A MIXED-METHODS ANALYSIS OF AGRICULTURAL ADAPTATION TO WATER STRESS

by

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This thesis is dedicated to the village of journalists who raised me to believe that among the greatest contributions we can make to this world is our written word.

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ABSTRACT

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The future success of agriculture in arid and semi-arid areas globally will be highly dependent on the ability of farmers and agricultural systems to adapt to climate change. Most of these areas, though tremendously productive, suffer from the same limiting resource: water. As that resource becomes more scarce and availability more difficult to predict, water managers and farmers will be forced to implement new, creative solutions to water supply challenges. This anticipated exposure suggests that an improved understanding of agricultural adaptation to water stress in such areas is critical to successful outcomes in these regions under a changing climate. This work focuses specifically on the adaptation strategies employed by farmers, strategies which are determined by farmers' assessment of their exposure and sensitivity to a stressor as well as their capacity to implement changes. This process of implementing change to limit vulnerability is broadly referred to as adaptation.

This project focuses on the Eastern Snake Plain of southeastern Idaho as a case study in agricultural adaptation to increased water stress. The Eastern Snake Plain (ESP) is a diverse and productive agricultural basin in the inter-mountain region of the American West. The region's primary products are potatoes, sugar beets, barley, and alfalfa, as well as a significant volume of livestock dominated by dairy cattle, and each of these products forms a significant share of the total US market for that crop. More than 74% of this agricultural land is irrigated, inextricably tying both the future of agriculture and the future of the Idaho economy to water in the state. In the mid-2000's, legislators and water managers from across the plain came together to negotiate a new water rights settlement, now known as the Eastern Snake Plain Aquifer Comprehensive Aquifer Management Plan (CAMP). The negotiations came in response to years of litigation involving groundwater and surface water conjunctive management in the region, and the resulting plan was designed to accomplish three goals: stabilize reach gains in the lower Eastern Snake Plain, replenish Eastern Snake Plain Aquifer (ESPA) levels, and ensure sustainable water resources for

agricultural, industrial, and domestic users across the basin. Though the water settlement was not directly caused by climate change, it is likely that water shortages will become more frequent under climate change, and this settlement represents a simulation of just such a shortage.

Broadly, this work and the work of collaborators hope to understand adaptation and decision-making of groundwater farmers throughout the Eastern Snake Plain as they adapt to the on-average 12.9% reduction in water availability. This thesis is divided into three primary sections (Chapters 2, 3, and 4).

Chapter 2 investigates tradeoffs in adaptation decision making, employing semi-structured interviews to learn more about tradeoffs as a framework for understanding adaptation more broadly. In particular, the work seeks to understand the types of tradeoffs present in ESP adaptation and when and how tradeoffs are implicitly or explicitly acknowledged. Findings indicate that tradeoffs occur both at the individual and regional scale and that shifts in crop patterns and irrigation water sourcing may have important implications for adaptation policy moving forward.

Chapter 3 employs a household survey and statistical analysis to investigate the iterative and complex relationships between exposure, adaptive capacity, sensitivity, and vulnerability. As an early attempt to examine these relationships quantitatively in the context of US agriculture and water stress, the works focuses on laying out a clear theoretical and methodological framework for continued exploration of adaptation and vulnerability in this context. Findings indicate that under-theorized components of adaptive capacity like linking capacity and exposure to simultaneous stressors may play important roles in determining farmer vulnerability in the context of policy-induced water scarcity.

Chapter 4 is designed to investigate and develop a novel tool for exploratory work in adaptation, examining the feasibility and predictive accuracy of an agent-based model of agricultural adaptation driven by social-psychological decision-making theories and parameterized using both secondary data sources and primary fieldwork. Findings indicate that such models may have the potential to produce well-informed macro-level patterns based on theoretically-informed micro-level inputs. This has important implications for the broader agent-base modeling community, and the work concludes with a call for further collaboration between agent-based modelers and social science theorists.

Collectively, this work seeks to inform theory on agricultural adaptation and vulnerability, as well as explore the potential role of theoretically-informed agent-based modeling in investigating such dynamics. In doing so, it lays the groundwork for future exploration of these ideas in the Eastern Snake Plain and throughout the arid American West.

