mindfulness and improvisation practices, and their connections to teaching and learning, we discovered that people who practice mindfulness develop skills very similar to those desired for interdisciplinary higher education. In the following sections I describe how mindfulness practices contribute to the development of characteristics desired for interdisciplinarians, how improvisation exercises provide an opportunity to practice mindfulness as a collaborative team, and how these connections can be used to develop a pedagogical strategy for interdisciplinary education.

Insights from mindfulness

Definitions and practice of mindfulness

The concept of mindfulness is at the root of Buddhism, Taoism and Yoga (Kabat-Zinn 1994). However, the appearance and common description of mindfulness across many traditions extending from ancient Greek philosophy, Western European naturalism, American transcendentalism and humanism, and Native American wisdom is evidence for its centrality to the human experience (Brown et al. 2007). Despite its widespread existence, mindfulness is not an easy concept to define (Langer & Moldoveanu 2000). Popular practitioners and teachers define mindfulness as appreciation of the present moment (Kabat-Zinn 1994) and consciousness of self, including body, breath, movements, thoughts, and feelings (Thich Naht Hahn 1987). Jon Kabat-Zin (1994), the founder of Mindfulness Based Stress Reduction programs, described mindfulness as the art of conscious living or practice of "paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally" (p. 4). Kabat-Zin emphasized that paying attention in this way fosters awareness and mental clarity that allows us to fully engage in each experience and access possibilities for growth and transformation in our lives.

Mindfulness is defined similarly in cognitive psychology literature as being aware of and receptive to present events and experience (Brown and Ryan 2003). This literature explains mindfulness as a quality of consciousness, which is determined by awareness (i.e., consciously registering stimuli using physical, kinesthetic and cognitive senses) and attention (i.e., noticing objects or stimuli) (Brown et al. 2007). We often process information by focusing our attention on an object very briefly before having cognitive and emotional

reactions, discriminating into categories and making judgments based on our past experiences; however, practicing mindfulness means processing information by focusing on making observations while limiting our judgments and reactions to them, thereby allowing us to observe and understand our own thoughts and feelings, and intentionally choose whether or how we respond (Brown et al. 2007). Mindfulness is a process of self-observation and "non-judgmental acceptance of all that arises in the mind and body as one observes oneself" (Holland 2004).

The practice of mindfulness can take many forms and there are ample resources for learning and practicing mindfulness. For example, Thich Naht Hahn (1987) presents many simple ways to engage in mindfulness practices in every day life, including making a half smile when waking up in the morning or when irritated, breathing deeply or counting one's breath, bring awareness to each part of one's body while lying down, and focusing on the exact present moment while washing dishes. Resources describing and guiding exercises in mindfulness are abundant, which will be described in curricula we are developing for our proposed pedagogical strategy.

Benefits of mindfulness

There is mounting evidence that practicing mindfulness results in positive benefits for health, well-being, personal development and social relationships (Brown et al. 2007; Carson and Langer 2006). Mindfulness practices also have positive benefits for cognitive capacities and development. For example, mindfulness has been shown to result in improved productivity and creativity among business associates, goal attainment among college students, and

increased attention, memory and creativity among elementary and college students (Langer & Moldoveanu 2000; Shapiro et al. 2011). Some reported evidence of mindfulness practices resulting in greater levels of ecological stewardship (Brown and Kasser 2005) and compassionate civic engagement (Burggraf and Grossenbacher 2007). Mindfulness can have many positive effects on social relationships by fostering interaction styles that promote healthy relationship functioning and enhance overall relationship quality. These benefits include improvements in communication quality, conflict management, feelings of interpersonal closeness, strong connections in personal and romantic relationships, and compassion and empathy for others (Brown et al. 2007; Shapiro et al. 2011).

Skills built through mindfulness practices overlap with interdisciplinary learning goals. The wide variety of benefits seen with mindfulness results from changes in attention, cognition and emotion (Brown et al. 2007), which translate into the development of habits and skills among people who regularly practice mindfulness. These habits and skills are strikingly similar to skills that interdisciplinary higher education programs desire to develop in their students, and many teachers have advocated for explicitly integrating mindfulness into curricula (Haynes and Brown Leonard 2010; Holland 2004; Hyland 2009; Roeser and Peck 2009). As mindfulness helps us foster more clear and ready access to our minds, contemplative pedagogies are an enriching complement to disciplinary modes of inquiry and learning (Burggraf and Grossenbacher 2007). Table 1.1 summarizes the skills that practicing mindfulness helps people develop and shows how these align with key skills desired as learning outcomes in interdisciplinary educational experiences. It is important to note that many habits of mindfulness can have insights for interdisciplinary pedagogy, and the

categories below are not mutually exclusive, and do not necessarily have a linear relationship. In the following section, I highlight some of the main insights from mindfulness and explain how these insights can inform some key learning goals of interdisciplinary programs.

Table 1.1. People who practice mindfulness develop habits and skills that can help students develop skills desired as learning goals in interdisciplinary higher education programs.

People who practice mindfulness develop habits and skills for…	***…that can help students in interdisciplinary programs develop skills for…***
Simply noticing: Careful observation without judgment; self-awareness; metacognitive insight into oneself and others	**Metacognitive awareness**: self-awareness of cognitive processes; ability to manage own cognitive processes; reflection about self (knowledge, tendencies, biases)
Tolerance for ambiguity and complexity: sitting with whatever arises; willingness to face and accept threatening thoughts and emotions; tolerance for unpleasant states	**Tolerance for ambiguity**: comfort with complexity and paradox; embrace multiple view points; humility
Cognitive flexibility for taking multiple perspectives: recognizing and accepting different perspectives; non-attachment to any one perspective, object or situation	**Epistemological development**: evolution of epistemological beliefs; awareness of one's own beliefs, values and perspectives, and sensitivity to others'; ability to cope with problems
Cognitive flexibility to create novelty: drawing novel distinctions; making new connections; creating new categories; beginner's mind	**Complex systems thinking**: identifying relationships among components; understanding non-linear dynamics; gaining holistic knowledge of a system
	Higher order thinking: capacity for analysis, application and synthesis; drawing connections between disciplines and integrating insights
Quality of relationships and social interactions: healthy social relationships; strong personal connections; quality of communication; conflict management; compassion and empathy	**Collaboration**: coordination and teamwork; communication (active speaking and listening); conflict resolution

Simply noticing enhances metacognitive awareness. Although mindfulness can be practiced in many ways, a common practice of mindfulness is to sit in silence and simply notice whatever arises (Carson 2003). Mindfulness is a systematic process of self-observation and self-inquiry (Kabat-Zinn 1994). The essence of mindfulness is being in the present moment, or consciously and intentionally observing the activities of the mind and body, without judgment. Although we constantly categorize and label objects of our observation, such as *good* versus *bad* or *favorable* versus *unfavorable*, mindfulness practices challenge us to let

go of these reactive tendencies and simply observe our experiences in order to be in the present moment. Non-judgmental observation in mindfulness is about being open to things just as they are (Brady 2007) and remaining impartial or unbiased as we witness our own experiences (Kabat-Zinn 1994) in order to better understand them. Keeping an unbiased mind and an empirical stance toward reality for more accurate knowledge acquisition is both a benefit of mindfulness and a goal of objective scientific processes (Brown et al. 2007).

The essence of mindfulness - simply noticing – is a form of developing metacognitive awareness. Careful observation and noticing objects and our thoughts about them in mindfulness practices contribute to heightened self-awareness. Mindfulness practices allow us opportunities to more deeply understand our thoughts, to develop new relationships with them, and to use them more effectively (Brown et al. 2007). This same awareness of our own cognitive processes and ability to manage them are key elements of the metacognitive awareness desired for interdisciplinary learning and inquiry, as described above. Mindfulness techniques can help us reflect upon our cognitive and emotional processes and learn how to control them by reacting less to our observations and "sitting with whatever arises" (Chödrön 2001). These practices allow us to limit habitual or impulsive reactions to stimuli and instead use more of our minds (Hart 2004), thereby granting us greater access to knowledge, understanding and insight. Quiet observation of whatever arises in mindfulness practices also "fosters an attitude of equanimity toward all that occurs" (Burggraf and Grossenbacher 2007:2). As interdisciplinarians are constantly exposed to multiple epistemological and ontological orientations, cultivating a habit of seeing diverse perspectives with equanimity

could enhance our capacities for understanding, insight, and achieving the difficult goals of integration (Tart 1994).

Tolerance for ambiguity and complexity. Mindfulness helps increase our tolerance for ambiguity (Chödrön 2012), or increase our level of comfort with ambiguous situations or large amounts of information, some of which may be contradictory or paradoxical. The practice of sitting with whatever arises inside us, no matter how complex or uncomfortable, allows space for careful observation, intentional reflection, and potential for growth. This practice in staying present expands our tolerance and acceptance of challenging experiences, and makes us more willing to accept what emerges (Brown et al. 2007). Acceptance and willingness to see things as they are, rather than wishing or expecting things to be different, allows for development and change, rather than passive or apathetic resignation to information or situations (Kabat-Zinn 1994). While practicing mindfulness helps instill an appreciation for complexity and build tolerance for ambiguity, ambiguous situations, in turn, foster mindfulness as unfamiliarity of information and situations demands more processing (Ritchhart and Perkins 2000).

In studying complex systems, interdisciplinarians are often faced with processing overwhelming amounts of information about multiple system components, relationships among them, and nonlinear dynamics from multiple disciplinary and epistemological perspectives. Mindfulness practices can support interdisciplinarians by enhancing capacity to face complexity and ambiguity, which is key for embracing multiple perspectives with humility, understanding complex problems, and achieving interdisciplinary integration.

Learning to mindfully sift through ambiguity also helps learners shift from a passive to a more active role as they focus less on memorizing snippets and more on processing information for greater understanding (Ritchhart and Perkins 2000).

Insights about tolerance of ambiguity from experiences with mindfulness in interdisciplinary education have been reported. In their collaborative interdisciplinary work developing pedagogical strategies together as teachers and students, Friedow et al. (2012) found their interactions grappling with different disciplinary views unsettling at times. They learned how to "sit with the dissonance" and to allow their disciplinary constructions of themselves to dissolve. They emphasized that these challenges are key to interdisciplinary pedagogy and suggested, rather than trying to eliminate them, using them as opportunities to reflect on strategies that will help further learning. The lessons from these authors' reflections about their own experiences with interdisciplinary education highlight how learning to "sit with whatever arises" through mindfulness practices offers valuable insight for interdisciplinary learning and pedagogy. This practice of slowing down can help reach goals for metacognition by allowing the space for reflection and development. Burgett et al. (2011) described how their course goal of "slowing down" the research process, by making it more inductive and openly revealing implicit choices in the process, opens up space for critical appraisal and reflection. Slowing down to observe and reflect in this way is an example of how mindfulness practices can contribute to enhanced awareness of both self and others. Just as building a tolerance for ambiguity can contribute to metacognitive awareness, this skill also influences our ability to process information with cognitive flexibility.

Cognitive flexibility for taking multiple perspectives contributes to epistemological development. Heightened awareness and clarity when practicing mindfulness allows for enhanced cognitive flexibility, or more flexibility in our thoughts and thinking processes (Brown et al. 2007). One major aspect of cognitive flexibility is the ability to see multiple perspectives, rather than rigidly adhering to a single perspective (Carson and Langer 2006). The processes of self-observation and self-reflection in mindfulness practices contribute to cognitive flexibility by encouraging deconstruction of our own beliefs (Hart 2004) and fostering the capacity to see a phenomenon or situation from multiple perspectives rather than searching for one optimal perspective (Langer 1993).

Carson and Langer (2006) highlighted two key attributes of mindfulness: (1) the ability to view both objects and situations from multiple perspectives, and (2) the ability to shift perspectives depending upon context. This ability to identify, analyze and shift perspectives is an important part of epistemological development in interdisciplinary education. In interdisciplinary higher education we are challenged to recognize our disciplinary biases and develop flexibility to relax our disciplinary tendencies in order to allow novel interdisciplinary insights to emerge. When we stick rigidly to the epistemological orientations and insights of any one discipline, we limit ourselves to one particular way of observing and analyzing phenomena of study. However, when we truly open ourselves up to exploring multiple perspectives of people and disciplines, we heighten our capacities to contribute to novel discoveries and address complex problems in the world.

This type of cognitive flexibility to see things from different perspectives is also about zooming in and out. In mindfulness practices we develop flexibility to shift between zooming in to focus our attention on details and zooming out to observe what is taking place on a larger scale (Brown et al. 2007). This process of zooming in and out parallels the balance between taking reductionist and holist views of a system and the components relevant to its functioning in interdisciplinary studies. Different disciplines have different tendencies for inquiry and analysis of systems and their components, and epistemological development among students, and all practitioners of interdisciplinarity, includes being able to shift perspectives and zoom in and out. There is huge potential for using mindfulness in education to develop capacities for critical and creative thinking and deepen understanding by exploring and testing ideas from different perspectives (Ritchhart and Perkins 2000).

Cognitive flexibility to create novelty contributes to complex systems thinking and higher order thinking. A second major aspect of cognitive flexibility is the capacity to create or discover novelty. We interpret the world and our experiences by establishing limited conceptual categories and making often arbitrary distinctions among them, a process which is heavily reliant on habit and routine (Carson and Langer 2006). Mindfulness habits foster cognitive flexibility and release us from the trap of rigid thinking. Through involvement in the present moment, mindfulness promotes flexibility in the way we process information that allows us to constantly reorganize our conceptual categories, make novel distinctions, and create new categories (Carson and Langer 2006; Langer & Moldoveanu 2000; Ritchhart and Perkins 2000). As we become more perceptive of information from the environment and more open to new ways of making sense of information, we enhance our capacities to

incorporate multiple perspectives for analysis and problem solving (Langer & Moldoveanu 2000).

By enhancing cognitive flexibility in this way, mindfulness practices can contribute to the development of higher order thinking and complex systems thinking skills desired in interdisciplinary pedagogy. Higher order and complex systems thinking in interdisciplinarity are about synthesizing multiple pieces or sources of information in order to draw new connections and make novel knowledge discoveries. Achieving higher order thinking is a process of shifting from distracted learning to achieving outcomes that exhibit more focus, perception, integration and generalization (Biggs and Collis 1982). These stages of learning are closely aligned with the phases of engaging in a mindfulness practice, as one shifts from distracted mindlessness to calmly sitting with what ever arises, observing without judgment, understanding how one's mind works, and cultivating habits of a mindful life. Mindfulness offers a way to develop the flexibility in information processing for making novel distinctions and creating new categories that higher order thinking requires.

These skills are also paramount for identifying relationships and synthesizing information for holistic understanding in complex systems thinking. Understanding our non-linear habits of mind can offer profound insight for inquiry into the non-linear dynamics of a complex system. Iterative reinterpretation of multiple pieces of information is an important process in complex systems thinking, however, "when information and experience are processed mindlessly, the potential for reconsideration and reinterpretation is abandoned" (Carson and Langer 2006:30). Learning to skillfully play with new categories of information and

mindfully process information would be powerful for discovering interdisciplinary insights. In general, less rigidity and more flexibility in the way we think and process information would help achieve integration of disciplinary insights and novelty in the process of exploring potential solutions to the complex problems the world faces. Mindfulness practices in higher education foster increased levels of engagement in learning and social issues that can contribute to a more nuanced, creative understanding of topics studied and greater capacities for problem solving (Burggraf and Grossenbacher 2007).

By allowing ourselves to notice new things, practicing habits of mindfulness also helps us become more creative (Dhiman 2012). Creativity is a key component of drawing new connections, establishing new categories and achieving novelty in knowledge generation in scientific processes; however, creativity is most often not described as part of the scientific process or explicitly taught in the sciences (DeHaan 2009; 2011). Mindfulness practices can help foster creativity among learners (Burggraf and Grossenbacher 2007; Shapiro et al. 2011) by providing a safe space to play with cognitive flexibility and knowledge generation. Creativity is also cultivated by having a beginner's mind (Kabat-Zinn 1994), or having an attitude that we are seeing something for the first time, instead of assuming that our previous knowledge and experiences are sufficient for understanding. This beginner's mind allows us to see multiple perspectives, make novel distinctions, create new categories, identify new possibilities, and create novelty in analyzing complex systems. Just as our minds have a tendency to follow habitual patterns and stick to familiar routines, our well-engrained disciplinary tendencies heavily shape the way we engage in scientific inquiry processes. Mindfulness allows us to practice stepping outside of our familiar habits to actively explore

new territory (Ritchhart and Perkins 2000) with our minds open to discovering something new and unexpected. In this way, mindfulness practices have powerful insights to offer our development of interdisciplinary learning and scientific inquiry.

Quality of relationships and social interactions facilitates collaboration. All of the skills and habits that mindfulness practices help us develop as individuals can also have profound effects on our social relationships (Brown et al. 2007). One way this happens is through heightened emotional intelligence (Brown and Ryan 2003) that allows us to understand our emotional processes and use this understanding to manage our thoughts, emotions, and behaviors (Goleman 1995). Mindfulness can also reduce feelings of rejection in social interactions and instill a deeper sense of self, self-worth and self-acceptance (Carson and Langer 2006; Brown et al. 2007). Mindfulness also contributes to our relationships through improving the quality of our communication (Brown et al. 2007). Mindful observation helps us become more aware of our own communication styles, and interacting with others from a place of mindfulness helps us communicate more intentionally and clearly. This disposition of patience and acceptance enhances our ability to interact with people with a variety of communication styles and accept multiple perspectives. This provides us the space to reduce levels of reactivity and develop skills for managing conflict (Shapiro et al. 2011). Heightened awareness and understanding of self also allows for insight into others and improves the quality of our connections and feelings of interpersonal closeness (Brown et al. 2007; Kabat-Zinn 1993).

The overall quality of relationships and social interactions that mindfulness fosters would be great assets for interdisciplinary teams. Creativity on a team depends not only on the information or content at hand, but more so on team processes and comfort felt in communication and interactions. In addition, by paying close attention to ourselves and others, mindfulness contributes to our relationships in the world by fostering our ability to understand and share in other's feelings or develop empathy (Brown et al. 2007; Roeser and Peck 2009; Shapiro et al. 2011). In order to contribute to critical thinking about and potential solutions for the complex problems the global society faces, higher education needs to help prepare students to be knowledgeable citizens with critical thinking skills, but also with a great sense of empathy and compassion (Mahani 2012).

Potential benefits of mindfulness in interdisciplinary higher education

Learning to be in the present moment does not happen magically (Kabat-Zinn 1994). Developing mindful habits requires a lot of time and energy equal to developing interdisciplinary skills. This close alignment of the habits and skills of people who practice mindfulness to the learning goals of interdisciplinary programs provides clear evidence that mindfulness practices can offer many insights for interdisciplinary education and the development and maintenance of interdisciplinary teams. Given the far-reaching benefits of mindfulness practices for individuals and social interactions, mindfulness has been considered a potential pathway to solving social problems. "Mindlessness can show up as the direct cause of human error in complex situations, of prejudice, and stereotyping, and of the sensation of alternating between anxiety and boredom that characterizes many lives" (Langer and Moldoveanu 2000:6). Given that the primary purpose of interdisciplinarity is to

contribute to studying and solving complex problems we face as a society, we should pay more attention to the insights from the study and practice of mindfulness to achieve goals for interdisciplinary learning and practice. If we are not fully present for the moments that make up our lives, we may fail to reach our potentials for growth and transformation (Kabat-Zinn 1994). Mindful practice in our research, teaching and learning can allow us the opportunity for drawing truly novel connections and achieving compassionate interdisciplinarity and integration.

The potential benefits of mindful habits of practice in educational and learning processes are promising, and there is a growing movement of using contemplation practices in education (Shapiro et al. 2011) and specifically higher education (Altobello 2007; Burggraf and Grossenbacher 2007). Contemplative pedagogy cultivates mindful awareness and insight by emphasizing values of learning, personal growth, moral living, and compassion (Hart 2004; Roeser and Peck 2009). There is great potential for using mindfulness in education to develop capacities for critical and creative thinking, deepen understanding by exploring and testing ideas from different perspectives, and to enhance student motivation for self-directed learning (Ritchhart and Perkins 2000). Mindfulness is a powerful tool for reflective teaching as well (Tremmel 1993). Despite this growing evidence for the potential benefits of mindfulness in learning and critical thinking, college course catalogs and syllabi give little, if any, attention to these principles of contemplation (Altobello 2007).

Just as mindfulness offers a practical way to develop metacognitive awareness of oneself and insight into other, improvisation is an interactive, experiential method to practice

mindfulness in groups. In the following section, I briefly describe the basic rules and practice of improvisation and how they connect to the development of interdisciplinary skills.

Insights from improvisation

What is improvisation?

Improvisation is spontaneity, communication, creativity, and creation. We naturally improvise every day of our lives in making do with what we have or adjusting to what is around us (Hodgson and Richards 1979). In performance art, improvisation occurs without a preset script (Sawyer 2004). As every action and response happens spontaneously with very little time for planning (Hodgson and Richards 1979), responding in improvisation is about being open, receptive and willing. The main rule is "Yes, and…", meaning that for every gesture offered, participants express willingness to engage by accepting the offer and, in turn, adding something new for others to accept (Sawyer 2006). Improvisation is a creative process that allows us to make discoveries about ourselves, others, and the world through attentive communication (Hodgson and Richards 1979). These discoveries are novel creations, as outcomes are not predetermined, cannot be predicted, and often cannot be replicated (Sawyer 2004). As members of an improvisational group or team play off of each other and inspire each other to think of new ideas, novel creations emerge that are unique from what any one member of the group could have created on their own (Sawyer 2006).