CHAPTER 1. INTRODUCTION

The future success of agriculture in arid and semi-arid areas globally will be highly dependent on the ability of farmers and agricultural systems to adapt to climate change. In many areas, climate change is expected to cause shifts in temperature, precipitation, and seasonal variability, as well as more frequent extreme events (Isik and Devadoss). Impacts on arid and semi-arid agricultural regions are expected to be particularly severe as climate change exacerbates existing water stress in many areas (Elliott et al.). This anticipated susceptibility suggests that an improved understanding of social-ecological vulnerability and adaptation in such areas is critical to successful outcomes under a changing climate (Burnham et al.). However, existing methods for assessing vulnerability and adaptive capacity are limited for several reasons. First, adaptation occurs not only at the level of the individual farmer but also at the organizational level as institutions react to the shifting natural context (Pérez et al.; Eakin, York, et al.). In addition, adaptation decision-making spaces do not remain constant, but shift both with the shifting climate and as a result of earlier adaptation decisions by individuals and organizations (Burnham and Ma, "Climate Change Adaptation: Factors Influencing Chinese Smallholder Farmers' Perceived Self-Efficacy and Adaptation Intent"; Fawcett et al.; Feola and Binder; Bennett et al.). Finally, farmers and other actors do not face only one form of risk at any one time, and these decision-making spaces overlap and shape one another in complex and unpredictable ways (Wood et al.). This Master of Science thesis attempts to address these limitations through an improved understanding of adaptation decision making and vulnerability in semi-arid agriculture, as well as the exploration of a novel method for understanding adaptation and adaptation outcomes in such a setting.

1.1 Project Description and Context

The project described herein forms an early component of a larger project aiming to build upon literature in adaptation and vulnerability. This larger project, a collaboration between Purdue University, Idaho State University, Boise State University, and the University of Idaho, focuses on the Eastern Snake Plain of southeastern Idaho as a case study in adaptation to increased water stress in semi-arid, irrigated agriculture. Though the water policy which created this stress was not caused solely by climate change, it is likely that water shortages will become more frequent under climate change, and this settlement is a simulation of such a shortage.

The Eastern Snake Plain is an arid agricultural basin in the inter-mountain region of the American West, producing a wide variety of crops, in particular potatoes, sugar beets, alfalfa, and wheat (USDA National Agricultural Statistics Service, "USDA National Agricultural Statistics Service Cropland Data Layer"). A significant volume of livestock dominated by dairy cattle also call the plain home (USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"). More than 74% of this agricultural land is irrigated, inextricably tying both the future of the area's agriculture and the future of the Idaho economy to water in the state (USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"). The Eastern Snake Plain was selected for analysis as a result of the 2014 introduction of a unique groundwater use restriction across the Plain, a consequence of nearly 30 years of legal proceedings and scientific studies. In 1984 as part of the Swan Falls Agreement, the state of Idaho elected to undergo a complete adjudication of water rights in the Snake River Basin, a process that led to a reconsideration of surface and groundwater management in the state (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). Following this, in the 1986 State Water Plan, the Idaho Water Resources Board recognized the need to conjunctively manage[1] the Eastern Snake Plain Aquifer[2] and surface water throughout the basin. Over the next two decades, two parallel processes set the stage for this conjunctive management: the Snake River Basin Adjudication and Eastern Snake Plain Aquifer hydrologic modeling.

The Snake River Basin Adjudication resulted in a complete record of all consumptive use permits in the Snake River Basin, allowing senior[3] water users to more effectively pursue litigation to ensure their access to sufficient water. The Eastern Snake Plain Aquifer hydrologic model provided scientific grounding for the policy of conjunctive management, providing users and the