Although we have natural abilities to improvise, improvisation is a conversational skill that can be taught and practiced intentionally (Sawyer 2001). Improvisation as a habit and art form can be practiced through many formats, most of which are fundamentally collaborative

(Sawyer 2000). Common art forms include music (i.e., jazz), theater, comedy, and dance. The most innovative companies of the business world also use improvisation to stimulate creativity and ingenuity (Sawyer 2006). Improvisation can also be a powerful tool for teaching and learning by fostering critical thinking and creativity through a collaborative discovery process (Berk and Trieber 2009; Sawyer 2003; Sawyer 2004; Spolin 1999). Improvisation practices offer profound insights for education where learning is a process of co-construction of knowledge among teachers and students (Sawyer 2004) and teachers take on the role of improvising facilitators of this collective learning process. Although there are examples of improvisation being used in education, there is much need for more development in this area (Berk and Trieber 2009; Inam 2010; Kelly et al. 2000; Sawyer 2004). Here, I explore improvisation as a powerful and productive pedagogical strategy for interdisciplinary education.

Skills built through improvisation practices overlap with interdisciplinary learning goals. Improvisation allows individuals and groups the opportunity to develop skills that can contribute to development of the skills desired as learning outcomes of interdisciplinary higher education programs. This alignment of skills is presented in Table 1.2. Principles of improvisation and exercises can be used in educational settings to foster creativity and reflection among team members. There are hundreds of games and developmentally staged activities that allow participants to experience collaborative exploration and creation through improvisation (Spolin 1999). Several examples of improvisation activities, drawing from dance, theater and other improvised performance arts, will be described in curriculum we are developing for our proposed pedagogical strategy.

Table 1.2. Practicing improvisation helps individuals and groups develop skills that can help students develop skills desired as learning goals in interdisciplinary higher education programs.

Practicing improvisation helps individuals and groups develop skills for…	***…that can help students in interdisciplinary programs develop skills for…***
Problem-solving: "Yes, and…" attitude; creativity; innovation and novelty; focusing on process more than product; unstructured conversation; no *right* way	**Complex systems thinking and higher order thinking**: identifying relationships and dynamics; gaining holistic knowledge of a system; drawing connections and integrating insights; ability to cope with problems
Embracing ambiguity: playing the game; embracing the unknown and unexpected; giving and receiving constant feedback	**Tolerance for ambiguity**: comfort with complexity and paradox; embracing multiple view points; humility
Awareness and understanding of self and others: active listening and responding; observation without judgment; acceptance of multiple perspectives; collective reflection	**Metacognitive awareness and epistemological development**: reflection about self (knowledge, tendencies, biases); awareness of one's own beliefs, values and perspectives, and sensitivity to others'
Collaboration: collective leadership; relational pedagogy; healthy communication; trust and respect; conflict resolution; empathy and compassion	**Collaboration**: coordination and teamwork; communication (active speaking and listening); conflict resolution

Problem solving, innovation and creativity contribute to complex systems thinking and higher order thinking. Improvisation is a collaborative problem-solving experience (Spolin 1999). Improvisation games present scenarios for participants to interact in as problems to address collectively. As there is no *right* way to solve any problem, problems in these games can be presented multiple times to make apparent the diversity of responses or ways of solving them (Spolin 1999). In improvisation and education alike, problems give focus and structure to the learning process (Spolin 1999). Improvising with a group is an experiential way of analyzing a complex system. Participants are components of the larger group system. As they pay close attention to each other in order to notice what each offers and how each responds to the offerings, interactions among components and whole system dynamics are created. The participants begin to see the system from different angles, and balance looking

closely at each component with awareness of the interactions among them and a holistic perspective of the whole system. By drawing connections, identifying relationships and understanding a system, improvisation, as both a practice and metaphor, offers insights for pedagogical strategies to help students interact with and analyze complex systems.

Improvisation also contributes to innovation and creativity, which are important for novelty and discoveries in science. The serendipitous discoveries that become possible with improvisation have also been described as powerful elements of the scientific process (Merton and Barber 2004). Unstructured group discussion in science education has shown to be effective for learning because it allows students to engage in collective knowledge creation together as a group (Sawyer 2006). Improvisation is like an unstructured conversation, where participants create their interactions spontaneously by listening carefully to themselves and others. This practice provides a process for innovation and creativity, as novel outcomes emerge from the interactions and exchanges of ideas and offerings (Sawyer 2007).

Although improvised creativity in many art forms is ephemeral and does not culminate in a permanent product (Sawyer 2000), the creative expression and inspiration of ideas that is the process of improvisation can contribute profoundly to educational outcomes. Just as John Dewey distinguished between the *product* of art from the *work* of art as an experience (Dewey 1934), the value of the learning experience should not be limited to the tangible products created. The process of exploration and discovery in interdisciplinary education is

an invaluable aspect of preparing professionals with skills to contribute meaningfully to complex problem solving as professionals.

Embracing ambiguity and the unexpected enhances tolerance for ambiguity. Just as no one knows the outcome of a game until one plays it (Spolin 1999), participants of improvisation do not know what is going to happen next. As everyone keeps playing the game they learn to embrace the ambiguity of the process and potential outcomes. In improvisation there are no right answers and this is the beauty of the creative discovery process. This is true for interdisciplinarians too, as there are no right answers to solve a complex problem, but there is beauty in the process of discovering possibilities when the ambiguity is embraced. Often it is hard for us as academics to fully embrace the complexity and ambiguity of not ever having *the* answer. Confronting ambiguity in multiple sources of information and interpretations in interdisciplinary education fosters maturity when students are encouraged to comfortably define themselves in the process (Baxter Magolda 2004). Improvisation practices can help us develop this comfort, and take a more playful and reflective stance toward embracing ambiguity.

Ambiguous situations often create anxiety and fear that we will fail to adequately understand or manage. Improvisation challenges us to embrace the possibilities of failure and embarrassment. Although children instinctively engage in improvisation together, it is often more difficult for adults. When we first start learning improvisation, we feel self-conscious and fear of embarrassment, but as we learn to concentrate and become more absorbed in the activity, we become more aware of ourselves and of others and less concerned with ourselves

(Hodgson and Richards 1979). In practicing interdisciplinarity it is easy to feel intimidated by not knowing enough about certain disciplines or inter-disciplines. Through improvisation practices we can learn to become less self-conscious by fully immersing ourselves in an ambiguous learning process for which outcomes are uncertain.

Another source of ambiguity in education is evaluation. Uncertainty about assessment of interdisciplinary integration is one potential source of anxiety among students (Burgett et al. 2011). In our experiences, this uncertainty has been due to not knowing which disciplinary insights will be expected to shine clearly and how *integration* of disciplinary insights will be judged. Two elements inherent to improvisation can help students learn to embrace the uncertainty and fear around evaluation. First, constant feedback from all participants and the collective group is a fundamental part of improvisation, as every reaction to an offering is a form of feedback for the one who offered it. As participants become comfortable with receiving and giving constant feedback, they can develop openness and receptivity to evaluation in other areas of their lives. Second, the constant evaluation in improvisation is co-constructed among all participants, including teachers, students, and often an audience. Although there are no *right* answers, what works to solve the problem at hand in an improvisation game becomes clear through collective agreement rather than rules or objective criteria (Spolin 1999). Improvisation offers a model for facilitating discussions about goals, processes, levels of achievement, and strategies for improving evaluation in interdisciplinary education.

Awareness and understanding of self and others contributes to metacognitive awareness and epistemological development. Improvisation is a process of interacting with others by balancing awareness of self with awareness of others (Peters 2009). Improvisation offers an explicit way to practice the mindful habits of concentration and observation while interacting with others, and a practical way to train ourselves to use all of our senses as a collaborative group (Hodgson and Richards 1979). Through exercising acceptance and willingness with "Yes, and…" responses, we learn to let go of preconceptions, withhold judgment and nurture acceptance of the different perspectives each member contributes to the group (Spolin 1999). Understanding and acceptance of multiple perspectives can then be used to create something new, as the unscripted nature of improvisation allows for unlimited and unbounded creativity, spontaneity, novelty and possibilities (Sawyer 2004; Spolin 1999). Collective reflection and discussion about these insights also offer huge opportunities for epistemological development and metacognitive awareness as learning becomes an inter-personal social process (Sawyer 2004).

Collaboration and collective leadership foster collaborative teamwork. Collaboration among participants is an essential part of the creative process in improvisation (Sawyer 2000). The process of interacting using the "Yes, and…" rule in improvisation makes the team process truly collaborative. Saying "yes" reflects attentive listening and acceptance of what team members offer, while saying "and" reflects willingness to contribute in return by building on others' ideas and offering something new (Berk and Trieber 2009). This rule for interaction helps group members learn to trust and respect each other and foster a sense of responsibility to participate fully in the collective process (Berk and Trieber 2009), all of which are

essential for healthy group functioning. Improvisation practices can contribute to the development of skills for engaging in collaborative teamwork in interdisciplinary learning and practice.

The ideas or actions that emerge from truly collaborative work depend on group dynamics and no one member of the group can control or predict them (Sawyer 2003). Improvisation fosters collaborative or collective leadership desired in personal and professional contexts to allow all participants to engage comfortably in discussions and contribute meaningfully to learning and discovery (Sawyer 2006). Improvisation also promotes a relational pedagogy where both teachers and students are learners, and the teachers' role is to provide the structure and environment for experiences to organically shape outcomes (Spolin 1999). When teachers relinquish their power as an authoritative figure with greater knowledge, and instead facilitate open-ended activities that embrace uncertainty, new opportunities for learning arise (Kelly et al. 2000). Both collaborative leadership and this type of teacher-student collaboration are called for in transformative and interdisciplinary education (Friedow et al. 2012; Holland 2004; Sawyer 2004; Schon 1983; Tremmel 1993).

Improvisation practices also foster healthy team dynamics through exercising skills in communication and flexibility. By being attentive to ourselves and others in improvisation we learn to communicate clearly, respond effectively and contribute positively to spontaneity and flow on a team (Hodgson and Richards 1979). We become patient in waiting to see what others will offer and nurture our own willingness to accept, understand and engage in what they do offer. Moreover, in facing a problem through an improvisation exercise, group

members learn to pay more attention to the problem itself than to the individuals trying to solve it (Spolin 1999). This is a practical example of focusing on an issue rather than an individual, which is a key concept for conflict management. Improvisation also contributes to the products that result from healthy team dynamics. While the process stimulates imagination and the creation of novelty (Hodgson and Richards 1979, Sawyer 2007), it also nurtures empathy and compassion that are so important for addressing the complex ethical issues we face in the world (Szostak 2013).

It is clear that improvisation offers participants opportunities to develop skills similar to those desired as learning outcomes of interdisciplinary higher education programs. Improvisation, as both a practice and metaphor, has incredibly powerful insight for creativity to share with participants, teachers and students alike, of interdisciplinary higher education (Sawyer 2004). As our own conceptual understandings of ourselves and the world is largely based on metaphors, teaching using metaphors, particularly rooted in experience, can provoke deep insight (Badley and Van Brummelen 2012; Lakoff and Johnson 1980). Improvisation offers a concrete, experiential way to learn about fundamental aspects of interdisciplinarity, practice mindfulness and collaboration, and engage in discussion about interdisciplinary team dynamics and development. Engaging in these deliberate, playful group activities can allow us to deeply experience creative collaboration and collectively reflect on how the lessons learned transfer to our academic, professional and personal endeavors.

Conclusions

The arts and practices of mindfulness and improvisation offer insights for interdisciplinary education and the functioning and maintenance of interdisciplinary teams. Both of these practices can contribute powerful insights to the development of the main skills desired as learning goals in interdisciplinary higher education programs – complex systems thinking, higher order thinking, tolerance for ambiguity, epistemological development, metacognitive awareness, and collaboration. While the principal focus of mindfulness is personal development, improvisation focuses on inter-personal relationships and is a way to practice mindfulness in a collaborative group. These areas of study and practice offer experiential, participatory, and problem-based exercises for educational settings. We are using the connections that we have discovered among the practices of mindfulness, improvisation, and interdisciplinary education to develop a practical pedagogical strategy to achieve widespread interdisciplinary learning goals in K-12 and higher education.

Based on literature reviews and our experiences so far, we believe that this type of a pedagogical strategy has the potential to foster deep learning, sincere reflection, epistemological sophistication, and true enjoyment of the learning process of interdisciplinary education. This orientation for developing interdisciplinary skills begins with mindful inward reflection that we can practice with others in improvised creativity to prepare ourselves to contribute meaningfully and intentionally to solving problems in the world around us. This approach could be particularly powerful for addressing environmental problems as they involve our common interest to take care of the environment that we all share and rely on for healthy sustenance of life on this planet, and both mindfulness and

improvisation practices emphasize the values of citizenship and community that are key to addressing environmental problems. Mitchell Thomashow (1996) encourages students of the environmental sciences to develop reflective and collective habits of "introspection for the purposes of ecological citizenship, personal awareness to promote common responsibility, [and] mindfulness to expand understanding of human/nature interactions" (170).

Most education and professional training is about outward searching and analysis, there is a growing recognition of the power of looking inward: "Indeed, sometimes as I read, the nagging suspicion grows that what really drives us forward is still the persistent hope that somewhere 'out there' is THE answer, THE formula, THE technology, THE research techniques that will solve all our problems and meet all our needs. Until we are seriously and equally willing to look within, I am afraid we will see little beyond what we have already seen" (Tremmel 1993:455). Through our own experiences and openness to learning from the insights others have to share with us, we have grown a sincere appreciation for the power of looking inward for intellectual and personal development. This chapter is a reflection of this development process. We have experienced much joy and inspiration in our inward journeys and we hope others enjoy their journeys too! We also hope that others will enjoy learning about these concepts, connections and potential applications in their own practices, and that they will use their experiences to contribute to ongoing research and development of engaging and effective pedagogical strategies for interdisciplinary education. Our combined efforts will contribute substantially to transforming learning and teaching experiences that are essential for improving our abilities to address the complex problems our world faces.

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CHAPTER 2

Using Attributes of Good Governance to Advance the Common Interest for Rural Drinking Water Management in Costa Rica

Abstract

Sustainability of drinking water resources is a growing global concern and most threats to these resources are more about governance than the resources themselves. Despite many improvements in recent decades, the quality and quantity of drinking water resources in rural Costa Rican communities face significant uncertainties and growing challenges. In addition, failure of current governance processes and resulting management practices to achieve goals of stakeholders in both rural communities and government agencies poses risks to drinking water resources. In this paper, I use problem orientation of the policy sciences to understand rural drinking water problems in Costa Rica. I then use the normative attributes of *good* governance from various bodies of literature as a lens to analyze multiple stakeholders' perspectives and identify alternatives to achieve desired outcomes for rural drinking water governance with a focus on serving the common interest. This case study provides a policy analysis for practical application in a specific context, and presents a generalizable method for analyzing problems in any governance context. This method relies on integrating a problem-oriented approach to policy analysis with multiple perspectives about attributes of *good* governance to reveal potential opportunities to improve governance in the common interest and achieve policy goals.

Introduction

Approximately 80% of the global population faces serious threats to water security (Vörösmarty et al. 2010), indicating widespread risks to the availability and acceptability of both the quantity and quality of water required to sustain public health, livelihoods, and ecosystems (Grey and Sadoff 2007). Global drinking water coverage reached 89% in 2012, meeting Millennium Development Goals (United Nations 2013); however, it is well documented that the poorest and least powerful members of society are the ones who lack access to clean drinking water (WHO/UNICEF 2014). Deterioration of water quality is a serious problem in most countries of the world, and the magnitudes and extent of water quality problems are largely unknown (Biswas et al. 2006). While consistent access to potable drinking water is essential for public health and sustainable social and economic development, few countries globally have reliable data about the quality and quantity of their water resources (World Water Assessment Programme 2009).

The Latin America and Caribbean region has made substantial advances in the last fifteen years, reaching drinking water coverage of 96%, the highest among developing regions (WHO/UNICEF 2014). However, disparities continue to leave low-income and rural populations disproportionately affected by poor quality of water services, with 72% coverage in rural areas of Latin America (Journalev 2004; WHO/UNICEF 2014). These same situations are observed in Central America where poor water quality remains an issue, particularly in rural areas (Ballestero and Reyes 2006). Although Costa Rica has made substantial progress in recent decades by increasing national coverage of drinking water to 98%, the country continues to face disparities in drinking water quality for rural populations

(Cunha Marques 2010; Madrigal-Ballestero et al 2013), as only 70% of rural drinking water meets national standards for potable water (National Water Laboratory 2010).

The water resource problems the world faces are much more about governance challenges than the resource base itself (Bakker 2008; Cosgrove and Rijsberman 2000; Pahl-Wostl and Ross 2010; Rogers and Hall 2003). Water governance is defined as "the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" (Rogers and Hall 2003:7). Water governance processes occur through the larger social system, and involve multiple actors and levels of authority in different sectors (Parkes et al 2010). Water governance is particularly complex due to the multiplicity of management actors and jurisdictions, fragmentation among institutions, physical nature of water connecting various elements across a landscape, and multiple scales of influence on the hydrologic cycle (Knuppe and Pahl-Wostl 2011).

Challenges related to the governance of water resources occur throughout Latin America. Regional experts have emphasized the need to address the lack of political attention and priority given to water quality management in this region and recommend strengthening and restructuring institutions, promoting the watershed as the appropriate scale of management, and increasing financial investments in the water sector (Biswas et. al. 2006). One response to the urban-rural disparities and lack of quality service provision in rural areas throughout the region has been decentralization of drinking water resource management and service provision (Akhmouch 2012). The Economic Commission for Latin America and the

Caribbean (ECLAC) has recognized deficiencies of decentralization policies, especially where it occurs without critical analysis of capacities and resources available at the local level (Solanes and Jouravlev 2006).

Costa Rica has an established policy for decentralized rural drinking water management. This policy names the National Institute for Water and Sanitation (ICAA in Spanish) as the governing body of community-based drinking water organizations (CBDWO) who are responsible for administration of service provision (Costa Rica Government 2005a). The existing 1500 CBDWO provide water to rural communities amounting to approximately one-third of the national population (National Water Laboratory 2010). In addition to ICAA and CBDWO, the Ministry of Health (MINSA) and Ministry of Environment and Energy (MINAE) also have formal roles in the supervision and regulation of drinking water quality and quantity (Ballestero and Reyes 2006). However, overlapping institutional roles and responsibilities have led to low levels of enforcement and accountability of agencies involved in the regulation of the water sector and protection of water resources (Ballestero and Reyes 2006). Costa Rica faces challenges with this decentralized drinking water governance system, particularly due to lack of technical and financial capacities in the sector, and processes for collaboration among institutions involved in drinking water service provision (Akhmouch 2012).

Findings from exploratory research leading up to this study indicated uncertainty about the quality, quantity and sustainability of rural drinking water resources in Costa Rica, and revealed that CBDWO and government agency representatives often hold different

perspectives about existing policies and governance processes. However, there are no known studies involving multiple stakeholder perspectives or addressing discrepancies between national policy prescriptions and outcomes in rural communities. Therefore, the objectives of this study are to assess multiple stakeholder perspectives (from local, regional and national levels) about existing and desired rural water governance processes, and to foster dialogue about current challenges and opportunities for improvement. Three main research questions further guided this study:

1) How well are current rural water governance structures and processes meeting goals of national agencies and CBDWO?
2) What factors do multiple stakeholders identify as influencing whether and how well these goals are achieved?
3) What alternatives exist to strengthen attributes of *good* governance and achieve goals for rural water governance?

The aims of this paper are: (1) to present a policy analysis of rural drinking water governance for practical application in Costa Rica incorporating multiple stakeholder perspectives, and (2) to provide an example of using normative attributes of *good* governance as a lens to analyze governance problems in any context and reveal potential solutions to improve policy with a focus on serving the common interest. In this chapter, I use problem orientation from the policy sciences to guide analysis of the context of rural drinking water governance in Costa Rica. First, I examine multiple perspectives in this system to explain factors that are inhibiting the achievement of goals shared by multiple stakeholders. Then I use normative

attributes of *good* governance as a lens to identify alternatives to achieve desired outcomes for rural drinking water governance with a focus on serving the common interest.

Policy sciences and problem orientation

Although there has been a strong focus on the development of predictive models of policy analysis (Smith and Larimer 2009; Weible et al. 2011; Weible, Sabatier and McQueen 2009; Weimer and Vining 2011), many prominent scholars criticize these approaches for their lack of incorporating normative inquiry into policy evaluation (Fischer 2006; Hajer 2003). Policy analysis can be used as an applied social science, where knowledge, rather than being the goal itself, is pursued to help resolve problems faced by society (Hajer 2003) and shape the future to advance the common interest (Brunner et al. 2005). The policy sciences framework is one conceptual approach to study public policy by expanding and deepening understanding of complex policy processes, and assisting in working toward resolving societal problems in the common interest and with human dignity as the single moral goal (Clark 2002; Mattson and Clark 2011).

One key dimension of the policy sciences framework is problem orientation. The purpose of problem orientation is to analyze and understand a policy problem by clarifying and describing participants' goals, analyzing contextual conditions, projecting developments of current trends, and identifying and evaluating potential alternatives. Problem orientation helps clarify multiple stakeholders' goals, understand why they are or are not being achieved, and critically analyze possible solutions based on clear problem definition (Clark 2002). Another key element of the policy sciences is a focus on the *common interest*, or interests

shared widely among members of a community (Clark 2002) that "would benefit the community as a whole and be supported by most community members, *if they can find it*" (Brunner 2002:8). Without attempting to predict policy outcomes, this framework can be used to carry out a comprehensive analysis to inform decision-making and planning to advance the common interest.

There are several examples of using problem orientation of the policy sciences framework to analyze complex natural resource governance problems. Rutherford et al. (2009) used this framework to guide multi-stakeholder workshops for grizzly bear management in Canada and Richie et al. (2012) used problem orientation to offer follow up recommendations for stakeholders to advance the common interest. Problem orientation has been particularly useful in identifying opportunities to advance the common interest in contexts involving natural resource governance and indigenous groups such as the Shuar of the Ecuadorian Amazon and Yorta Yorta in Australia (Lynch et al 2013; Hammer 2013). This framework has also been used to describe emerging patterns of adaptive governance for natural resources management in the United States (Brunner 2010) and as a basis for analysis of community-based timber management in Mexico (Wilshusen 2009).

Attributes of good governance

The role of society in governance is emphasized in the definition as "a process whereby societies or organizations make their important decisions, determine whom they involve in the process and how they render account" (Graham et al. 2003:1). A transition from conceptualizing *government* to *governance* has occurred as a response to the limitations of

government alone to solve the pressing, complex problems societies face. This shift reflects a broadening and deepening of non-state activity in policy-making and implementation processes (Fish et al. 2010) and an understanding that multiple actors are central to decision making (Armitage and Plummer 2010). Water governance specifically has also witnessed this shift, which is particularly clear in decentralized systems. While water governance extends beyond the formal processes of government to civil society, the government remains a key player as the term implies a relationship between a society and its government (Parkes et al. 2010; Reed and Bruyneel 2010; Rogers and Hall 2003).

Although defining what constitutes *good* governance can be a difficult task, there appears to be some degree of universality among principles (Graham et al. 2003). Principles of *good* governance are based on normative assumptions about what types of processes are better suited for decision-making and planning, and emerge from both theoretical and empirical work. Natural resource literature is full of normative statements about what principles or attributes will lead to better governance processes and better procedural and resource outcomes. While this literature is much too vast for an exhaustive review, I compiled attributes that are generally advocated for in a review of academic and practitioner-oriented literature about governance of natural resources, and specifically water resources[1]. Figure 1.1 broadly summarizes five categories of attributes of *good* governance.

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[1] Andersson, Gibson and Lehoucq 2004; Andersson and Ostrom 2008; Armitage et al. 2007; Armitage 2008; Armitage and Plummer 2010; Ascher and Steelman 2010; Brunner et al. 2005; Brunner and Lynch 2010; Bunn et al. 2010; Clark 2002; Cunha Marques 2010; Dietz 2003; Dietz et al. 2003; Folke et al. 2005; Klijn and Edelenbos 2012; Knuppe and Pahl-Wostl 2011; Koontz et al. 2004; Lebel et al. 2006; Pangare et al. 2006; Parkes et al. 2010; Plummer and Armitage 2010; Reed and Bruyneel 2010; Scheberle 1997; Scholz and Stiftel 2005; Solanes and Jouravlev 2006; Steelman and Ascher 1997; Stern 2005; Susskind 2005; UNDP 1997; Walker et al. 2002

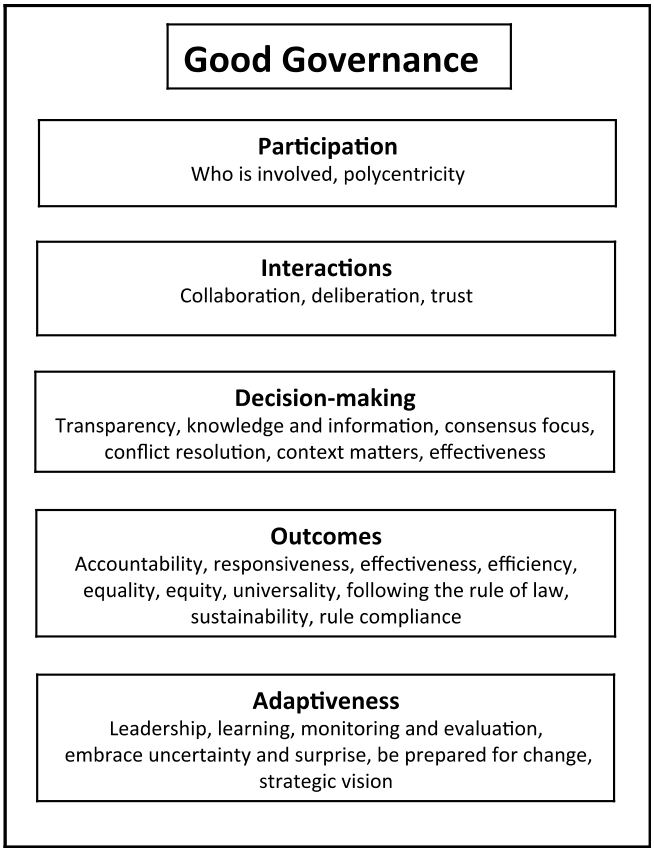

Figure 1.1 Attributes of *good* governance found in the literature, arranged into five main categories — participation, interactions, decision-making, outcomes, and adaptiveness.

These five categories of attributes of *good* governance represent the main themes that emerged through literature review, and they reflect my own systematic grouping of attributes. These categories are not mutually exclusive, but rather they are interconnected and influence each other. For example, while accountability is highlighted as an important attribute for outcomes, accountability is also important for decision-making processes, which shape outcomes. In addition, while trust is an important element for positive interactions, trust can be gained through many of the other attributes, and once gained can influence the development of other attributes.

Participation has to do with who is involved in governance processes and polycentricity, or the existence of multiple levels of authority in a governance system. Literature highlights that *good* governance processes involve multiple stakeholders and are inclusive, representative and open to any individual or group interested in participating (Cunha Marques 2010; Lebel et al. 2006; Steelman and Asher 1997; UNDP 1997). It is important that all participants (individuals or groups) have freedom of speech and a voice in decision-making so that different interests, perceptions and interpretations are considered in decision-making processes (Parkes et al 2010; Scholz and Stiftel 2005). Polycentricity means that institutional arrangements exist at multiple levels and multiple scales. Governance literature often promotes decentralization of decision-making where citizens are authorized to self-organize and self-govern, local institutions have rule making authority and policy integration proceeds from the bottom-up (Andersson, Gibson and Lehoucq 2004; Andersson and Ostrom 2008; Armitage et al. 2007; Armitage 2008; Armitage and Plummer 2010; Brunner et al. 2005; Brunner and Lynch 2010; Koontz et al. 2004; Lebel et al. 2006; Parkes et al. 2010; Reed and Bruyneel 2010; Steelman and Ascher 1997).

Interactions refer to the way in which participants interact with each other in governance processes, and include collaboration, communication, deliberation, trust and respect. Collaboration means that participants are networked, allowing for interactions among participants at different levels (e.g., national or local). Collaborative governance processes emphasize positive relationships and are interactive and integrative of people, perspectives and goals (Andersson and Ostrom 2008; Armitage 2008; Armitage and Plummer 2010; Brunner et al. 2005; Brunner and Lynch 2010; Koontz et al. 2004; Solanes and Jouravlev

2006). Governance literature promotes effective communication for exchange of information and ideas, and deliberative processes that facilitate open discussion, consideration of information in policy processes, and the potential for compromise (Armitage 2008; Bunn et al. 2010; Lebel et al. 2006; Solanes and Jouravlev 2006; Steelman and Ascher 1997; Stern 2005). Trust and respect foster social capital among participants in these interactions, and citizen trust and respect for politicians or authority figures is particularly important (Armitage 2008; Brunner et al. 2005; Folke et al. 2005; Scheberle 1997; Scholz and Stiftel 2005).

Decision-making as a category refers to *how* decisions are made throughout governance processes. Decision-making processes are considered to be *good* processes when the work that institutions carry out to arrive at decisions is transparent, or publicly accessible, clear and coherent (Cunha Marques 2010; Pangare et al. 2006; Scholz and Stiftel 2005; Solanes and Jouravlev 2006; UNDP 1997). *Good* processes also incorporate multiple types (facts and values) and sources (e.g. scientists, managers, policy makers, resource users, citizens) of knowledge in decision and policy-making (Ascher and Steelman 2010; Scholz and Stiftel 2005). Particular emphasis is placed on information being trustworthy and competent, transparent and clearly accessible to the public, and congruent with decision-makers' needs in terms of timing, content and format (Armitage 2008; Brunner et al. 2005; Dietz 2003; Dietz et al. 2003; Folke et al. 2005, Knuppe and Pahl-Wostl 2011, Pangare et al. 2006, Solanes and Jouravlev 2006; Steelman and Ascher 1997; UNDP 1997). *Good* decision-making processes focus on consensus among participants by making the primary goal identifying and advancing the common interest (Brunner et al. 2005; Dietz 2003; UNDP

1997). *Good* processes also use mechanisms to deal with power differences and to prevent and manage conflicts, such as mediation, arbitration, negotiation and deliberation (Cunha Marques 2010; Dietz et al. 2003; Steelman and Ascher 1997). It is important that all of these tools, processes and decisions are specific to the relevant context (Armitage 2008; Brunner et al. 2005; Brunner and Lynch 2010; UNDP 1997). All attributes of *good* decision-making processes should aim to produce decisions that are effective for meeting multiple needs and in a timely manner (Steelman and Ascher 1997; UNDP 1997).

Governance literature advocates for outcomes, or results of decision-making processes, that promote accountability, responsiveness, effectiveness, efficiency, equality, equity, universality, the rule of law, compliance, and sustainability. *Good* governance includes mechanisms for participants to hold each other accountable for institutional functioning, decision-making and following through to outcomes. Particular emphasis is placed on processes for the public to hold decision-makers and institutions accountable for their decisions and actions, and incentive structures to hold local politicians accountable in decentralized contexts (Andersson and Ostrom 2008; Armitage 2008; Clark 2002; Lebel et al. 2006; Pangare et al. 2006; Scholz and Stiftel 2005; Solanes and Jouravlev 2006; UNDP 1997). Outcomes are most effective when decisions and decision-making processes are viewed as legitimate, given that legitimacy reflects participants' willingness to accept and comply with decisions (Klijn and Edelenbos 2012). Effective policies have clear objectives for efficient use of resources to meet needs (Clark 2002; Dietz 2003; Pangare et al. 2006; Scholz and Stiftel 2005; Solanes and Jouravlev 2006; Steelman and Ascher 1997; UNDP 1997), and are non-discriminatory by granting equal access to benefits (Armitage 2008;

Cunha Marques 2010; Dietz 2003; Pangare et al. 2006; Scholz and Stiftel 2005; UNDP 1997). *Good* governance results in ethical legal frameworks that are impartially enforced (Lebel et al. 2006; Solanes and Jouravlev 2006; UNDP 1997), as legitimacy of enforcement processes and enforcers leads to greater compliance (Clark 2002; Dietz et al. 2003). Sustainability of outcomes refers to decisions, benefits, and resource use that are viable for the foreseeable future, and balances human and environmental well-being (Cunha Marques 2010; Dietz 2003; Scholz and Stiftel 2005; Solanes and Jouravlev 2006).

Adaptiveness in governance refers to institutional capacity to respond to changes by embracing flexibility, learning and responsiveness in iterative decision-making, implementation and evaluation processes (Brunner et al. 2005; Plummer and Armitage 2010; Scholz and Stiftel 2005; Susskind 2005; Walker et al. 2002). Adaptiveness includes leadership, learning, monitoring and evaluation, embracing uncertainty and surprise, being prepared for change and developing a strategic vision. Adaptive capacity is built through *good* governance processes that develop leadership among participants extending well beyond authoritative decision-making (Armitage 2008; Brunner et al. 2005; Folke et al. 2005; Solanes and Jouravlev 2006). Adaptive capacity is enhanced when social and individual learning occurs through collaboration and sharing knowledge about science, facts, values, and a diversity of interests and perspectives (Armitage 2008; Armitage and Plummer 2010; Dietz 2003; Folke et al. 2005; Scholz and Stiftel 2005; Walker et al. 2002). Monitoring and evaluation of policy implementation and outcomes that continuously influence management actions are also key for adaptiveness (Armitage and Plummer 2010; Brunner et al. 2005; Bunn et al. 2010; Cunha Marques 2010; Pangare et al. 2006; Scholz and Stiftel

2005). Flexible institutions designed for ongoing knowledge acquisition allow them to embrace uncertainty and develop adaptive capacity (Armitage and Plummer 2010; Brunner et al 2005; Bunn et al. 2010; Dietz et al. 2003; Steelman and Ascher 1997). Developing a strategic vision is a means to incorporate aspects of adaptiveness by forming a broad and long-term perspective on *good* governance, and building understanding of the historical, cultural and social complexities in which that perspective is grounded (UNDP 1997).

The attributes of *good* governance shape the way goals are met in society. The participants in a governance process and how they interact with each other to make decisions determines what outcomes will be seen over short- and long-terms. These attributes are discussed and promoted throughout environmental governance literature as a normative description of what governance processes should ideally achieve. However, perfect governance does not exist (Andersson and Ostrom 2008). Although too much focus on normative principles could appear as promotion of a recipe for *good* governance (Armitage 2008), they are not meant to be a panacea. Attributes of *good* governance are a useful lens to address governance challenges in specific cases and to design systems for governance carefully for and within a specific context (Graham et al. 2003).

Methods

Study region

Costa Rica is a Central American country with a total 2011 population of 4,301,712 inhabitants (National Institute of Statistics and Census 2011), of which 64% live in urban areas and 36% in rural areas (United Nations 2010). The country is territorially divided into 7

provinces, 81 cantons and 470 districts; within each district are multiple communities (Bixby 2002; Costa Rica Government 2009). This study was carried out in the Turrialba, Jiménez and Orosi Cantons of the Cartago Province, referred to here as the Turrialba region. The study region lies within the Reventazón watershed, which contributes 11% of the nation's agricultural exports and 38% of national hydroelectric energy production (Catano et al. 2009). While the Reventazón supplies 25% of the drinking water to the metropolitan region of San Jose, it is also the second most contaminated watershed in the country, as it receives large amounts of untreated wastewater from San Jose (Marchena 2009).

The current study was designed based on exploratory research carried out between May-July 2011 about rural drinking water governance in the study region. This research included twenty-five semi-structured interviews (with CBDWO representatives, government agency representatives, regional conservation groups, and scientists), eleven field site visits to springs and drinking water systems in rural communities, and document review. Findings from this exploratory research phase highlighted: (1) disparities among CBDWO effectiveness in providing services, (2) uncertainty about the quality, quantity and sustainability of rural drinking water resources in this region, and (3) different perspectives about current policies and governance processes among stakeholders from CBDWO and government agencies.

Study design: participants, sampling and data collection

Study participants were CBDWO representatives at the local level and government agency representatives at regional and national levels. Purposive snowball sampling (Creswell 2003;

Lofland et al. 2006) was used to identify relevant stakeholders at local, regional and national levels. CBDWO representatives were identified through a database of existing CBDWO in the study region, including both formal associations (Asociaciones de Acueductos y Alcantarillados Rurales, or ASADAS in Spanish) and informal committees (Comités de Acueductos Rurales, or CAAR in Spanish). Regional government agency representatives were contacted directly and asked to provide the names of agency representatives at regional and national levels working in areas relevant for rural drinking water governance. Data were collected between February 2012 and May 2013 using semi-structured interviews.

A total of 37 interviews were conducted- 18 interviews with 13 different CBDWO in the study region, 13 interviews with government agency representatives (7 at the national level and 6 at the regional level), and 6 interviews with non-government professionals. Local level CBDWO interview participants included current and past board members and administrators. Representatives of government agencies involved in development and implementation of policy related to rural drinking water, both nationally and in the study region, were interviewed, including the following agencies: National Institute of Water and Sanitation (ICAA), Ministry of Environment and Energy (MINAE), Ministry of Health (MINSA), and the National Service for Ground Water, Irrigation and Drainage (SENARA), and the Commission for the Protection of the Reventazón Watershed (COMCURE). Professionals included representatives from non-government organizations, foundations, private businesses and academic institutions whose work is related to rural drinking water governance. All interviews were conducted in person, for 1-2 hours, and in Spanish.

Semi-structured interviews included primarily open-ended questions, and were conducted as directed conversations with research participants (Lofland et al. 2006). This type of intensive interviewing allows for an in-depth exploration of the participants' interpretations of their own experiences (Charmaz 2006). The main purpose of these interviews was to assess multiple stakeholder perspectives about: (1) trends and conditions related to drinking water resources and service provision, and (2) current and desired rural water governance processes. The interview guide (see Appendix A) was written with focus questions and potential probing questions for a larger study on drinking water, wastewater and river health. Although these interviews comprise the data used for analysis in this manuscript, data collected through an additional 24 interviews, 5 facilitated workshops, and eight months of fieldwork carried out over 3 years on the topics of rural development and water governance contributed significantly to my contextual understanding for this study and policy analysis.

All participants provided verbal consent to participate in this research and permission for audio recording of interviews. This research was approved by the Institutional Review Board of the University of Idaho's Office of Research Assurances (Appendix B).

Data analysis

I utilized a grounded theory method, a systematic yet flexible approach to data analysis (Charmaz 2006). Audio recordings of interviews were transcribed and then coded using the ATLAS.ti 7 software program. Coding was carried out using a general notice-collect-think model (Friese 2012) in an inductive process. Initial coding was used to identify and define categories by assigning descriptive codes based on sensitizing concepts (i.e., initial ideas for

conceptual framework development), then more focused coding was used to explain categories by assigning analytic and conceptual codes for theoretical integration of categories (Charmaz 2006; Patton 2002). Findings from the exploratory research phase, elements of the policy sciences framework, and normative attributes of *good* governance in Figure 1.1 were used as sensitizing concepts. I used emergent themes to construct *theory*, or my description, explanation and interpretation of this particular context (Charmaz 2006), resulting in this policy analysis grounded in the data and my interpretations of it. To honor the complexity of qualitative data analysis, I would like to highlight that "no abstract processes of analysis, no matter how eloquently named and described, can substitute for the skill, knowledge, experience, creativity, diligence and work of the qualitative analyst" (Patton 2002). Coding and analysis processes were carried out in the Spanish language, and only direct quotations were translated for use in this manuscript.

Findings and interpretations

In the following sections, I present findings and interpretations using the steps of problem orientation from the policy sciences- goals, trends and conditions, projections, and alternatives.

Goals

The first step in problem orientation is to identify the goals or preferred outcomes of stakeholders relevant to the problem context at hand. CBDWO and government agencies, the main stakeholder groups involved in the rural water sector, expressed the same principal goals for governance of drinking water resources (Table 2.1). The primary goal identified by

both CBDWO and agency representatives was that all rural citizens have consistent access to drinking water of sufficient quantity and quality. Both CBDWO and agency representatives emphasized the need for expanding adoption of conservation practices to ensure the sustainability of water resources in the present and future. While CBDWO were more focused on water quantity and availability, government agency representatives focused more on the importance of drinking water quality. Both CBDWO and agency representatives expressed preference for the current governance model for community-based drinking water management over alternative municipal or government control models and expressed a desire for strengthening CBDWO capacities. Representatives from both stakeholder groups also expressed the desire to see actors in the water sector working together to achieve their common goals.

Table 2.1. Summary of main goals for rural drinking water governance shared by CBDWO and government agency representatives.

Shared goals	Supporting quotations from interviews
Potable drinking water: consistent access, of adequate quantity and quality	The goal is to have a CBDWO at 100%, 100% water quality and quantity. That's our goal, to provide service of full quality and quantity. (CBDWO) It's sad to have a family without water, awful, it's terrible. So we don't want that for anyone, not for ourselves or for anyone who comes to live here. (CBDWO) I want to help the community so they always have access to potable water. (CBDWO) Our goal is for Costa Rica to be a place where we have sufficient water in quantity and quality. (Government Agency) Potable quality, which is only achieved with treatment. We should be a country with 100% potable water. (Government Agency)
Increased conservation practices: protect water quantity and quality for rural populations	We don't know how long our water will last, but we always have to think about the future…I'm worried about the water that is wasted because we have to think about the future. Water cannot be substituted for anything else. If the lights get cut off you can substitute a fire, but water cannot be substituted for anything else. So we have to take care of it. (CBDWO) Water is one of the greatest things we have and if we don't take care of it we will surely end up having huge problems. (CBDWO) We shouldn't waste water, one day they have to understand. (CBDWO) I hope people will one day have awareness that water has to be treated in some way. (Government Agency) The fear about water is a national priority, because remember that water is an essential element for life and people's health. If we don't' have good conditions water becomes contaminated, and if people have contaminated water health problems arise. (Government Agency)
Community-based management of drinking water	I think this is a good form for management because, for instance, if we as a committee are failing at something, the community has all the right to bring it to our attention. (CBDWO) The Turrialba Municipality doesn't have the capacity that we have in the community to manage water. I could say the same about ICAA… we are the ones who make sure the community has sufficient water. (CBDWO) The municipality cannot provide water to the whole region, so in a lot of places people prefer to form their committee and provide water in their community through a CBDWO. And there is a lot of interest in maintaining management this way through CBDWO. (Government Agency)
Work toward common goals	Our goal is to provide a service in quality and quantity. I think this is everyone's goal, what the government wants, and that we all support this same goal for water resources, that we all put our efforts toward the same goal, work toward the same thing. (CBDWO) We have to teach people that everyone has feelings, and we all have the same needs, we have to teach this culture…we don't need to see differences…we have to teach people that everyone here is fighting for the common well-being of everyone. (CBDWO) If only we could channel all of these efforts, not only of this institution, but everyone in the water sector, toward the same direction. (Government Agency)

Each of these stakeholder groups also expressed specific goals related to their institutional roles and responsibilities. CBDWO board members emphasized their motivations in contributing to the well-being of their communities and all members.

> We always have to consider the community. (CBDWO)
>
> I'm not benefitting myself from doing this. What I do is for the benefit of the entire community. (CBDWO)

While government agencies are also concerned for the well-being of citizens, their key goal is to ensure that CBDWO follow established laws and regulations regarding drinking water administration.