[1] Conjunctive management refers to the linked issuing and adjudication of water rights in ground and surface water systems. In the state of Idaho, conjunctive management is required whenever "a hydraulic connection exists between ground and surface water" (Idaho Department of Water Resources, *Idaho State Water Plan*).
[2] The Eastern Snake Plain Aquifer is commonly referenced both in this document and throughout discussion of the region. That said, this phrase actually refers to a collection of basaltic and sedimentary aquifers throughout the region. A more thorough description can be found at (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*).
[3] "Senior" and "junior" water rights holders refer to water users with water rights older and younger, respectively. This is in keeping with the principle of prior appropriations, which states that older water rights have primary claim to available water. In Idaho, senior rights can also refer to rights older than 1972 and junior rights the inverse.

courts with a reference for the impacts of groundwater withdrawal across the basin (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). Both the model and historical record showed dramatic decreases in water levels across the aquifer, and this fall in water levels could now also be tied to falling surface water gains[4] across the basin. Across the Eastern Snake Plain, ground water rights are predominantly junior, setting the stage for large-scale litigation on behalf of surface water users in an effort to limit ground water extraction across the basin (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). In the mid-2000's, a large-scale suit threatened to fallow between a quarter- and a half-million acres in the upper[5] Eastern Snake Plain in what would have been a crippling blow to the region's economy (du Bray et al.). As a result, legislators and water managers from across the plain came together to negotiate a new water rights settlement, now known as the Eastern Snake Plain Aquifer (ESPA) Comprehensive Aquifer Management Plan (CAMP) (Idaho Department of Water Resources, *Idaho State Water Plan*). The resulting plan was designed to accomplish three goals: stabilize reach gains in the lower Eastern Snake Plain, replenish ESPA levels, and ensure sustainable water resources for agricultural, industrial, and domestic users across the basin (du Bray et al.).

1.2 Research Description

Through this thesis, I pursue an improved understanding of agricultural adaptation to water scarcity in irrigated, highly industrialized agricultural systems; the Eastern Snake Plain serves as a case study for this. The larger collaborative study is working to understand the perceptions, decision making, and adaptation pathways of groundwater farmers throughout the Eastern Snake Plain as they adapt to the on-average 13% reduction in water availability. This thesis is the culmination of work designed to support that collaborative effort, presented in a multi-paper format composed of this introduction, three articles, and one summary chapter. My specific objectives in this thesis are two-fold. First, I seek to generate an initial analysis of the vulnerability, adaptive capacity, and adaptation decision-making of Idaho farmers in response to recent water

[4] Gains refers to the "surfacing" of ground water into streams and rivers. Referred to as reach gains when describing a specific stretch or "reach", this source of water contributes heavily to surface water in the western half of the Eastern Snake Plain.

[5] Upper and lower Eastern Snake Plain are used interchangeably with eastern and western Eastern Snake Plain, respectively. This terminology references the east-to-west flow of the Snake River throughout the plain.

use restrictions, particularly focusing on tradeoffs as drivers of adaptation decision making and farmer characteristics as predictors of vulnerability to policy-driven water scarcity. Second, I aim to establish a theoretical foundation for the integration of descriptive decision-making theory into agent-based modeling of adaptation in agricultural systems. The first objective is addressed in Chapters 2 and 3, while the final objective is addressed in Chapter 4 and is the primary subject of future work.

Chapter 2 presents a qualitative analysis of adaptation decision making in ESP agriculture, paying particular attention to the role of tradeoffs in shaping adaptation. Supported by semi-structured interviews with farmers across the Eastern Snake Plain, this analysis is used both to inform theory in this context and to inform and structure the following two chapters. The second section presents a quantitative analysis of farmer vulnerability to water scarcity, employing both multimodel selection and inference and a population segmentation analysis. This work is presented in Chapter 3. This approach allows a multi-dimensional view of vulnerability in the Eastern Snake Plain, examining drivers of vulnerability and how those drivers and outcomes vary across the population of farmers. The final analytical chapter examines a novel tool for exploratory work in adaptation, examining both the feasibility and implications of theory-based agent-based modeling as it relates to the study of agricultural adaptation. Chapter 4 focuses on the development and analysis of the produced agent-based model. Some of the research questions identified in Chapter 4 remain to be addressed in future work. Broadly, this future work will use the model to investigate adaptation practices, resilience, and hidden vulnerabilities in the ESPA agricultural system, incorporating data from the quantitative and qualitative sections of this thesis to enhance model performance. Chapter 5 presents overall conclusions and recommendations from this project.