> What the board of directors mainly has to do is follow the rules and laws, follow the ICAA regulations. (CBDWO)
>
> What we want is for the associations [CBDWO] to understand the responsibilities that they have. (Government Agency)

Although these stakeholder groups have specific institutional goals, their expressed desire to work together to serve the common interest will be a valuable asset when identifying and implementing alternatives to achieve these common goals.

Trends and conditions

Once goals are clarified, the next step in problem orientation is to explore movement toward and away from the stated goals (i.e., trends) and factors that have been influencing this movement over time (i.e., conditions). Here I describe the dominant trends and conditions related to drinking water quality and quantity, protection zones, community-based management, and relationships between CBDWO and government agencies.

Drinking water quality

Many improvements in Costa Rica's drinking water sector have been observed in recent years. These include reaching national rates of 98% service coverage, 77% disinfection (i.e., chlorination), and 90% potability of drinking water (National Water Laboratory 2007; 2010). Government agencies recognize these positive advances in development and public health benefits. They also recognize the need to continue improving drinking water quality, particularly in the rural sector.

Although the rate of potability specifically in rural communities has increased, 28% of rural populations remain without potable water (National Water Laboratory 2007). CBDWO use chlorination as the mechanism to treat drinking water for contamination with bacteria and other potentially harmful pathogens. While ICAA has promoted the treatment of drinking water and donated chlorination systems to some CBDWO, many communities in the study region continue to rely on untreated drinking water. Moreover, national data on the rates of "potable" water among CBDWO are limited to the presence or absence of bacterial coliforms, and levels of heavily used agrochemicals are not monitored. While CBDWO express a lack of awareness about the existence of agrochemical testing, government agencies recognize the need to have a more holistic perspective of water quality that includes other potential contaminants of concern.

> In reality we haven't tested the water for agrochemicals. ICAA doesn't do this type of analysis and I don't know if they would do it if I asked, or if it is within the parameters of what they do test the water for, or if they can detect that kind of contamination. (CBDWO)

> We don't do analysis for agrochemicals. It is a very, very expensive and unusual test. I have never seen anyone in this region ask for this kind of test. (Government Agency)

> It's scary that we are realizing that water quality is not just about fecal coliforms. Right now we have some CBDWO that are drinking arsenic in their water, above the limits allowed according to the Potable Water Regulation, so there we have a lot of work to do. It's not simply a matter of eliminating coliforms, but also knowing the physical-chemical quality of the water that could eventually affect people's health. (Government Agency)

Low rates of drinking water treatment present public health concerns, and rural communities are vulnerable to drinking water contamination based on the infrequency of water quality monitoring. Water quality testing is required by law, and mandated testing frequency is dependent on population size of each community, ranging from twice a year for less than 2,000 people to once a month for greater than 100,000 people (Costa Rica Government 2005b). However, compliance and enforcement are limited, as most CBDWO in the study region report having their water tested once every six months to two years at best, principally due to limited financial resources to pay for tests. Moreover, given that water resources can be affected on the order of hours or days after a contamination event (American Water Works Association 2003), the frequency of water quality monitoring in this region is insufficient to detect and respond to potential public health concerns in a timely manner. In addition, as one government agency representative pointed out, current testing is unable to detect, let alone prevent, the long-term effects of potentially harmful water contaminants.

> If there is a contamination with fecal coliforms, it will likely give you diarrhea, all of a sudden, from one day to the next. But in the case of agrochemicals, like arsenic among other things, by the time you know it is giving you problems, there's nothing you can do about it. (Government Agency)

In spite of the infrequency of water quality monitoring and the absence of testing for widely used yet potentially harmful contaminants, many CBDWO report a high level of satisfaction with the quality of their drinking water. However, due to limitations in data about water quality, it is likely that reports of adequate water quality reflect a false sense of security among CBDWO about rural drinking water quality.

> They have never monitored water because it has always appeared to be clean. There are standards for water quality, but nobody enforces compliance. It is very likely that what we call potable water is not potable. (Non-government)

Government agency representatives also express perspectives that are likely overly optimistic about rural drinking water quality, in viewing the frequency of water quality analysis as adequate and dismissing the general need for drinking water treatment.

> In Turrialba and Jimenez I have never heard about health problems from water. Years ago there used to be a lot of illness because they didn't test water, but now people care about the quality of their water. People generally care about quality and that is why they do so many tests, and that is why they have improved the spring capture tanks and storage tanks, it's all for the quality of their water and the well-being of the population they serve…Tests didn't used to exist and that's why there used to be so much contamination. (Government Agency)

> Most CBDWO have potable water without the need for treatment, however, the rules of the OPS and OMS [Pan-American Health Organization and World Health Organization] require water purification, even if it is potable like our water, so we follow the international norms that aim to prevent or even further guarantee water quality. (Government Agency)

CBDWO and government agency representatives also expressed concern about land use practices, particularly agrochemical use and cattle grazing, which could negatively impact rural drinking water resources. These existing risks to drinking water sources on the landscape coupled with the lack of monitoring of drinking water quality leaves rural

communities highly vulnerable to compound risks to their health and well-being. As one agency representative points out:

> It doesn't matter if the country has a lot of water if it's contaminated, right. (Government Agency)

Drinking water quantity

Both government agencies and CBDWO in this region reported overall sufficient water quantity, but many CBDWO reported declining water availability during the dry season when decreased precipitation results in decreased spring flow (i.e., amount of water per unit of time available in the spring). Many CBDWO also reported declining water availability due to deforestation around springs. Although decreased spring flow after removal of trees from land immediately around a spring is reported as common knowledge in Costa Rica, there is limited empirical evidence for this process (Bruijnzeel 2004). Some CBDWO are also worried about their capacities to meet water demands of growing populations in the future and dry seasons becoming more extreme. One CBDWO representative expressed frustration that citizens have not cared enough to help prevent or fix the problem before it became so extreme.

> Personally I am very worried, very worried, because I live here and if one day we no longer have water, we would have to leave and we wouldn't have another option. And the dry season every year is stronger… we're already seeing a difficult situation since we don't have water here. We have problems now, and people have already seen that the problem is serious. I've been telling them that it's not a situation to play with, that we need to take it seriously or else we are going to remain without water. Because how is it possible that we don't have water here and we have to leave, and people haven't been interested in getting involved, they've stayed on the sidelines for a long time. And now that they see the problem, that our water supplies have decreased so much, now they are going around trying to see how we can recover what is almost lost. (CBDWO)

The level of concern about water quantity that CBDWO expressed is influenced by a lack of knowledge about current water supplies and uncertainty about future water supplies. Very few CBDWO in the region monitor water quantity or spring flow. Government agency representatives recognized the need for monitoring flow, but support for rural CBDWO to learn how to record and analyze flow data is limited to trainings offered by ICAA. The effectiveness of these trainings appears to be limited, as few CBDWO implement monitoring practices. Limited effectiveness of trainings could be due in part because they are offered annually at most, and carried out by presenting slides to large groups, without hands on demonstrations, and allotting very little time for questions and group discussion. One agency representative highlighted the need to monitor flow in the region, and the need to protect springs and other areas contributing to spring flow.

> We need to start monitoring flow… but first we need to protect the springs and the recharge zones. (Government Agency)

The location of recharge zones (i.e., areas of land that directly contribute to replenishing spring flow) is largely unknown. Costly hydrogeological studies would be needed to gain this knowledge. Both government agencies and CBDWO reiterated the need for knowledge of recharge zones contributing to springs. One study (Vásquez del Castillo 2008) has provided a few CBDWO in the study region preliminary information about where their recharge zones are located, although they lack funds to purchase this land as well as authority to enforce protection measures on others' land. Lack of knowledge about quantity of drinking water sources currently and for the future, coupled with limited protection measures, contribute to uncertainty about drinking water resources that sustain rural communities.

Protection zones

Protection zones have been established to increase both quality and quantity of drinking water. Two existing laws - the Water law (Costa Rica Government 1942) and Environmental law (Costa Rica Government 1995) - establish protection areas around springs with 200- and 100-meter radii, respectively. These laws prohibit agricultural activities and require forestation within these areas. Since both laws are valid, CBDWO are often confused about which area they should aim to respect. Moreover, these areas were established arbitrarily by policy makers and not based on scientific evidence (González Cueva 2011). In addition, these protection zones for springs are based on an assumption that forestation results in increased spring flow. Although widely believed to be true among citizens, CBDWO and government agencies in Costa Rica, there is limited scientific evidence to support this assumption about biophysical processes contributing to water resources (Bruijnzeel 2004). Both CBDWO and agency representatives express the importance of protecting the land directly around springs to ensure both water quantity and quality.

> We need a forested area that protects the springs with two objectives. One, to protect the spring so we have enough water. And the other essential objective is to prevent contamination. Because they are areas with cattle grazing so the second objective is protect the springs from microbes from the cattle getting into the water. That is the objective of having the areas covered. (CBDWO)

> For me the idea is to see the system completely restored, with the protection zones totally registered in the name of the CBDWO so this zone doesn't impose any risks. (CBDWO)

> They [CBDWO] have to acquire the land where their groundwater is, right…that these zones are protected and without human activity, whether industrial, agricultural or grazing, it should be eliminated. They should purchase and protect these areas to assure that there will be water in the future, for everyone. These are goals that are being achieved little by little and the communities and CBDWO are concerned about acquiring these lands. (Government Agency)

The 1942 water law also establishes that landowners do not own the water with their land, but that water is owned by the state and all citizens have a right to water. CBDWO are encouraged to sign a formal agreement with owners of land where springs are located to register the spring and surrounding land in the CBDWO's name, or to purchase land around springs when possible, in order to ensure CBDWO access to springs and respect for protection zones. While a few CBDWO have been able to purchase land around their springs to increase their certainty about protection of the spring itself, most rural CBDWO lack financial resources to purchase land.

Although these laws defining spring protection areas exist, there are many challenges to adequate enforcement. For example, the total area of a circle with radius of 100 or 200 meters amounts to approximately 3 - 12.5 hectares. The landscape of the study region is largely a matrix of private land with predominantly small landholders who typically own less than 3 hectares and depend on using this land for farming or raising cattle for their livelihoods. Enforcement of forestation for spring protection would have drastic effects on farmers' abilities to live off of their land. One CBDWO representative and land owner in the region explained that although necessary, these water protection measures place unrealistic expectations on land owners in the region without providing safety nets (e.g., government compensation or payments for ecosystem services) to support small landholders facing these tradeoffs between spring protection and agricultural income.

> I have an area of two hectares and I grow cilantro, lettuce, tomatoes when I can, and peppers too when I can, chayote, cucumber, and I have an area with bananas… I can't spray chemicals because the spring is right there… and if they tell me that I can't grow there then they leave me like this, with my arms crossed, because the spring is in the middle of the property… Imagine if they apply this law to me, they take

> everything away from me, everything, everything, and how would I maintain my family. (CBDWO)

The main enforcement mechanism for water resource protection is through formal complaints filed by citizens, and often CBDWO board members, who are aware of laws and looking out for the best interest of the community's drinking water resources. When a formal complaint is filed to report a landowner cutting down trees or spraying agrochemicals within a spring protection zone, the regional MINAE office is responsible for following up with enforcement and sanction processes. However, lack of financial and human resources faced by agencies in the study region and throughout the country limit their enforcement capacity. In addition, one agency representative explained that if a landowner facing penalty for breaking spring protection laws raises the argument that such laws are not based on scientific evidence, then all claims can be dropped. Despite existing protection measures, many CBDWO report problems with landowners in the region cutting down trees and planting crops within the protection zones established by law, resulting in concerns about drinking water quantity and quality for CBDWO.

> In this moment we are having problems with a man who recently bought a farm here…he got here and cut down everything, he cut down everything, to plant coffee…there is a small spring there and he cut everything. He said 'this farm is mine' and just cut it all. He knew he couldn't, but he says that he didn't know that he couldn't cut down the trees. Everyone knows that wherever there is a spring, you can't cut trees. (CBDWO)

> We are really affected by deforestation here, not everyone thinks about taking care of water, some people aren't interested. Personally, I have always fought for taking care of water, for taking care of the environment, for trying to get people to not waste water, but it's really hard, people often aren't interested. (CBDWO)

Thus, although existing laws determine that drinking water protection is focused on the area right around each spring, enforcement is limited. Moreover, the majority of the area in each

spring area is downslope from the spring and not likely influencing spring water, thereby limiting the expected effectiveness of focusing spring protection on these rings. Government agency and CBDWO representatives recognize that areas upslope from the spring that directly contribute to spring water (i.e., watersheds) and recharge zones, both of which are critical to protecting water quantity and quality, remain largely unprotected.

> We have had a hard time having a holistic vision for CBDWO. From the storage tank upslope, they still don't have it covered. Their focus is from the tank to the homes. A holistic vision has been hard for us to achieve, because CBDWO are dispersed around so many different places. (Government Agency)
>
> We've changed. We're not the same Costa Rica as twenty or thirty years ago when there were fewer people. The population has grown, and a lot of housing projects have been built on groundwater recharge zones… this has caused greater contamination of water resources, whether through filtration or runoff, so it's clear that now we can't just drink water anywhere we go. (Government Agency)
>
> The problem is that these springs are very deep, and they are not completely protected. (CBDWO)

A vision toward watershed scale management is made evident in the MINAE National Plan for water resources management (Costa Rica Government 2010) and a new water resource law with this vision was recently passed (Costa Rica Government 2014). However, watershed scale management has yet to be operationalized and implemented in Costa Rica. Many agency representatives emphasized the pressing need for a watershed vision to adequately protect water resources in country. This transition appears to be underway, although it is in its early stages.

Community-based management

Costa Rica has an established policy for decentralized drinking water service provision. National policy places the responsibility of providing rural drinking water services in the hands of rural communities themselves through the formation of CBDWOs (Costa Rica Government 2005a). Approximately 1,500 CBDWO exist throughout the country (Madrigal-Ballestero et. al. 2013). These include both formal associations (Asociaciones de Acueductos y Alcantarillados Rurales, or ASADAS in Spanish) established under the CBDWO regulation (Costa Rica Government 1995), as well as informal committees (Comités de Acueductos Rurales, or CAAR in Spanish) established prior to this regulation. The government promotes that these informal committees follow procedures to sign a legal agreement with ICAA to become formal CBDWO (Madrigal-Ballestero et al. 2013); however, there is evidence that this legal framework is not sufficient to improve CBDWO performance drinking water quality (Flores Noya 2009).

The successes of community-based management of rural drinking water can be largely attributed to the dedication of community volunteers. CBDWO are established by forming board of directors through a community-wide election. The only paid position in most CBDWO in the region is the plumber (*fontanero* in Spanish) who oversees the system infrastructure. Some CBDWO who have sufficient funds to hire an administrator to manage service provision and user fee collection. The CBDWO board members who make community-based drinking water management possible exhibited an incredible amount of dedication to their communities.

> All my life I have been dedicated to community leadership, all my life I have been positive, and I always say that if we are not positive we will never achieve anything. (CBDWO)

CBDWO representatives explained how strong leadership and relationships among board members is key for improving and maintaining drinking water systems.

> Luckily, we have a very good board of directors in this moment, and for the last two or three periods they have been very, very involved in maintenance, improving the tanks, we're improving little by little. We just finished lining the storage tanks with ceramic and putting fencing around the spring capture tanks. (CBDWO)

Although CBDWO volunteerism and dedication appears strong in many communities, participation in CBDWO decisions and actions among the larger community is often difficult to achieve. Many CBDWO expressed a desire to see more active involvement and dedication among community members.

> Most communities have the same serious problem we do, that nobody likes to participate. You invite them to a voting assembly and 50 of 200 show up. People don't like to collaborate, they don't like to show up…if we could only drag everyone to a meeting to see what it is that we do and what we need to do to improve things, this is what I always say, the general participation of people is missing. (CBDWO)

Despite low levels of community-wide participation in CBDWO affairs, awareness and concern for water issues has increased among citizens in recent decades. Many interviewees described a sort of cultural shift that has occurred among the general population over recent decades. Although considered a renewable resource historically, it is now widely accepted that water is a nonrenewable resource that must be conserved and protected. CBDWO and government agency representatives both viewed this as an important achievement for

increasing conservation practices and enhancing the sustainability of water resources in the country.

> A greater common interest in water has been sparked. (CBDWO)
>
> Years ago we were taught that water was a renewable resource…now it's a non-renewable resource and we are taught to take care of it. (CBDWO)
>
> In this country, back when I was studying, water was included in the renewable resources of this planet. Not anymore, now it has switched from a renewable to a non-renewable resource… a cultural change has occurred. (Government Agency)
>
> I think it is getting better, people are understanding that the resource is not only finite, but also that it is a resource that needs to be taken care of. (Government Agency)

Despite increased awareness for water issues, many CBDWO still expressed frustration about the lack of concern and action to conserve and protect water resources in their communities.

> As human beings we haven't understood that what we throw into the river we ourselves will drink in a few years. And it's pathetic when one works for the CBDWO to know that there is so much contamination, and when you try to talk about it with people they don't understand. Until the water is gone, they won't value it. (CBDWO)
>
> What one plants, one grows. If you plant tomato seeds, you pick tomatoes. If you plant potatoes, you pick potatoes. If you plant indifference for water, for not caring, we won't have water. (CBDWO)

Between the 1960s and 1990s the government invested heavily in construction of infrastructure for rural CBDWO (Madrigal-Ballestero et al. 2013). However, most CBDWO in the region reported challenges related to development and maintenance of system infrastructure. They also reported difficulties related to understanding laws, and maintaining bookkeeping and administrative documentation consistent with ICAA regulations.

> CBDWO need a lot of help, help with information, help with materials, legal help to keep documents up to date. They need new tanks and updated distribution systems too, a lot of pipes are seventy years old. (Government Agency)

The current governance system for rural drinking water was designed making ICAA the state level governing body of CBDWO who are responsible for administration of service provision (Costa Rica Government 2005a). Regional representatives of ICAA are assigned the main role of providing administrative support and supervision, while CBDWO are responsible for infrastructure development and maintenance. A few key laws are meant to contribute to the financial and administrative stability of CBDWO, including CBDWO signing a formal agreement with ICAA (Costa Rica Government 2005a), charging citizens the state-established rate for water services (Costa Rica Government 2005a), and installing meters to monitor household water consumption (Costa Rica Government 2008). However, many CBDWO in the study region have resisted implementing these policies in their communities. The source of this resistance is CBDWO failing to perceive that the benefits of compliance with laws outweigh the risks they take in their communities.

> They get scared, scared to follow the laws and regulations, because they want to avoid making enemies with the people in their communities. (Government Agency)

Table 2.2 presents the different perspectives held by CBDWO and agency representatives about the implementation of these laws that have been the source of much contention in this region in recent years.

Table 2.2. Different perspectives about the implementation of existing laws that influence CBDWO management and administration of drinking water resources.

Policy or law	CBDWO perspectives	Government agency perspectives
Formal agreement between ICAA and CBDWO	If you don't sign the agreement, it's bad, and you don't have any rights with ICAA, but you don't receive any benefits. People think that when we sign the agreement with ICAA we will be directly accountable to them. There are a lot of committees that haven't signed the agreement, that don't want to become ASADAS [formal CBDWO], because they say that it's like giving what belongs to the community to the government. This is not true, they don't take anything away from you, they simply delegate the management so we can work.	In Turrialba we have a lot of resistance to signing the agreement because they think that if they sign it, then ICAA can take the CBDWO away from them. That's what they think… CBDWO provide a public service, and public services belong to the state so one cannot escape the State's responsibility for the CBDWO. So we have to explain to them [CBDWO], nobody is going to take anything away from you, you are going to continue to manage the CBDWO, but there has to be formal documentation required by the government inspectors that shows that you are managing it. That's the agreement.
Water service fees charged by CBDWO	For the moment, the committee is saying that hopefully we aren't thinking about increasing fees. In the past we have considered increasing fees, even if only a little bit…but not now…it would be hard for some families, even with a small increase…people get angry when we talk about increasing fees. We haven't tried more due to the low income in this community, we are a totally rural community and the income is low. When the new President was elected, the fees being charged were not enough to do what needed to be done… what we were charging couldn't cover maintenance costs, so we decided to increase the fees to the legal level, and honestly this has helped us very much.	In Turrialba people don't want to pay the fees established by ARESEP, they absolutely don't want to. In many parts of the country they do, but in Turrialba this resistance is common… we have tried to enforce this because it is a law and we can't not respect it, but we can't force them to follow it…but without having sufficient financial resources they can't hire accountants…and they lack water treatment. There are a series of things about not charging the legal fees that make them very vulnerable. The problem is that CBDWO are poor businesses precisely because they don't charge what water is really worth, so they don't have resources available to invest in the system.
Installation of household meters	No, no meters here, because we have sufficient water, water isn't scarce here. In the dry season water is scarce, there's not enough. In reality, we aren't educated and we waste a lot of water, so with support from the CBDWO maybe in the future we will have to install meters, but people don't accept the idea yet. So we have to work little by little trying to make them see that, with support from ICAA, what's best for the community, and most importantly learn to teach ourselves to conserve this liquid. I tell people that it's not a bad idea, to improve a little bit how we use water, the liquid that gives us life. Because without water we are nothing. Because with meters if you waste it, you pay for it. Because water is very valuable.	We have a lot of laws in this country, it's a fantastic country with a whole lot of laws…but they aren't applied. I have been explaining to them [CBDWO] the importance of the meters policy because they waste a lot of water…but they don't want to talk about installing meters and being charged for the water they use.

Relationships between CBDWO and government agencies

A key role of government agencies is to ensure that citizens follow established rules and laws. However, CBDWO reluctance to implement the laws presented above is often in order to respect citizen resistance to increased government control and fear of losing local autonomy. This resistance could be a reflection of historical trends of limited government involvement in the rural water sector. For example, devolution of responsibility for drinking water management to CBDWO could be seen as giving communities more power and autonomy. However, the existing decentralization policy as an unfunded mandate (i.e., without a transfer of financial resources) could also be viewed as government failure to attend to the needs of the rural sector. Both CBDWO and government agencies recognized the lack of attention paid to the rural sector historically and currently.

> For many years the State hasn't cared about supplying potable drinking water, it's given less importance… just recently with this administration, water has begun to play an important role, and there has been a big boost for rural areas, at least now they are taking us into consideration. (Government Agency)
>
> ICAA works a little better in the urban zones, but they are lacking in the rural zones. (CBDWO)
>
> Maybe, maybe ICAA has reduced the attention they give to CBDWO in rural areas, they worsened a lot, but as of a couple of years ago they tried to improve their image, but ICAA deteriorated again, in the rural areas they have deteriorated too much. ICAA has neglected the rural areas… the advisers for rural areas haven't come back, the adviser is never here. (CBDWO)

CBDWO desire increased agency support for financial, technical, and capacity building. One CBDWO representative pointed out that even after signing the formal agreement with ICAA, they have not received agency support, reflecting that ICAA's main goal was to get them to sign the agreement, rather than offer support.

> ICAA doesn't help us with anything. We haven't received even five dollars from ICAA and after we became a formal CBDWO [by signing the formal agreement] they didn't even come, the ones who came here to meet with the community, they never came back, never again. They were coming here so we would sign the agreement. And we signed it and they never came back. (CBDWO)

Agency representatives recognized that CBDWO would like to see more agency presence in communities and admit that they need to improve their support for rural CBDWO.

> They ask us for more presence, for us to support them more. (Government Agency)

> We should have more presence… the institution needs to have more presence, we have to show up more often. (Government Agency)

And another agency representative acknowledged the lack of attention paid to CBDWO in small communities and highlighted the importance of supporting them in particular.

> Many CBDWO are very poor... for example there are CBDWO with twenty-four users and the majority are poor people, so it's hard for those CBDWO to improve their conditions, and ICAA doesn't support the CBDWO very much even though they are responsible. Most often CBDWO have to work alone trying to see how they can get resources and loans, and they have problems with materials and water distribution, and some people don't pay for their water or they pay very little. (Government Agency)

It is clear that government agencies want to help improve drinking water management in rural communities. While agency representatives emphasized the role of the State in strengthening political will and commitment to investing in the rural water sector, they also stressed the need for State support for agencies. One agency representative expressed frustration about having to constantly lobby for adequate State commitment to the water sector in general.

> The government should be more involved in this. I mean potable water should be one of the top priorities for the government. The first goal should be to establish the priority, but who is going to do it… none of the Executive Presidents in this institution have been able to achieve that the government sees water as a priority… as an institution we should be the voice, right, to say, hey, you are planning to build another freeway, but potable water needs investment, where are we going to get the resources? The institution doesn't have them… up until now water has not been a priority. It's our role to put it on the table and keep hammering, hammering and hammering about water, water, water. (Government Agency)

While agency representatives pointed out the consequences of the lack of attention paid to the rural sector historically, some claimed that the current rural drinking water situation is adequate. An overly optimistic perception of adequacy might hinder agencies from garnering the political will and commitment to investing in the rural water sector that they desire.

> Water in rural areas, I'd consider it pretty acceptable. Why? Because we have reached 97% of the population in the country… there are still five hundred communities without water, very small communities…the most important is that people have access to water in their homes… and access to water in rural areas is much higher than in other countries, and efforts have been huge, all that has been done with limited resources, I'm satisfied, there's a lot left to do, but I am satisfied with what has been done so far. (Government Agency)

> A high percentage of the population has water suitable for human consumption. At least in this region around Cartago we don't have problems like other regions… Up until now we have had considerably good, quality water and we haven't seen extreme situations that put the quality of the water in this region at risk. Currently there are certain elements are appearing in the water that could be damaging to health, but in other regions… the quality here is normal, good quality water, even though you can find coliforms in places without proper care, but this is relatively treatable, right, not like other types of contamination that are very dangerous. (Government Agency)

In addition, one agency representative's disappointment about not being able to hide potentially harmful consequences of drinking water contamination from an increasingly educated population reflects a lack of transparency and respect for CBDWO.

> The level of education among the population has increased, so now it is more difficult to keep hidden the problem of water quality. (Government Agency)

Government agency representatives' attitudes and actions influence their relationships with CBDWO. For example, the fact that government goals related to drinking water are unknown or unclear to CBDWO is likely contributing to CBDWO distrust and skepticism toward agencies.

> No, I haven't heard, well I don't know, I haven't heard myself that they [government] have any certain goals. (CBDWO)
>
> Honestly I can't tell you anything about [their goals] because I don't know what it is that they want. (CBDWO)
>
> About government goals, I do not, do not, do not, see… what vision they have for water… I ask myself what is the goal of the government of Costa Rica… I don't see it anywhere. (CBDWO)

Without a clear sense of government goals regarding water resources, it is hard to imagine rural citizens gaining trust for agencies. It is also difficult for agencies to build positive relationships based on trust without a consistent presence in communities. Government agencies reported lacking the financial and human resources necessary to maintain a constructive presence, develop positive relationships, and contribute substantively to development of infrastructure and governance in rural communities. With only one ICAA representative responsible for overseeing an entire region of 150-200 CBDWO, the agency's ability to fulfill their supportive role is compromised. With this limitation in human resources, it is difficult to maintain the consistent presence and level of attention desired by CBDWO and agency representatives. Moreover, when agency representatives do show up in a rural community, they are attempting to achieve their goals of increasing compliance with

laws and regulations on a very tight timeline and without offering much needed financial support. Several CBDWO representatives expressed frustration about the communication style of agency representatives. For example, one CBDWO representative explains that agency focus on legal discussions scare community members, and another explains how threats from agency representatives for not following ICAA regulations disregard the dedicated volunteer work that he does for his community and make him feel disrespected.

> In the meetings that they [ICAA] had with us, we got the town together with them, and they [ICAA] would only talk about the law, and since they would only talk about the law, you see, they scared everyone. And if someone from ICAA were here right now, I would say the same thing right in front of them. They scare people when they come here. (CBDWO)

> What they told me is this… you are vulnerable that in any moment, anyone can sue you and you can go to jail because you are not accepting to do things the way the law says they should be done. So I told them, ok, if I go to jail for something like that, I know that when the community finds out, they will come get me out because they won't leave me in there for even a day. I am working for my community, not for myself… So I would have to resign, and if I resign and leave everything abandoned, then we would really have problems because who is going to work for the CBDWO? But they scare me when they come threatening me, that if I don't do things like they tell me to, that I'm breaking the law, that I'm making myself vulnerable… so I tell them today I give them all the papers, because I don't want to work like this, being pressured. I want to help. I accepted because there wasn't anyone else to accept the position. From the first day that I took oath I told everyone at the assembly that I want to work for the CBDWO, so I am going to work for the community, not for me. I am going to do what I can to help the community and I truly feel satisfied with all that I have done, and I have done it all for my community. (CBDWO)

Feeling threatened by agency representatives contributes to distrust toward agencies. Some CBDWO have grown frustrated with feeling like agencies simply tell them what to do, but without offering the types of support they need. One CBDWO representative expressed a desire for agencies to show up in communities offering resources and support rather than

injecting fear, and reiterated that this approach would help instill confidence and trust among community members.

> *I would like ICAA to come to my community and get us all together to say, 'we have come to meet with you today to present some projects that we have for all of the CBDWO, including the rural CBDWO like you. And the project that we have is for you to improve your storage tanks and pipes, and the way we are going to do it is by starting to give you financial support.' This would make people trust ICAA, but no, they only come here to tell us 'with this you can't survive, you have to charge higher fees.' They just want to take advantage of the community. Imagine if they came to offer support, saying 'You need another storage tank. Here's our proposal, we will give you 70%...and you put 30%.' We aren't going to say no… But they don't come to cheer up the community, encouraging the community like this, ok, this has to improve, so ICAA comes to the communities to offer support, not fear. Up until now, I'm telling you how they come here, the people who work for ICAA come here and frighten the community. (CBDWO)*

Although well intentioned on the part of agencies, their communication style often results in increased animosity toward agencies instead of increased motivation to follow laws. In addition, these interactions leave agency representatives increasingly frustrated with seemingly unnecessary resistance among CBDWO. Whereas agencies prioritize enforcement and compliance with laws and regulations to improve rural drinking water, CBDWO perspectives reiterate the importance of communication style and relationships in achieving such goals.

Projections

The next step in problem orientation is to use understanding of trends and conditions to make projections about future trends and evaluate the likelihood that identified goals will be achieved (Clark 2002).

Many improvements to drinking water systems and community-based management have been observed in recent decades. However, dominant trends and conditions that emerged from this analysis illuminate existing uncertainty about the likelihood that certain goals shared by CBDWO and government agencies will be achieved. There are clear threats to the quantity and quality of potable water in these rural communities given the lack of information, monitoring systems and adequate protection measures. It is also clear that relationships between CBDWO and agency representatives undermine the adoption of laws and practices designed to support community-based management of drinking water. Based on these trends and conditions it is likely that CBDWO and government agencies will continue to face challenges in meeting these shared goals. Risk of failing to achieve goals for consistent access to sufficient and high quality drinking water increases the vulnerability of rural communities.

While CBDWO and government agency representatives share goals for rural drinking water governance, different perspectives about how to achieve such goals has led to increased perceived conflict and movement away from meeting common goals. One agency representative recognized this tension in spite of wanting the same thing.

> We have the same objective to improve water resource management in the communities, and if this is our objective, then why are we all pulling in different directions? (Government Agency)

Given that both CBDWO and government agency representatives emphasized the value of actors in the water sector working together to achieve common goals, there are clear opportunities to serve the common interest. This expressed desire to serve the common

interest will be a valuable asset when identifying and implementing alternatives to achieve these common goals.

Alternatives

The next step in problem orientation is to identify potential alternatives to address challenges and achieve goals. I used normative attributes of *good* governance as sensitizing concepts in the coding process to analyze multiple perspectives about rural water governance in this context. This analysis included identifying attributes of governance that exist, need more attention, and are desired by stakeholders in this context. Emergent themes revealed key attributes of governance that would contribute to moving toward achieving shared goals and four alternatives as strategies to strengthen these key attributes of governance (Table 2.3).

Table 2.3. Alternatives to strengthen key attribute of governance and move toward achieving shared goals.

Alternatives	**Key Attributes of Governance Strengthened**
1. Increase financial investment in the rural water sector	Policy responsiveness, Accountability
2. Develop a shared monitoring system for drinking water quantity and quality	Knowledge, Collaboration, Monitoring
3. Define spring protection areas by watershed	Policy responsiveness, Effectiveness
4. Improve the quality of interactions between CBDWO and agencies	Participation, Deliberation, Communication, Trust

Alternative 1: Increase financial investment in the rural water sector to strengthen policy responsiveness and accountability

Opportunities to increase financial investment in the rural water sector exist on behalf of national government, CBDWO and citizens. These opportunities would strengthen two key attributes of governance – responsiveness and accountability – in this system.

Community-based management of rural drinking water in Costa Rica has the advantage of transferring authority and power to local citizens who have the most knowledge and understanding of their resource systems (Andersson et al. 2004; Brunner et al. 2005; Ostrom et al. 1993; Wondolleck and Yaffee 2000). However, caution must be taken not to assume that decentralization of natural resource governance will inevitably result in greater democracy and efficiency (Andersson and Ostrom 2008; Armitage 2008; Ostrom et al. 2007; Reed and Bruyneel 2010). As the regulation establishing CBDWO (Costa Rica Government 2005a) does not include provision of funds for drinking water service administration, some view this decentralization policy as the government washing its hands of responsibility for the rural sector whose needs they were unable to meet through previously more centralized municipal provision of water services. Unfunded mandates – orders imposed upon local governments to carry out national policies without a transfer of financial resources – often reflect a lack of accountability on the part of the central government (Posner 1998). It has been recommended that central governments transfer sufficient and appropriate powers to local democratic institutions for successful decentralization of natural resource governance (Ribot 2002).

In interviews for this research, agencies emphasized the need to make rural water a national priority and advocate for greater political commitment to the rural water sector that translates into allocation of government funds to agencies to enhance support for CBDWO.

However, direct investment by the national government is not the only option for increasing financial investment in this sector. One agency representative interviewed proposed the creation of an investment fund to make credit more accessible and affordable for CBDWO.

> It would be ideal if they [CBDWO] had resources, an investment fund created by the CBDWO themselves, that they could get low interest loans from… that all CBDWO could access… and with strong regulations so it doesn't end up being like a piñata… it is possible to create and for everyone to contribute so they can access subsidized low interest loans. (Government Agency)

There is also a clear role for CBDWO to contribute to increasing financial investment in the rural water sector. Both CBDWO and agency representatives pointed out the need for CBDWO to operate formally like a business. This includes implementing adequate administrative practices, fulfilling legal requirements and maintaining a revenue stream in order to make necessary system improvements to guarantee high quality service provision.

A key component of CBDWO operating like a business and maintaining a necessary revenue stream is charging adequate fees for water service provision. Both agency and CBDWO representatives express a desire to strengthen CBDWO ability to implement legal rates by garnering citizen support for increased fees. Trends and conditions show that CBDWO representatives are often placed in difficult situations when making decisions about water service rates. These dedicated volunteers have to balance the need to increase user fees for

water services and pressure from agencies to do so, with the desire to respect citizen demands for cheap, affordable drinking water and maintain a positive reputation in their communities. The struggle for local institutions to collect sufficient fees has led to under-pricing of tap water and insufficient infrastructure and service provision in neighboring Nicaragua as well (Vásquez and Franceschi 2013). Increasing water service rates to nationally established levels is a viable, although somewhat contentious, option to increase investment in their own communities. There is a clear need for CBDWO to develop mechanisms to open healthy discussions within their communities in order to build awareness and support for this decision among rural citizens. It is possible that if citizens perceive that they are investing in their own communities, while reducing fear that the government could take it away from them, progress could be made on this front. Implementing higher rates will likely require carefully crafted educational opportunities at the local level (Vásquez and Franceschi 2013), and communities in the region who have achieved shifts in perspectives and increased rates could be instrumental in assisting the design and implementation of such strategies.

Increasing financial investment in the rural water sector is a viable alternative to improve rural drinking water governance by strengthening key attributes of responsiveness and accountability. As allocation of sufficient funds is essential for the effectiveness of a formal policy (Clark 2002), increased targeted government investment would make CBDWO policy decisions more responsive to meet needs of rural citizens. Such financial responsiveness would also allow agencies to better fulfill their commitments to CBDWO and rural citizens. This level of commitment from the government would, in turn, reflect clear objectives to rural citizens including CBDWO representatives. Trends and conditions revealed that

government goals related to water are often not clear to rural citizens, resulting in skepticism about national support for the rural water sector and a lack of trust in government to prioritize rural livelihoods. Adequate agency funding would also reflect a greater sense of government accountability by providing opportunities for CBDWO to hold agencies accountable for fulfilling their formally established roles and responsibilities. Ability to hold authorities accountable can contribute to social justice and a reduction in threats perceived when compliance with rules is enforced (Lebel et al. 2006). This in turn, would increase CBDWO accountability to providing high quality drinking water services in rural communities. Implementing these options for financial investment will also rely on attributes of governance related to interactions, as I will discuss below.

In addition to improving responsiveness and accountability, increasing financial investment in the rural water sector would also contribute to increasing self-sufficiency among CBDWO, and a reduced sense of paternalism or dependency. This might sound contradictory; however, government funding can reinforce an agency's ability to provide necessary support and promote desired local self-sufficiency. Both CBDWO and agency representatives are eager for strengthening of CBDWO capacities, and financial investment is one essential piece to achieve this. Available funds will also help with implementation of other identified alternatives and strengthening other attributes of governance.

Alternative 2: Develop a shared monitoring system for drinking water quantity and quality to strengthen knowledge, collaboration, and monitoring

Knowledge, collaboration, and monitoring have key roles in reducing uncertainty about drinking water resources and vulnerability of rural populations. One government agency representative clearly expressed the role of knowledge in reducing risk and vulnerability for rural populations.

> I think that more knowledge means less risk. Yes, that is clear, so it is better to know more. (Government Agency)

Knowledge about specific resources and the larger biophysical system is important for effective natural resource management (Dietz et al. 2003; Knuppe and Pahl-Wostl 2011). Specifically, effective groundwater governance requires collection of data on hydrogeologic processes, as well as open sharing of this information between scientists and managers (Mukherji and Shah 2005). Data about groundwater recharge zones, flow pathways and potential contamination pathways are needed in Costa Rica, but expensive hydrogeologic studies required to collect this information are largely lacking (Gentes and Madrigal 2009). While there are some examples of state investment in hydrogeological studies in Costa Rica, there is much room for expanding these efforts, particularly to benefit rural populations.

Knowledge about water quantity and quality, how these are affected by influencing factors on the landscape, and how they change over time, is critical for effective management of drinking water resources. For example, increasing the frequency and robustness of water quality testing and spring flow monitoring are needed in this context. A monitoring system to collect, analyze and share this type of information would reduce uncertainty and vulnerability

by creating an effective early warning system that would allow both CBDWO and agency representatives to make evidence-based decisions for prevention and mitigation of potentially harmful events (Lebel et al. 2006). While local level monitoring (i.e., carried out by CBDWO) would be more efficient for informing local actions than through a single centralized system (i.e., one regional agency), monitoring systems shared among local and regional or national actors would allow for necessary actions at multiple levels (Lebel et al. 2006). Monitoring data collected by CBDWO would provide important information about water quality and quantity at the local level, whereas currently ICAA reports such data as national averages of the rural sector. While these aggregated data allows observation of national trends, it does not allow for identifying problems and developing necessary solutions at the local level (Dietz et al. 2003). Shared monitoring systems that promote robust data collection and transparent information sharing are essential for effective governance of water resources (Bunn et al. 2010).

A shared monitoring system in this particular context could consist of water quality and quantity data collection by CBDWO, collaboration among regional CBDWO and between CBDWO and government agencies to share data and create a collective database. This type of a system integrating scientific, local and policy knowledge and promoting cross-scale collaboration would contribute to improving rural drinking water governance (Ascher et al. 2010). Vertical integration, or collaboration and knowledge sharing among actors at different levels of governance, is important for the sustainable, adaptive management of water resources (Knuppe and Pahl-Wostl 2011). While data collected locally and shared regionally would increase capacity for local responsiveness, it is also important that the central

government pay close attention to changes in key indicators (Ribot 2002). There is also a clear role for government agencies in creating rules and oversight mechanisms to promote collaborative leadership among local actors that contributes to this adaptive governance (Stiftel and Scholz 2005).

Collaboration may not be the goal of natural resource management per se, but it can be a tool to improve the effectiveness of management or governance (Wondolleck and Yafee 2000). There is much evidence that enhancing attributes of *good* governance such as knowledge and collaboration in this way would contribute to building understanding through information exchange, providing a mechanism for effective decision making across scales, and developing capacities of agencies and communities to deal with future challenges (Wondolleck and Yafee 2000). In developing a shared monitoring system, it is important to keep in mind that appropriate participation of local stakeholders and managers in the planning and decision-making processes is key for successful implementation of new monitoring tools (Knuppe and Pahl-Wostl 2011). Therefore, taking an inclusive, collaborative approach to planning and developing this shared monitoring system with stakeholders at local, regional, and national levels, is recommended.

Alternative 3: Define spring protection areas by watershed to strengthen policy responsiveness and effectiveness

Laws that define protection zones around springs in Costa Rica do not effectively protect watersheds and spring water resources. Most of the land within established protection zones (i.e., rings with 100-200 meter radius around springs) is not contributing to the spring water,

and areas of land (i.e., watersheds) contributing directly to the quality and quantity of drinking water remain largely unprotected. This type of mismatch between the scales of water resource management and biophysical provision on the landscape is widespread (Cash et al. 2006, Dore and Lebel 2010, Fremier et al. 2013, Moss and Newig 2010). In addition, trends and conditions display how inconsistent enforcement of these laws among small landholders is often perceived as unjust. Effective policies that respond to the needs of citizens are important for achieving societal goals and reflecting legitimacy (Pangare et al. 2006; Solanes and Jouravlev 2006; Klijn and Edelenbos 2012, Lasswell 1971). And policies that can be enforced fairly and impartially promote social justice and democratic ideals (Dietz et al. 2003; Lebel et al. 2006; UNDP 1997). Redefining spring protection areas with a watershed focus is an opportunity to promote *good* governance in this system by improving responsiveness and effectiveness of water resource policy.

Redefining spring protection areas as the watershed, or upslope area contributing to the spring, would shift the focus of CBDWO management actions to an area more likely to be affecting springs. Although changes in legislation most often require long-term processes, a mechanism to shift CBDWO management focus in the meanwhile could be devised by actors in this context. Development of a shared monitoring plan for CBDWO in collaboration with government agencies, as described above, could help achieve this shift and increase ability to identify factors that negatively influence spring water and to prevent and mitigate their impacts.

Redefining spring protection areas as watersheds would contribute to the continued development and promotion of watershed scale management for water resources in Costa Rica. A vision toward watershed scale management is made evident in the MINAE National Plan for water resources management (Costa Rica Government 2010) and a new water law with this vision was recently passed (Costa Rica Government 2014). This law is based on Integrated Water Resource Management (IWRM), an approach used globally to promote establishing the basin as the territorial unit for management (Pangare et al. 2006). Although watershed scale management has yet to be operationalized and implemented at the national level in Costa Rica, there are examples of efforts for watershed scale perspectives in the country (Marchena 2009; University of Costa Rica 2013). However, these efforts do not currently allow CBDWO to focus their management actions at the watersheds contributing to springs. There is clearly a role for CBDWO as active participants in the development and implementation of watershed management in Costa Rica, although this remains undefined. Redefining spring protection areas, together with establishing a shared monitoring system, could contribute substantially to this continued policy discussion in Costa Rica.

Alternative 4: Improve the quality of interactions between CBDWO and agency representatives to strengthen participation, deliberation, communication and trust

Effective policy is not guaranteed with a government structure and a formal legal framework developed within that structure. Effective governance is reliant upon the relationships among actors at local, municipal and national levels and these relationships are defined by the overall context in which institutions are embedded (Andersson and Ostrom 2008). It is clear in this Costa Rican case that relationships matter. The attributes of *good* governance provide

insight for overcoming this challenging situation. Decision-making processes in governance systems often focus almost entirely on resulting policies and pay limited attention to the process used to design and implement policy options (Dovers and Hezri 2010; Majone 1989). However, carefully designed governance processes can help improve the quality of interactions among participants, which are influenced heavily by attributes of *good* governance. It appears that key attributes to strengthen in this particular case are participation, communication, deliberation, and trust.

As stakeholders involved in implementing policies are often not included in policy design processes (Fischer 2000), greater attention can be given to individual or specific interests, making it difficult to identify and advance toward common goals (Brunner 2002; Clark 2002). Moreover, failing to adequately consider stakeholders and their interests in policy discussions can result in poor acceptance of decisions and difficulties in implementing programs and policies on the ground (Brunner et al. 2005; Fisher et al. 1991; Knuppe and Pahl-Wostl 2011; Rowe and Frewer 2004). The notion that "when people deliberate in a fair and open process, they naturally tend to accept the result" (Stiftel and Scholz 2005:235) is widely assumed in academic and practitioner-oriented literatures (Fisher et al. 1991; Hill et al 2011; Rowe and Frewer 2004; Susskind and Cruikshank 1987; Webler and Tuler 2000). Democratic legitimacy, or preparedness to accept policy decisions, is more reliant on authorities and citizens perceiving a decision-making process as adequate than the actual content of the decision (Klijn and Edelenbos 2012). Public involvement in policy making processes can increase the legitimacy of local governing bodies and public officials, thereby

increasing support for proposed initiatives, and improving communication between citizens and local governments (Marquart-Pyatt and Petrzelka 2008).

While increasing opportunities for CBDWO and rural citizens to participate with government agencies in policy processes would improve governance in this case, participation alone will not guarantee better results. Developing processes for CBDWO and government agency representatives to engage in open communication and deliberation that foster trust is a potential alternative to improve the quality of interactions between these groups and allow for effective governance outcomes. Collaborative natural resource management can create new opportunities for interaction among stakeholder groups that foster flexible mind-sets to help individuals reframe their focus on problems (Wondolleck and Yaffee 2000). Spaces for open communication and deliberation in policy making and implementation processes allow all stakeholders to be heard and contribute fully; traditional bureaucratic, administrative approaches do not foster these spaces (Susskind 2005). Deliberative methods for collaboration and participation aim to create a more comprehensive understanding of problems by revealing the different perspectives of citizens and government agencies, thereby leading to better decisions (Wondolleck and Yaffee 2000). These types of collaborations can also improve relationships by helping stakeholders recognize that partnerships are made up of people not institutions (Brunner 2002).

Trust is often underestimated in conventional top-down management processes (Armitage 2008), but is a key element of positive social interactions and effective collaborations. While a sense of trust is important for successfully initiating collaborative efforts, building

collaborations and trust is an iterative process. Collaborations grounded in a *good* process, (i.e., emphasizing attributes of *good* governance) build trust and foster mutual respect among participants regardless of their positions on issues (Folke et al. 2005; Brunner et al. 2005). While trust creates a sense of community and makes it easier for people to work together (Shannon 1990), trust also contributes to legitimacy (Schneider et al. 2003). Public authorities play a key role in building leadership and trust through collaborations that help transform organizations toward a participatory learning environment (Folke et al. 2005; Stiftel and Scholz 2005; Wondolleck and Yaffee 2000).

Analysis of trends and conditions shows that many CBDWO and rural citizens in this region do not feel that the policy making and implementation processes are open, fair and *good*. It is also clear that government agency representatives are unsatisfied with the level of acceptance of decisions, reflected in low rates of compliance with key policies. Although these policies aim to improve drinking water service provision and support rural livelihoods, the process of implementing them in this region is not working well. Extensive theoretical and empirical evidence supports the notion that an intentional process for open communication and deliberation around perspectives about these policies could result in increased acceptance and compliance. Building such a process would provide a space for CBDWO and agency representatives to recognize their shared goals for rural drinking water resources and work together to develop mutually beneficial strategies to achieve them. In this particular case in Costa Rica, developing a process for decision-making and implementation that prioritizes improving the quality of interactions between CBDWO and agency representatives could help make huge strides toward achieving goals for policy compliance and improved rural drinking water governance. While numerous resources are available in academic and

practitioner-oriented literatures to assist in the design and implementation of such processes (e.g., Bunker et al. 2006; Chambers 2002; United Nations 2007), it is important that processes are carefully crafted to meet the needs of participants in this specific context.

These four alternatives are not the only options to achieve shared goals or improving rural water governance in this context. However, since they were identified through careful analysis of multiple perspectives and principles of governance commonly accepted as universal (Graham et al. 2003), they are a reasonable contribution to moving toward achieving shared goals for rural drinking water governance in this Costa Rican context. In addition, focusing on key attributes that emerged from this analysis may result in improvements for other attributes as well, thereby enhancing the effects of applying these alternatives.

Conclusions

Uncertainties about the quality and quantity of drinking water resources are a source of vulnerability for rural populations in Costa Rica. Both CBDWO and government agencies share goals for sustainable drinking water resources and community-based management; however, trends and conditions present risks to achieving these goals. Analysis of multiple stakeholder perspectives revealed opportunities to develop governance options to address this uncertainty and vulnerability, and achieve goals to serve the common interest. This analysis revealed attributes of *good* governance that appear to be most critical in this case- responsiveness and effectiveness of policies, accountability mechanisms, monitoring and knowledge sharing, and interactions based on communication, deliberation and trust- and

four alternatives to strengthen these attributes. Focusing on these alternatives and key attributes will, in turn, strengthen other attributes and enhance the effects of investing in these efforts.

Natural resource governance problems abound. Developing *good* governance contributes to improving policy by promoting human dignity (Mattson and Clark 2011) and serving the common interest (Clark 2002). The method used in this study uses problem orientation from the policy sciences to analyze multiple perspectives, which are key for identifying the common interest. In this analysis normative attributes of *good* governance provided a tool for discovering alternatives that contribute to solving governance problems by advancing the common interest. This method serves as a practical approach to policy analysis in this context. In addition, this approach contributes to the theoretical and methodological development of governance studies, and achieving shared goals for sustainability of natural resources and human dignity. Although the findings and interpretations are specific to this case study, the process or method of using problem orientation and attributes of *good* governance is generalizable and can be used to analyze problems related to governance in other contexts.

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CHAPTER 3

Reconciling Resource Management with the Landscape: An Approach to Identify Scale Mis-fit in Social-ecological Systems

In preparation for submission to *Ecology and Society*

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Abstract

Scale mis-fit occurs when natural resources are not managed at the spatial or temporal scale at which they are provisioned. Issues of scale mis-fit abound in social-ecological systems. They can hinder efforts to effectively manage resources and threaten resilience of the larger ecosystem, thus affecting societal well-being and livelihoods. Here, we present an approach to identify issues of scale mis-fit. Our approach can be used to define a specific natural resource problem, determine the scales at which relevant biophysical processes and management actions occur, assess spatial and temporal scale mis-fits, and identify potential solutions. We provide two case studies of drinking water resource management in Costa Rica and the Pacific Northwest United States as applications of our approach to natural resource management. While our case studies focus on a subset of water resources, the approach we present is broadly applicable to an array of social-ecological systems.

Introduction

Humans rely on natural resource provision for many facets of life, including sustenance, energy, livelihoods, recreation, and shelter. Effective management of natural resources is crucial to ensure their sustained use. Natural resource provision results from complex ecosystem interactions occurring across spatial and temporal scales, but resource use by society often occurs without understanding of the multi-scale biophysical processes that produce the resource or the complex response to management (Levin 1992). As a result, this lack of understanding is often exacerbated when management of natural resources occurs at different scales than those at which natural resources are provisioned and has been recognized within a variety of social-ecological systems (SES) and governance approaches (Ludwig and Smith 2005, Cumming et al. 2006, Dore and Lebel 2010, Termeer et al. 2010, Carmona-Torres et al. 2011, Apostolopoulou and Paloniemi 2012, Johnson et al. 2012, Paloniemi et al. 2012, Vervoort et al. 2012, Cumming et al. 2013).

Failing to manage natural resources at the appropriate scales can compromise both the long-term availability of the resource and the functioning of the larger SES (Lee 1993, Cumming et al. 2006, Wilson 2006, Dore and Lebel 2010, Moss and Newig 2010, Johnson et al. 2012, Fremier et al. 2013). Therefore, effective management of natural resources requires reconciling complex biophysical and social interactions that occur across different temporal and spatial scales within an SES (Gunderson and Holling 2002, Cash et al. 2006, Cumming et al. 2006) to fit management actions to the scales at which biophysical processes are provisioning the natural resource.

The SES perspective to natural resource management has emerged from the recognition that: (i) interactions and feedbacks between the biophysical processes that provision resources and actions related to their management commonly occur, (ii) unexpected changes in natural resource availability are common (e.g., due to natural and social system dynamics), and (iii) management actions aimed at adapting to changes in natural resource flows, rather than maintaining constancy, are necessary to sustain natural resource availability (Folke 2006). Thus, the SES framework requires holistic approaches to management that integrate system components (social and ecological) and their interactions to analyze and elucidate problems of natural resource sustainability (Liu et al. 2007, Ostrom 2009). Interdisciplinary SES approaches provide a unique opportunity to analyze complex environmental problems from varying perspectives and to investigate a problem more thoroughly (Newell 2001).

Scale mis-fit commonly exists and has been recognized within SES; however, systematic approaches to identify scale mis-fit are lacking. Therefore, we present an integrated approach to analyze natural resource problems using a scale mis-fit lens that deconstructs components of an SES while enhancing understanding of complex interactions within the system. Users of this approach determine the scales at which relevant biophysical and governance processes occur to identify spatial and temporal scale mis-fit and propose potential solutions to a natural resource problem in an effort to align management actions to the relevant biophysical scales.

We suggest that framing complex natural resource issues explicitly in terms of spatial and temporal scales may allow for new insights to identify, analyze, and resolve natural resource

problems in SES. By defining a system based on the scales of biophysical processes that sustain natural resources and the scales of management actions that influence these processes, the complex interactions between the biophysical and human components of the SES can be reduced to fundamental elements underlying a specific natural resource problem. This clarity may reveal critical mis-fits in the scales of biophysical processes and management actions, highlighting possible improvements for natural resource problems. For example, natural cycles of forest loss and regeneration take much longer than historical management practices of wildfire suppression allowed. Recognizing this as a temporal scale mis-fit places more focus on defining management actions that allow forests to burn at a recurrence interval that better aligns with natural forest regeneration processes.

Our approach is designed for researchers, managers, and other practitioners to become aware of spatial and temporal scale mis-fits within various SES and identify solutions to address problems arising from them. The overall goal of this approach is to advance management by understanding the integrated biophysical and governance context of natural resource problems and applying that understanding to management actions. Systematically identifying sources of scale mis-fit and outlining solution options will assist users in achieving this goal. We recognize that no simple or single solution exists for resolving scale mis-fit complexity. However, this approach can be useful across a wide variety of SES to identify scale mis-fits and possible solutions without suggesting panaceas (Bovens and Hart 1996, Brunner et al. 2005, Ostrom et al. 2007).

Scale mis-fit definitions

Scale is a fundamental aspect of social, physical, and biological systems and is considered a unifying concept between different academic traditions (Silver 2008). Scale has previously been studied and defined in the literature (see Gibson et al. 2000, Young 2002, Cash et al. 2006, Cumming et al. 2006), and we adopt the following definition "dimensions used to measure and study any phenomenon" (Gibson et al. 2000, p. 218). However, both within scientific literature and colloquially, scale is also used as an overarching term to refer to points along a spatial or temporal scale. We adopt this common terminology. For example, the terms "national scale" and "local scale" (i.e., jurisdictional boundaries) and the term "watershed scale" refer to different geographically defined areas on a spatial scale; different time frames (e.g., decades or minutes) refer to different points along a temporal scale. Table 3.1 presents several key definitions related to scale that we have adopted for this approach.

Table 3.1. Key definitions and explanation related to scale mis-fit.

Scale: "The spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon." (Gibson et al. 2000:218)
Spatial scale: The geographically-defined area where biophysical, management, or governance processes occur in a system.
Temporal scale: The amount of time it takes for biophysical, management, or governance processes to occur in a system.
Scale mis-fit: When adequate management actions do not occur at the spatial scales (i.e., geographic areas) or temporal scales (i.e., amount of time) most relevant to the biophysical processes provisioning the resource.

Here, biophysical processes are the interactions between two or more components of a natural system that contribute to the provisioning of a resource. We use the term biophysical explicitly to include both biological and physical components of an SES. The term

management specifically refers to the actions of overseeing resource provision and usage. Management actions are the implementation of rules and regulations that are determined by governance processes, which occur through the larger social system (Parkes et al. 2010). Governance processes extend beyond formal government and include the actions of all individuals and institutions involved in making decisions and establishing rules and norms that influence a natural resource (Richards and Smith 2002, Graham et al. 2003, Armitage and Plummer 2010).

We define scale mis-fit as a discrepancy between the scales of biophysical processes and management actions (Table 3.1). Spatial and temporal scale mis-fits exist when adequate management actions do not occur at the spatial scales (i.e., geographic areas) or temporal scales (i.e., amount of time) most relevant to the biophysical processes provisioning the resource. Although governance processes occur at multiple scales, resolving scale mis-fit problems necessitates adequate management actions at the spatial and temporal scales most relevant for the biophysical processes specific to the natural resource problem of concern.

Sources and consequences of scale mis-fit

Scale mis-fit in SES may arise from a variety of causes. Note that the terms “mis-fit” and “mismatch” are often used synonymously; we prefer the term “mis-fit” because it does not imply the existence or feasibility of an exact match between scales and/or processes. Cumming et al. (2006) categorize sources of scale mis-fit (referred to by the authors as “scale mismatch”) as mainly social, ecological, or coupled social-ecological, clarifying that mis-fit can be caused by environmental factors, the organizations responsible for management, or interactions between them. These authors provide examples of environmental sources of

scale mis-fit including natural cycles within ecological communities (e.g., due to disease outbreaks or predator-prey interactions) or unexpected environmental responses to management. They also describe social drivers of scale mis-fit as changes in land tenure, technology, human population growth, markets, infrastructure, and values. Others have further described the sources of scale mis-fit as rooted specifically in the governance system, such as imperfect knowledge about the biophysical system being managed (Hessl 2002, Apostolopoulou and Paloniemi 2012), constraints within the institutions charged with management (Paloniemi et al. 2012), short-term economic returns overshadowing environmental processes in policy development (Ludwig and Smith 2005, Dore and Lebel 2010, Ahlborg and Nightingale 2012, Paloniemi et al. 2012), and difficulty in adapting legislation and agency practices to meet environmental needs (Gibson et al. 2000, Young 2002). In our view, the primary source of scale mis-fit is a failure to fully understand and consider the scales of biophysical processes provisioning a resource and to subsequently align management actions and governance processes accordingly.

A lack of understanding or recognition of the most relevant scales at which biophysical processes provision a resource can hinder efforts to align resource management with these processes (Cash et al. 2006). For instance, Johnson et al. (2012) explored potential causes of sea urchin declines in Maine, USA in the late twentieth century. They concluded that the small-scale biophysical processes most important for maintaining sustainable sea urchin fishery levels (local migration of sea urchins to areas in which they were easily harvested) were not adequately incorporated into state-scale fishery co-management policies, resulting in persistent sea urchin decline. In another example in the western United States, management actions designed with a temporal understanding discordant with cross-scale

ecological dynamics, including forest dynamics, grazer population dynamics, and fire regime, have also have been blamed for decline of forests (Holling 1986, Hessl 2002). Furthermore, since natural systems rarely follow socio-political boundaries, consequences of management actions in one region can have transboundary effects. For example, upstream river degradation can influence downstream water quality, flood occurrence, and fisheries (Fremier et al. 2013). While it is increasingly evident that effective resource management necessitates that social processes are consistent with the scales of related biophysical processes (Cleveland et al. 1996), scale mis-fit continues to exist within many SES and contribute to many environmental problems (Young 2002).

Toward an approach to identify and address scale mis-fit

Many examples of natural resource problems resulting from scale mis-fit in SES exist in the literature (Wilson 2006, Dore and Lebel 2010, Ahlborg and Nightingale 2012, Apostolopoulou and Paloniemi 2012, Johnson et al. 2012, Kane 2012, Vervoort et al. 2012). However, systematic identification and analysis of scale mis-fit is lacking. Moreover, identifying problems related to mis-fit prior to natural resource decline or system collapse is more effective to prevent and mitigate problems than retrospective analysis. Cumming et al. (2006) concluded that once identified, resolving scale mis-fit first requires an awareness of how scale contributes to problems within an SES, followed by the development of a range of potential solutions. We build on this conclusion by proposing that systematic problem definition should be the first step towards diagnosing and potentially resolving issues of scale mis-fit and presenting a process for identifying scale mis-fit.

Our approach to identify and analyze scale mis-fit integrates concepts from existing theoretical frameworks, mainly the policy sciences (Lasswell 1968, Clark 2002) and social-ecological resilience (Cumming et al. 2005, Walker and Salt 2006, Walker and Salt 2012). Both frameworks have been used to map biophysical and social processes within SES (Walker et al. 2002, Rutherford et al. 2009, Wilshusen 2009, Brunner and Lynch 2010, Walker and Salt 2012), and our approach incorporates insights from specific aspects of both. The policy sciences framework offers a problem definition process as a starting point for natural resource managers to guide their analysis and resolution of complex problems (Clark 2002, Lynch et al. 2013, Hammer 2013). Resilience theory, with its origins in describing non-linear behaviors in biophysical systems (Holling 1973), offers tools to assess complex dynamics in coupled SES (Walker and Salt 2006). These frameworks help define a system based on available knowledge and we propose applying this knowledge specifically to identify issues of scale mis-fit and potential ways of improving alignment of management actions to the relevant scales of resource-sustaining biophysical processes. In our approach, we reiterate the emphasis that both of these frameworks place on promoting participatory processes to engage multiple stakeholders in research and practical applications of analyzing these dynamics in SES (Clark 2002, Walker et al. 2002, Walker and Salt 2012).

Much of the published literature related to scale mis-fit in SES focuses primarily on the effects of scale mis-fit in natural resource provisioning (Gunderson and Holling 2002, Cumming et al. 2006, Moss & Newig 2010, Carmona-Torres et al. 2011, Ahlborg and Nightingale 2012, Johnson et al. 2012, Vatn and Vedeld 2012, Vervoort et al. 2012). Identifying effective solutions to problems within SES often requires addressing scale mis-fit, although tools to identify and analyze scale mis-fit are lacking. The only approach that we

have found in the literature to identify scale mis-fit is presented by Ludwig and Smith (2005) based on Walker et al. (2002). Their four-step approach to address scale mis-fit uses resilience analysis in Australian rangelands. The steps include: (i) mapping the scales at which key processes and components of the SES occur, (ii) evaluating potential trajectories of the SES, (iii) assessing the effects of scale mis-fits driving uncertainty in trajectory predictions, and (iv) gauging how different methods for correcting scale mis-fits may affect management actions. We expand on this approach by beginning with focused problem orientation, followed by a systematic appraisal of the relevant scales for both the biophysical processes that provision a natural resource and the management actions pertinent to the stated problem.

An Approach to Identify Scale Mis-fit

Our stepwise approach to identify and address scale mis-fit in SES is presented in Table 3.2 as a series of six steps, where each step builds on understanding gained in previous steps. The approach is designed to focus on one specific natural resource problem, although many problems may exist within an SES. We see great value in using professionally facilitated, interactive processes engaging multiple stakeholders to complete these steps.

Table 3.2. A six-step approach to identify, analyze and address scale mis-fit.

Step 1. Define the problem related to the natural resource of concern. a) What is the natural resource of concern in the system? b) What is the specific problem related to this resource?
Step 2. Describe biophysical processes that provision the resource. a) What biophysical processes are relevant for providing the resource? b) Where do these processes occur on the landscape? (spatial scales) c) How much time does it take for these processes to occur? (temporal scales) d) What are the spatial and temporal scales most relevant to address the specified problem?
Step 3. Describe how humans influence biophysical processes contributing to the resource. a) How do human activities influence the biophysical processes at the most relevant spatial and temporal scales (from Step 2d)?
Step 4. Describe management actions and governance processes that influence the resource. a) What institutions (governmental and non-governmental) play a role in managing these human activities, and what management actions do they take? b) What governance processes determine these management actions? c) Where geographically are management actions focused? (spatial scale) d) What time frames do management actions address? (temporal scale)
Step 5. Assess spatial and temporal scale mis-fits. a) Do adequate management actions (Step 4) occur at the biophysically relevant spatial and temporal scales (Step 2)? b) What spatial and/or temporal scale mis-fits exist?
Step 6. Identify potential solutions to address scale mis-fits. a) What management actions are needed at the relevant spatial and/or temporal scales to address the scale mis-fits identified? b) What governance processes are needed to achieve these management actions? c) What barriers exist under current laws and policies and what process would be necessary to overcome these barriers? d) What potential solutions could be implemented over short-, medium-, and long-terms?

Scale Mis-fit in Water Resources Management

We found our approach useful for examining case studies in water resource management, where scale mis-fit exists prominently (Cash et al. 2006, Dore and Lebel 2010, Moss and Newig 2010) but has not been resolved effectively (Poff et al. 2003). As with other natural resources, the biophysical processes that influence water resources occur at multiple spatial scales ranging from small-scale molecular processes (e.g., interactions between chemical pollutants) to large-scale basin, continental, or global-level processes (e.g., groundwater flow

and climate, flood, and drought regimes). Management actions often are not aligned with the scales of these biophysical processes. For example, political boundaries generally do not follow watershed boundaries, making watershed management more complex when crossing multiple jurisdictions. Moreover, defaulting to a focus at the watershed scale could ignore or fail to prioritize biophysical processes that occur at different scales, such as climate regimes or groundwater recharge, which do not generally adhere to topographic watershed boundaries (*sensu* Vatn and Vedeld 2012).

One example of an effort to address issues of scale in water resource management problems is Integrated Water Resource Management (IWRM). IWRM promotes both a watershed vision for management actions (Agarwal et al. 2000) and integration of governmental authority over various activities that impact the water resource (Cosens and Stow 2014). However, water resource problems are often very unique and cannot utilize one standard solution (Biswas 2004). While IWRM is an attempt to address water issues at the most appropriate biophysical spatial scale (i.e., the watershed), some point out that the watershed is not always the most appropriate scale of addressing governance processes (Cohen and Davidson 2011). In addition, despite the prevalence of scale issues in water resource systems, IWRM principles do not specifically address the issue of scale mis-fit. IWRM is designed to address fragmentation in management of human activities that affect the same connected water resource. While this may at times address scale issues, they are not the focus. Ultimately, given the multiple spatial and temporal scales that are involved in water resources, water management must address scale mis-fit issues to be effective and to produce long-term results. In addition, participatory methods that engage multiple stakeholders have been particularly effective in establishing opportunities to overcome scale mis-fit (Dore and

Lebel 2010) and in enabling vertical integration, linking the levels of water governance (Knuppe and Pahl-Wostl 2011). We demonstrate how our approach promotes integration and multi-scale considerations in two water resource management case studies.

Case studies: Water Resource Management in Costa Rica and the Pacific Northwest USA

We present two case studies focused on drinking water management to demonstrate the utility of our approach in analyzing SES problems. By presenting these case studies, we aim to contribute to the continuing development of heuristic approaches to identify, understand, and resolve scale mis-fit. The first case is based in Costa Rica and was developed through interdisciplinary teamwork of four doctoral students in the Joint Doctoral Program between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) and the University of Idaho (UI). The second case is based in the western United States and draws from long-term involvement of the UI in scientific studies on regional water resources, as well as interdisciplinary studies by faculty and students in the UI Waters of the West Program. With both case studies, we present relevant background information before using our scale mis-fit approach to analyze the SES.

Costa Rica case study background

The Costa Rica case study focuses on drinking water quality in rural communities in the Cartago Province of central Costa Rica. This case study draws from findings from interviews with community organizations and government agencies involved in drinking water management and a survey and workshop with community drinking water organizations in the study region. Drinking water quality remains largely unknown, although potentially

hazardous contaminants, such as agrochemicals, are used within the watershed and are likely entering community water sources. Throughout the country, local community-based drinking water organizations (CBDWOs, or ASADAs and CAAR in Spanish) are responsible for overseeing the management and provision of drinking water in rural communities. In this region, drinking water is piped directly from springs and most CBDWOs use chlorine treatments to reduce the risk of bacterial contamination. Water quality testing is conducted once every six months to two years, if at all. In addition, common land uses within the contributing area include agriculture and pasture, and contaminants from these practices threaten water quality. The Water Law (Costa Rica Government 1942) and the Environmental Law (Costa Rica Government 1995) mandate forested protection zones of 200 m and 100 m radii, respectively, around the spring. Most citizens are uncertain about which radius to use, and enforcement of the two laws is minimal. Moreover, these protection zones are not based on scientific evidence. The upstream area contributing to a spring (springshed) lies largely unprotected, while the majority of the protected area lies downstream of the spring in areas that do not contribute groundwater to the spring flow (Figure 3.1). Therefore, much of the springshed is not protected under the two laws. We use the term springshed to refer to the area of land in which water infiltrates into the ground and exits at a common spring source. We differentiate springshed from watershed, which is typically determined by topography, since springs mainly rely on only groundwater sources that may not follow topographic relief.

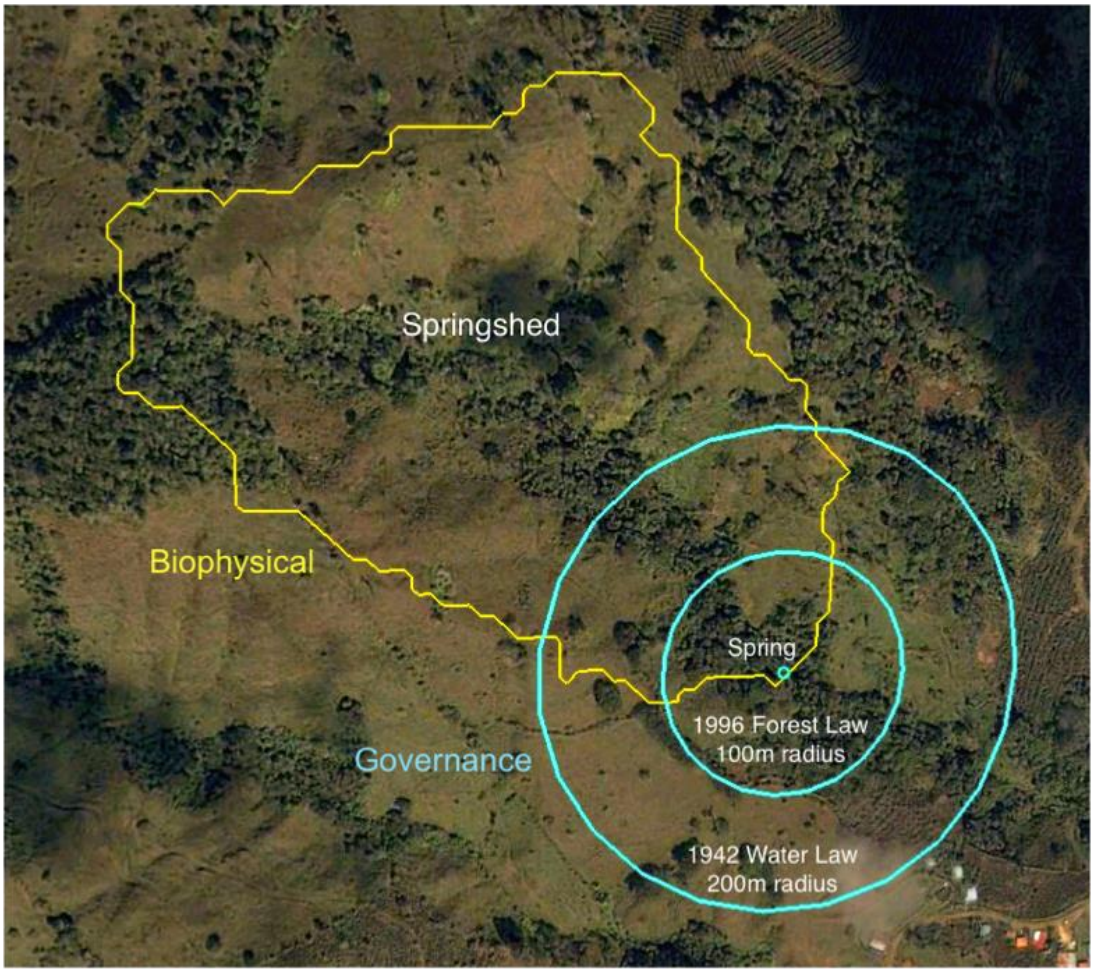

Figure 3.1. Illustration of a spatial scale mis-fit between the upstream area contributing to spring discharge (the potential springshed, yellow polygon) and the protection buffers surrounding the spring (blue polygons) managed by a CBDWO in the Cartago Province of Costa Rica. Management actions primarily occur within the protection buffers, which do not fit the spatial scale of the biophysical processes that provision the drinking water (i.e., within the springshed) (Map data ©2013 Google, Digital Globe).

As a result of the discrepancy between the protection areas and the boundaries of the springsheds, CBDWOs often are not aware of the influence that the springshed has on water quality and do not monitor activities that occur in these regions. Due to limited or non-existent water quality testing, CBDWOs and users lack information about the quality of their drinking water sources. Potential threats that exist in the springshed interfere with the ability

of CBDWOs to provide potable drinking water for local communities. In some cases these threats may pose hazardous to community members' health. Limited financial and human resources prevent communities and government agencies from conducting studies to identify where groundwater recharge occurs, to determine whether water contamination is occurring within the springshed, and to establish effective management plans.

Six-step approach applied to the Costa Rica case

Using the six-step approach presented in Table 3.2, we analyze the SES related to drinking water in the Cartago province of Costa Rica.

Step 1: Drinking water quality is a significant concern within rural communities of Costa Rica. Water quality monitoring is infrequent, and understanding of groundwater recharge zones for the springs is limited, preventing CBDWOs from identifying both potential contaminants and the human actions that are responsible for contamination. This uncertainty about water quality jeopardizes human health.

Step 2: Many biophysical processes influence the provision of clean drinking water, including climate processes (precipitation) and hydrogeologic processes (infiltration, groundwater flow, and spring water discharge). Precipitation occurs at a regional scale, while the interactions between infiltrated water, groundwater, and spring water occur at the scale of the springshed. Precipitation occurs on the order of minutes to hours, while infiltration and shallow groundwater flow to springs occur on the order of hours to months, depending on springshed size, soil parameters, and precipitation intensity and magnitude. In order to

address the problem of focus, the relevant spatial scale is the springshed, while the relevant temporal scale is in the range of hours to days.

Step 3: Human activities primarily influence water quality through land use management practices. Within the springsheds, which are not protected by the Water Law (1942) or Environmental Law (1996), many concerning land uses occur, such as intensive agriculture and cattle grazing. Agrochemicals applied to crops and fecal coliforms from cattle manure can enter soils and flow to the spring on the temporal scale of hours to days.

Step 4: Several institutions are responsible for management actions and governance processes in this region. The National Institute for Water and Sewage (ICAA, or AyA in Spanish) is responsible for providing CBDWO administrative support; they also provide occasional training and limited financial resources. The Ministry of Energy and the Environment (MINAE) developed and enforces the Environmental Law (Costa Rica Government 1995) that stipulates the 100 m radius protection area around drinking water sources. The Water Law (Costa Rica Government 1942) stipulates the 200 m radius (Figure 3.1). The CBDWOs act on the local community scale to develop spring sources, maintain infrastructure for water delivery, collect fees, and finance maintenance of the system. Spatially, management actions are limited to areas directly around the springs, although very few springs are fully protected by the mandated 100 and 200 m radius zones. Temporally, the relevant management actions, water quality tests, generally occur on a scale from once every six months (most frequent) to once every two years (least frequent), or sometimes not at all.

Step 5: The relevant biophysical spatial scale is the springshed, where recharge contributes to spring flow. Land use within the springshed, including agriculture and cattle grazing, threatens water quality, but management actions to regulate these practices, when undertaken, usually only occur within the 100 to 200 m surrounding the springs. Of the limited management practices undertaken to mitigate the effects of land use on water quality, many are targeted in locations outside of the springshed, downslope of the spring in the area that does not contribute to spring flow. Therefore, there is a spatial scale mis-fit between the scale of drinking water management with the scale of the biophysical processes that provision the resource. Management actions also do not occur at the temporal scales most relevant for drinking water provisioning. Water quality tests are conducted infrequently, but potential threats to water quality (e.g., agrochemicals and fecal coliforms) are possibly occurring in the springshed, ranging on the order of minutes to days (Figure 3.2). Therefore, the limited testing that is conducted has a high probability of not identifying any acute contaminants that pass through the system; this results in a temporal scale mis-fit.

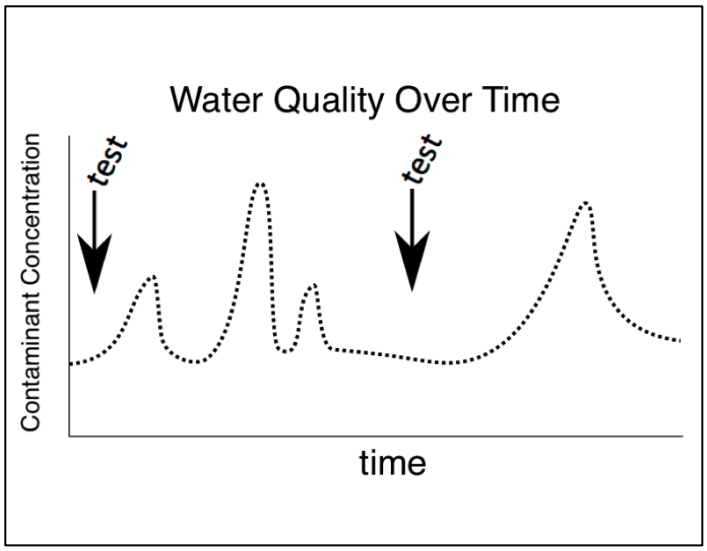

Figure 3.2. Conceptual illustration of a temporal scale mis-fit between the frequency of water quality testing and the probable changes in water contaminant concentration over time. CBDWOs in Costa Rica typically sample water for contaminants less than twice per year, and thus the tests are not likely revealing the suitability of the water for drinking.

Step 6: To address these scale mis-fits, management actions are needed at the springshed scale, and governance processes should focus on establishing the springshed as the protection area for management focus. Delineation of springshed boundaries requires significant resources given the difficulty of determining the extent of groundwater contribution to springs. However, the watershed, based on topographic boundaries, may be initially considered, given the likelihood of significant overlap with the springshed. Also, the watershed is a more feasible and cost-effective scale to begin protecting. More frequent water quality monitoring aligned with the temporal scale of infiltration and shallow groundwater flow rates is also needed to identify potential rapid changes on the landscape that lead to contamination of drinking water supplies.

Potential short-term solutions include delineating watershed boundaries for all springs and conducting targeted sampling after rainfall events when occurrence of contaminants might be

greatest. Two medium-term solutions could include 1) developing a monitoring plan to capture the appropriate spatial extent and temporal variability of the biophysical processes to sustain consistent, clean drinking water for the communities, and 2) forming regional bridging organizations (i.e., a watershed management group) among CBDWO water managers to promote water quality training, shared knowledge, communication, and collective garnering of financial resources. Two potential long-term solutions are to 1) modify existing laws and enforcement mechanisms to establish appropriate upslope spring protection areas and focus management actions at the watershed scale and 2) determine groundwater contributions to the springs for management at the springshed scale.

Overview of the six-step approach in Costa Rica

Applying the six-step approach to this SES in Costa Rica reveals a predominant issue of spatial scale mis-fit involved in drinking water management, as management actions do not exist at springshed levels. The spatial scale of biophysical processes responsible for water provisioning (i.e., the springshed) is not sufficiently considered in the design of Costa Rican drinking water management policy. Use of this approach indicates that several potential options exist for community members to address water quality in this region, including short-term efforts that can provide insight into the problem while longer-term solutions are refined and implemented. Results of our approach also emphasize the importance of monitoring water resource dynamics at the appropriate temporal scale. The strategy of focusing water protection efforts at the springshed scale, monitoring spring water quality more frequently, and sharing this information throughout a local CBDWO network would establish community knowledge to inform short-term actions in lieu of long-term policy that will

require significant time to reform. Therefore, a change in the spatial and temporal scale of management actions would more closely align the governance actions with the biophysical processes for water provision in this particular case as well as in other cases facing similar issues.

Palouse Basin case study background

The Palouse Basin case study focuses on groundwater availability in the Palouse Basin located in the Inland Northwest of the United Sates (Figure 3.3). The majority of water from the basin is pumped from the Grande Ronde, a deep fractured basalt aquifer that provides groundwater for domestic and industrial users located in the Idaho and Washington states. Significant concern exists over aquifer levels, which have been declining at a rate of 20-45 cm per year for the past 60 years (see Figure 3.4; Beall et al. 2011, Moran 2011) with no direct evidence of aquifer recharge (Belknap 1999). Water allocation occurs at the state level in the United States (California Oregon Power Co. v. Beaver Portland Cement Co. 1935, Tarlock 2011), but the Washington/Idaho state line divides the Grande Ronde Aquifer. Idaho state law prohibits aquifer mining, defined as water pumping rates that exceed the rate of natural groundwater recharge (Idaho Statutes 42-237a(g)). Therefore, the occurrence of aquifer mining as defined by law cannot be determined without knowing the recharge rate, which has not been determined in this case. Washington state law is less specific but prohibits pumping beyond the source's yield capacity (RCW 90.44.070), which has not yet been scientifically determined for this aquifer. Continued need for a scientific answer to the questions of the exact size and recharge rate of the aquifer has diverted attention from developing plans to reduce pumping rates, reinforcing the spatial and temporal mis-fits.

With approval of Congress, federal law allows the creation of an interstate authority that crosses state lines and allows the region to control management of their water system as one unit. However, studies show that decision makers in the region have rejected this approach based on fear that federal approval will complicate management (Richartz 2011). The Palouse Basin Aquifer Committee (PBAC) was established in 1967 as a voluntary entity bridging the state divide and has been instrumental in facilitating voluntary conservation measures. However, PBAC lacks management and enforcement authority for conservation goals in the region.

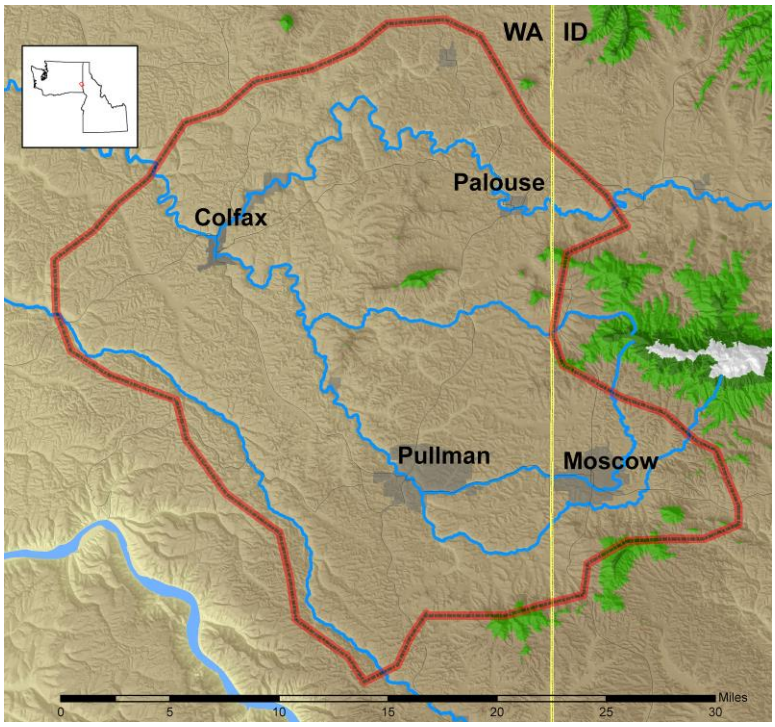

Figure 3.3 Palouse Basin showing boundary between Idaho and Washington (yellow line) and the approximate boundary of the Grande Ronde aquifer (red line) located within both states. The inset shows where the aquifer is located within both states.

Six-step approach applied to the Palouse Basin case

Using the six-step approach presented in Table 3.2, we analyze the SES related to the Palouse Basin.

Step 1: The resource of concern is groundwater from the Grande Ronde Aquifer. The water level of the aquifer has been declining significantly for the last 60 years. However, uncertainties remain over whether the aquifer is recharging and if the basin will experience a water shortage, since the recharge rate has not been scientifically determined. Existing local policies encourage voluntary conservation measures. State law requirements for curtailment of pumping on a "mined" aquifer have not been met in either state in which the aquifer occurs. Political will to develop alternative drinking water sources is lacking, as any viable surface water sources are shared by the two states.

Step 2: The biophysical processes that influence the aquifer include climate processes (precipitation) and hydrogeologic processes (primarily infiltration and aquifer recharge). Precipitation occurs at a regional scale, whereas infiltration and recharge occur on the aquifer scale. A shallow aquifer provides water to portions of one city and its recharge occurs on a scale of hours to months. The occurrence of recharge to the primary deep aquifer is unknown, but movement of recharge, if any, into production zones is clearly not occurring in a timeframe to prevent aquifer decline. In order to address the problem of focus, the relevant spatial scale is the aquifer, while the relevant temporal scale is unknown, but longer than the current period of record (60 years).

Step 3: Municipal groundwater pumping accounts for the most significant use of water from the aquifer and pumping rates increase with population growth. Groundwater pumping is likely occurring at a rate greater than recharge to the production zone given declines in the level of the aquifer over the last 60 years.

Step 4: The aquifer extends across the Washington-Idaho border and, as a result, is managed independently by the two states, invoking jurisdictional complexity. The PBAC, composed of representatives of the communities reliant on the aquifers and representatives of each state in an advisory capacity, was established to bridge efforts at the aquifer scale. The PBAC promotes information sharing and establishment of joint conservation goals, including the 1993 Groundwater Management Plan (GWMP). Although suggested management actions such as the GWMP are not legally binding, generally communities have complied. Although the rate of aquifer decline has slowed since implementation of the GWMP, aquifer levels continue to decline (Figure 3.4). In the state of Idaho, Statute 42-237a(g) prohibits aquifer mining exceeding the groundwater recharge rate (a standard that cannot be met if recharge is unknown), while Washington law (RCW 90.44.080) prohibits pumping an aquifer beyond its "safe yield." The relevant spatial scale of management actions includes the four cities that pump water from the aquifer and the state scale at which management is dictated. The temporal scale of management actions ranges from daily (pumping) to years (for development of city and university plans) to decades (for development and implementation of legislation).

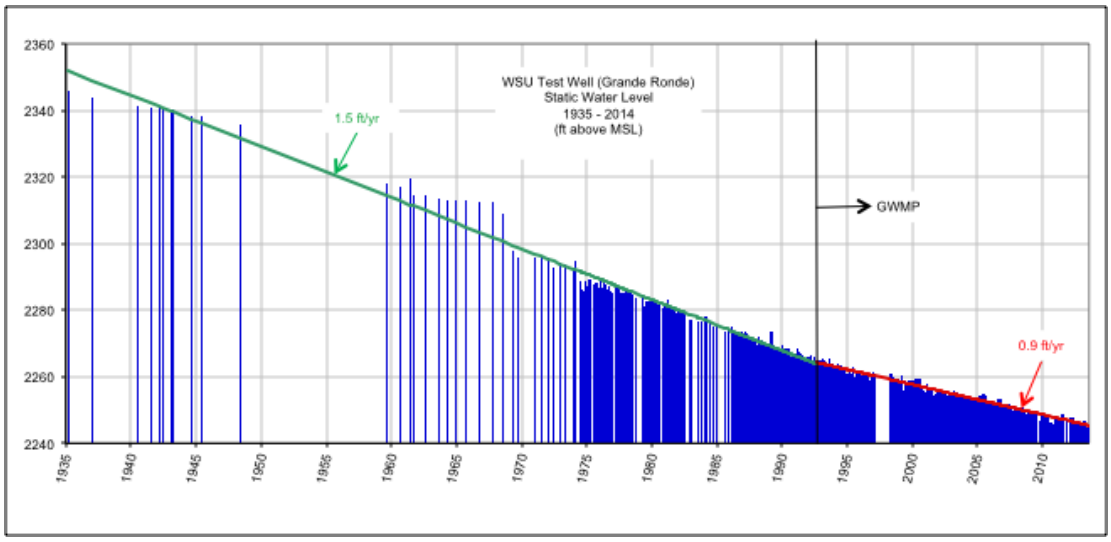

Figure 3.4. Static water levels in the Washington State University Test Well. Green and red regression lines show decrease of levels prior to and after 1993, respectively, when the Groundwater Management Plan (GWMP) was developed by PBAC.

Step 5: Currently there is no legally binding governance or management at the aquifer scale, which is the scale at which groundwater resources are provisioned, resulting in a spatial scale mis-fit. However, PBAC forms a bridging organization between the states of Idaho and Washington at this scale. The rate of aquifer recharge has not been determined and steady decline of the aquifer level over time suggests that the rate of extraction is greater than the rate of recharge at least to the production zone of municipal wells, indicating that a temporal mis-fit is occurring. The limited scientific investigations of recharge rate preclude imposing legal restrictions on pumping rates. The high cost associated with such research has inhibited the necessary scientific studies. Stakeholder attention primarily focuses on the state-defined spatial mis-fit and the need for further scientific study. However, application of this approach indicates that the temporal scale is far more important.

Step 6: Strategies to overcome scale mis-fit in the Palouse Basin must address the problem of declining groundwater reserves at the aquifer scale and at a temporal scale that matches the

discrepancy between the recharge rate to the production zone and rate of groundwater decline. Adequate investment to develop new water sources is paramount. Continued effort to determine recharge rates is warranted, although they have proved unsuccessful to date. The basin may be better served by determining the maximum depth of production through test wells and consideration of the economics of pumping from that depth. Based on maximum depth of pumping, the timeframe for aquifer decline to this point (assuming current rate of decline) and thus the need for supplemental resources may be determined.

One potential short-term strategy to address these issues is the establishment of a facilitated forum where scientists and decision makers can discuss relevant issues and identify the roles of science and policy in addressing existing problems. Over several years, a medium-term strategy to incorporate university-based research to determine maximum economic pump depth and possibly aquifer recharge rates could provide student training and valuable knowledge to the regional groundwater problem. Efforts to identify alternative water sources and design, permit, and develop compliance measures for new water sources could move forward. Potential long-term strategies include determining a more robust means for communities to work together across the state line, potentially through empowering PBAC, and coordinating appropriate pumping levels of the aquifer based on scientific evidence.

Overview of the six-step approach in the Palouse Basin

Applying the six-step approach in the Palouse Basin reveals a spatial scale mis-fit in this SES. Given that a state line divides the Grande Ronde Aquifer, management occurs within jurisdictional boundaries that do not overlap with the most appropriate spatial scale, the aquifer scale, for regional groundwater resources. While the scale at which PBAC is focused

aligns well with the biophysical scale at which water is provisioned in the Palouse Basin, the organization has no enforcement authority. However, this spatial scale mis-fit overshadows and tends to mask the temporal scale mis-fit, which lies at the heart of the problem. The main source of the water resource problems in this region is that the withdrawal rate exceeds the timeframe in which aquifer recharge occurs within the production zone. Since legislation in both states requires scientific determination of the general recharge rate in order to legally limit pumping, costly and lengthy studies are needed before adequate water conservation practices will be implemented. Using our approach in this case study helps users identify the temporal scale mis-fit occurring and place more focus on potential short-term solutions to mitigate the effects of waiting for necessary long-term solutions.

Applicability of the six-step approach for the case studies

The case studies demonstrate a useful approach to identify, further understand problems associated with, and discuss alternative solutions for scale mis-fit. In the Costa Rica case, by framing the management problem in terms of spatial and temporal scales, potential avenues for improving resource governance and defining management actions emerged. Our approach revealed feasible means to address water quality issues in drinking water. CBDWOs are spending human and financial resources to manage protection areas that do not contribute to the quality of spring water in the region. Resources would be more effectively used to protect those areas that have the most influence on drinking water quality. Delineating watersheds in lieu of springsheds provides an essential and feasible starting point for aligning the spatial scale of management actions with the spatial scale most relevant (and practical) for water resource provisioning. Ultimately, identifying the scale mis-fit between management actions

and biophysical processes of an SES exposes potential vulnerability that may threaten the ability of an SES to provision an adequate supply of resources. Addressing this weakness could strengthen the SES to address ongoing large-scale issues including increasingly common problems associated with climate change and population growth.

Restatement of the Palouse Basin aquifer issue from a scale mis-fit perspective distilled the complex problem to an awareness of specific spatial and temporal mis-fit in water resource governance. Focusing on both spatial and temporal scales clarified the multi-scale nature of the problem and highlights the need for cross-scale collaborations. Using our approach revealed that a critical temporal mis-fit issue is likely masked by the obvious spatial mis-fit created by the political border dividing the aquifer. Significant attention is being placed on the political boundaries rather than focusing on the likely decline of the aquifer, precluding more appropriate sustainable management of groundwater resources. Our approach identified that more knowledge of the system could potentially improve mismanagement. The lack of management actions at the basin scale and the lack of a long-term, legally binding conservation plan contribute to uncertainty about the future availability of drinking water in the Palouse region.

These two cases provide examples of how our approach is useful for identifying and understanding issues of scale mis-fit within SES. The steps in our approach provide a process for navigating environmental problems by first focusing on a specific natural resource problem and then framing the problem explicitly in terms of the scales of both biophysical and governance processes, thereby making the problem more manageable to tackle without

ignoring system complexity. When addressing complex problems with an interdisciplinary systems approach, it is often difficult to strike a balance between holistically understanding a problem that involves multiple interactions and feedbacks and deconstructing the problem into individual components. With this approach we intend to provide an entry point for breaking a problem down into manageable components through an analysis that acknowledges system complexity while identifying specific vulnerabilities. This approach is applicable to other contexts, both in water resource management and with other natural resource problems where spatial and temporal scales are of particular relevance and will be useful to researchers, managers, and other practitioners involved in natural resource management.

Discussion

This six-step approach to analyzing scale mis-fit has several unique aspects. First, a focus on scale can facilitate mutual understanding among researchers and stakeholders with different disciplinary orientations. This focus is of particular importance given the need for interdisciplinary approaches to SES (Redman et al. 2004, Lang et al. 2012) that can be hampered by the inherent difficulty of interdisciplinary collaboration (Eigenbrode et al. 2007, Morse et al. 2007). Second, specifically emphasizing the scales of resource provision and management offers an opportunity to identify “critical causes,” when they are related to scale, of natural resource problems that are not always intuitive or obvious in SES. Third, this approach explicitly places a concurrent emphasis on both spatial and temporal scales, as well as biophysical and governance systems, which are critical for effective natural resource management. Lastly, our approach encourages users to identify a range of possible solutions

over different time frames rather than focusing on a single solution to resolve problems of scale mis-fit.

We also recognize the need to address potential weaknesses of this approach. For example, solutions to address scale mis-fit are often complex and not straightforward. After identifying an existing scale mis-fit, one cannot simply “align the scales” to “fix” the problem. For example, where a problem is identified in an SES, creating or changing legislation might better protect resources and prove to be necessary to address the scale mis-fit. However, as new legislation requires a long-term vision, waiting for changes in legislation without additional short-term actions to address problems could allow them to worsen. More importantly, uncertainty requires a more nimble approach than legislative action in a governance structure that fits the scale of today’s problem but may prove inadequate in the future. Therefore, short- and medium-term mitigation strategies that address certain aspects of a problem could be explored concurrently with comprehensive long-term approaches. We propose that considering multiple solutions for different time frames will avoid issues that occur when focusing on one solution for a specific time frame.

Potential solutions and governance approaches need to be tailored for each resource and unique SES (Vatn and Vedeld 2012). Therefore, we envision that this approach will require in-depth, participatory discussions involving multiple stakeholders relevant for a specific case. Given that identifying solutions to scale mis-fit is complex, we would like to highlight that Step 6 is intended to encourage users of this approach to consider potential solutions to specifically address identified scale mis-fits. However, further work would be needed to identify a range of potential options that would satisfy multiple stakeholders’ interests and to

analyze the benefits and drawbacks of each solution. In addition, some factors influencing natural resource use, such as culture, history, religion, or economics, may not be explicitly addressed in this approach and may need further consideration in some cases. We encourage users to apply other relevant conceptual models, frameworks or analytical tools in conjunction with this approach specific to scale mis-fit.

Conclusions

Issues of scale mis-fit, when natural resources are not managed or governed at the scale at which they are provisioned, exist in a wide variety of SES. Lack of understanding the scales at which biophysical processes influence natural resource provisioning can lead to misalignment of management actions influencing resources. Identifying effective solutions to problems within SES often requires addressing scale mis-fit, although limited tools to identify and analyze scale mis-fit have been developed. We propose a systematic, approach for identifying, analyzing, and addressing scale mis-fit in environmental problems, based upon the premise that many natural resource problems are ultimately caused by a misalignment of the scales of management to the scales of resource provisioning.

The two case studies presented, from Costa Rica and the Inland Northwest region of the United States, highlight the applicability of our approach in two different social-ecological contexts related to water resource management. However, this approach for interdisciplinary investigation of spatial-temporal phenomena will be useful to analyze natural resource problems across a variety of SES contexts. We encourage others to test and refine this scale mis-fit approach for a range of natural resources issues, such as species, forest, and marine

management, in various SES contexts to aid in its development and practical application. While identification of scale mis-fit is an imperative step towards reconciling natural resource management with biophysical processes occurring on the landscape, additional work is particularly necessary to identify and implement solutions to address scale mis-fit problems.

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APPENDICES

Appendix A. Interview Guide

Purpose and use of this interview guide

It is important to note that this interview guide is not meant to be a list of questions that are worded exactly the way they are written here or asked in exactly the same order every participant interviewed. There are certain pieces of information that I am attempting to collect with the design of this interview guide and I wrote the guide with that in mind. However, the nature of each interview will be slightly different. For example, I will phrase some questions differently if I am talking to a CBDWO or government agency representative. In addition, although all of the interviews will address rural water issues (drinking water, wastewater and river health), some interviews will focus more on one of these. For example, some interviews with regional agencies or conservation groups may focus on river health and much less on drinking water and wastewater, in order to meet the interdisciplinary research goal of my team.

Introduction statements

- I am a researcher at CATIE and UI, conducting a research project about water — drinking water, wastewater and river water. I am conducting interviews with multiple stakeholders in order to understand policies, attitudes and actions that affect water in this community (or region). Thank you for your willingness to talk with me and help support our research efforts.

- Before we begin, I would like to let you know that this research has been approved by the University of Idaho and CATIE. I would like to remind you that your participation is voluntary and that you can decline to answer any questions if you wish. And your identity will remain anonymous, and your name will not be attached to any statement you make or be given to others.

- I would like to know if I could record our conversation. The sole purpose is to transcribe the interview for analysis, but neither your name nor your identity will be made known anywhere. Only my advisors and I will have access to this information. Would you be

willing to allow me to record our conversation? (If yes: If at any point during the conversation you would like to turn the recorder off for any reason at all, you can let me know.)

- Do you have a time limit for today's conversation? It should take about 1 to 1 ½ hours.
- I would like to ask you specifically about issues related to water in rural areas of this region, specifically drinking water, wastewater and rivers.

[Note: I use abbreviations DW (drinking water), WW (wastewater) and RH (river health) below for convenience, but the actual wording will vary throughout, including "potable water", "sanitation", "surface water" or "rivers" depending on the conversation.]

Institutional roles, responsibilities and goals
1. What **role** does your **institution** play in rural **drinking water (DW)**, **wastewater (WW)** and **river health (RH)**? **1A.** What **activities** related to DW, WW and RH does this institution carry out? **1B.** Are these **roles** and **responsibilities** written into **laws** or **regulations**? **1C.** What **goals** does your institution have related to DW, WW and RH? [OPTIONAL **1D.** What is your role in this institution, and these activities? What does your job entail?] **2.** What are **national goals** for DW? For WW? For RH? What are **local/regional goals**? **2A.** Are national and local/regional goals **similar or different**? **2B.** Would you say that **national goals** for rural DW, WW and RH are **being met**? Are **rural community goals being met**?
Awareness & concern for DW, WW and RH situations and trends
You mentioned that national and community goals are xxx, … **3.** How would you **describe the current situation** of rural DW in Costa Rica/this region/community? Rural WW? RH? **3A.** <u>If no problem is identified</u>, ask whether DW and WW services and RH are adequate for all people living in rural areas/this region/this community, and whether they are concerned about DW and WW services or river contamination. Probe into details. **3B.** <u>If a problem is identified</u>, ask for **description of each problem**. [Probe into **severity and scale** of each problem?] **3C.** What are the **causes** of this problem? (ask for ea. major problem identified) [Probe into: Who is involved in causes? What situations or actions are involved?] **3D.** What are the **consequences** of this problem? (ask for ea. major problem identified) [Probe into: ecological or environmental effects (i.e., river health), human health, effects on rural communities] **3E.** Are these situations **likely to improve** if actions stay the same? Likely to

worsen?

3F. How concerned are you about these problems? **Why**? [Notice how they describe their concern, whether concern is primarily for self, families, future generations, urban/rural]

[Probe into: concerns for DW, WW and RH. Are CBWWA and NIWS representatives concerned about WW and RH? Are institutions mostly concerned according to their formal roles?]

3G. How concerned are others living in this region/district/community?

Evaluation of actions for DW, WW and RH

You mentioned that your/this institution's role is xxx and xxx, ...

4. Who else (what other institutions) has a key role in DW, WW and RH?

4A. What are **their main roles and responsibilities**?

(brief, see how they describe these broadly)

4B. Do **efforts or actions of this institute connect with those of other institutions**? How? (**overlap in institutional goals and activities? inter-institutional coordination?**)

[Probe into: **multi-level or scale linkages**, with who, how they work, how well they work; **Direction of relationships**: who helps who? Do you help others? Do others help you?]

4C. Are these **connections helpful** to achieve DW, WW and RH goals?

[Probe into: *Communication and interactions*: Collaboration, deliberation, trust, respect]

4D. Are there **conflicts** between your roles and responsibilities?

[Refer back to Q1 responses (their role in DW, WW and RH) for probes and clarification]

5. How well do you think your institution meets its goals, and responsibilities?

[Probe into: **Level of success of their actions and efforts**]

[Note: If they say, "oh, we do everything perfectly" then I will probe into the problems identified above, their role in addressing them, how responsible they are to help improve those situations, and who needs to do what to improve them]

5A. What **factors facilitate or inhibit** achieving institutional goals?

5B. Depending on responses here an in Q3 (current DW, WW and RH situation and trends), I might ask: **Are these efforts addressing the extent and severity of problems identified**?

[Probe into specific efforts, policies, regulations, programs to address problems related to DW, WW, and RH and improve negative impacts on ecological and human health]

[Notice where blame is placed on others]

5C. How well do other institutions meet theirs? (brief about other institutions)

Desired changes and description of 'ideal' governance for DW, WW and RH

6. What things do you think **need to be changed** in order to meet institutional/community goals and improve DW, WW and RH? What needs to be done?

Listen for and probe into attributes of 'good' governance:

<u>Who is involved</u>: participation, polycentricity

<u>Communication and interactions</u>: collaboration, deliberation, trust, respect

Decision-making: transparency, knowledge and information, consensus-focus, conflict resolution, context-based, effectiveness,
Outcomes: accountability, responsive/effective/efficient, equality/equity/universality, follows law, sustainability, rule compliance
Adaptiveness: leadership, self-governance authority, learning, M&E, uncertainty, prepare for change, strategic vision
[NOTE TO SELF: BE OPEN TO ADDING new categories or sub-categories!]

[Note: If interviewee responds, "All we need is money" then I would probe into what they would do with that money and how those actions would be carried out, etc. If interviewee responds "*they* just need to do their job better" then I would probe into why *they* aren't doing it well and probe into description of what would actually change and how if they did do their job better.]

During above discussion ask:
6A. Who should take these actions or be responsible for them?
6B. What is needed in order to make these changes?
6C. How possible or likely is it to get those needs met? What would it depend on?

After this discussion, I will say something like: You have been mentioning what you think needs to happen in order to make changes and improve rural DW, WW and RH. In a sense you are describing what you see as the ideal way rural DW, WW and RH issues would be managed. I hear you saying that ideally A, B, and C would be present in this ideal system and X, Y and Z would occur.

7. How would you describe the ideal system to manage or govern rural DW, WW and RH? In other words, **what would you like** management and policies for WW, DW and RH to look like **in the future**?

Use what I learned above, but still listen for and probe into attributes of 'good' governance:
Who is involved [**Ex Qs.** Who would be involved? What connections should there be between institutions at different levels/scales?]
Communication and interactions: [**Ex Qs.** What would institutional interactions look like? How would competing needs be met or conflicting goals be managed?]
Decision-making: [**Ex Qs.** How would decisions be made? What would the process look like?]
Outcomes: [**Ex Qs.** What outcomes are desired from decision-making process? And from the management/governance process as a whole?]
Adaptiveness: [**Ex Qs.** What's needed to be able to respond to social, political or environmental changes over time?]

7A. What connections should there be between DW, WW and RH? Are these separate goals? Should they be managed together or separately? Why? [Probe into details]

Additional potential probes:
Q. Does "Attribute X" exist in current governance process? In what form? Explain.
Q. Would you like to see "Attribute X" existing? Would others like to see this? Why or why not?

[Note to self: Refer to sheet with 'good' governance attribute categories and sub-categories in my notebook, and mark those that they mention, in order to probe well]

Closing statements and questions

- Do you have any additional comments for me?
- Do you have any questions for me?
- Is there anything that you think I should have asked you, but did not?
- Who else would you recommend that I talk to about these topics? [Probe for: different stakeholder groups and potentially different perspectives on relevant issues]
- [Ask only when appropriate: I would like to know if I can send you a summary of our conversation (or the interview transcript) to give you the opportunity to review it and make any necessary changes. The purpose would be to ensure that I have understood our conversation today. Can I send you the summary/transcript for your revision?]
- Would you be interested in receiving a report with the findings from my research about water in this region?
- [Ask only when appropriate: After I have completed these interviews it is possible that I will help organize some workshops where people from the CBWWA can discuss water-related issues in this region. Would you be interested in participating in something like this? Why or why not? Probe into potential formats or topics for the workshops.]
- Thank you for your support in this effort and for taking your time to talk with me about these topics. I wish you the best in all of your efforts and work. We will be in contact soon. Thanks again.

Post-interview notes and reflections

- Anything new that I learned from this interview?
- Today, how am I seeing the whole picture?
- What other questions should I be asking and to who?
- Are there any questions that don't work or are awkward? Should I revise or rephrase?
- Overall reflections of how things are fitting into my disciplinary research, interdisciplinary research ideas.
- Anything particular I should be communicating to my team about this?
- Anything particular I should be communicating to my committee about this?
- Add to this list as I keep these notes and my field journal.

Appendix B. Institutional Review Board Research Approval Letter

University of Idaho

Office of Research Assurances
Institutional Review Board
PO Box 443010
Moscow ID 83844-3010

Phone: 208-885-6162
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To: J.D. Wulfhorst
Cc: Renée Hill

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

IRB No.: IRB00000843

FWA: FWA00005639

Date: Approved as Exempt June 9, 2011

Project: 10-295 has been approved as Exempt under Cat 2
'Taking an interdiscplinary approarch to exploring social dimensions of rual watershed management and conservation in Costa Rica'

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the above-named project is approved as exempt from review by the Committee. Please note, however, that you should make every effort to ensure that your project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Traci Craig