1.3 Research Questions

1.3.1 Paper 1

RQ1: What individual-scale and multi-scalar tradeoffs emerge in the context of adaptation to water scarcity in the Eastern Snake Plain?

RQ2: To what degree do ESP farmers actively or passively engage with individual or collective tradeoffs in water use planning?

1.3.2 Paper 2

RQ1: What components of sensitivity, adaptive capacity, and exposure are most determinate of who is vulnerable to policy-driven reduced water availability?

RQ2: How are the drivers of vulnerability distributed within the population, and to what degree does this distribution result in differential vulnerability among farmers?

1.3.3 Paper 3

RQ1: Of the theories selected, which most effectively predicts crop patterns among Idaho farmers? Which most effectively predicts crop patterns adaptation?

RQ2: What limitations exist in translating social theory to model operationalization?

RQ3: To what degree can theory-driven agent-based models be parameterized with secondary data to support rapid, exploratory assessment of adaptation in novel contexts?

CHAPTER 2. USING A TRADEOFFS-FOCUSED ANALYTICAL LENS TO EXAMINE ADAPTATION DECISION MAKING IN THE EASTERN SNAKE PLAIN OF IDAHO

2.1 Abstract

Tradeoffs are a central component in understanding complex systems management, applied across disciplines as a framework for describing compromises across competing ideals, approaches, or outcomes. By integrating tradeoffs conceptualizations in psychology, economics, and ecosystem services, this work develops and uses a tradeoffs-focused analytical lens to understand adaptation decision making in complex systems. In particular, by analyzing the adaptation of a highly industrialized agriculture system in the Eastern Snake Plain of Idaho to policy-imposed water scarcity, this paper seeks to understand public and private adaptation as products of intertemporal, multi-scalar interactions of individual and collective value systems. We conducted and analyzed 20 semi-structured interviews with agricultural producers. Through these interviews, we found that individual farmers are faced with a variety of tradeoffs which can shape their adaptation decision making simultaneously. These include tradeoffs in soil health and water conservation, tradeoffs in farming identity and economic stability, and tradeoffs in tradition and successful adaptation. Collectively, individual decisions around these tradeoffs can interact with policy to generate a variety of potential tradeoffs at the regional scale. For example, water savings may come at the expense of reduced production of key agricultural crops, while continued productivity could exact a toll on key surface water infrastructures. Our results suggest that such intertemporal and multi-scalar interactions come together to shape individual and collective outcomes in the face of policy-induced water scarcity. Overall, our results highlight a selection of tradeoffs with particular relevance to the development of adaptation policies and programs, suggesting tradeoffs as a useful lens for envisioning adaptation across contexts.

2.2 Introduction

Adaptation to climate change is a context-dependent, intertemporal, and multi-scalar process that involves a variety of individual and organizational actors. Each individual and organization has a unique history and value-set that will frame adaptation decisions, and institutions and social-ecological context at each scale further shape decisions. Thus, adaptation is not a single decision or set of decisions, but rather a collection of beliefs, values, and actions that together comprise an individual or organization's response to environmental change; these beliefs, values, and actions change over time, both in response to environmental change and as a result of adaptation itself (Carr). Additionally, adaptation is inevitably multi-scalar, comprised of both public and private adaptation efforts (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"; Eakin, Lerner, et al.). Multi-scalar processes are invariably challenging to understand and can become nearly illegible when divorced from their context. Thus, adaptation research is traditionally highly context-dependent and can struggle to generalize to other locations. A variety of analytical lenses have been used in the examination of adaptation, particularly in the context of climate change (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"); these include adaptation governance, adaptive capacity and social capital, risk management, livelihoods, and vulnerability. While each of these lenses has proven invaluable for improving our understanding of adaptation in context, less has been done to acknowledge and document the inevitable tradeoffs (explicit or implicit) associated with each adaptation decision (Weber et al.). In this work, we develop and apply an analytical lens for the study of adaptation to environmental change: tradeoffs. In doing so, we suggest that the lens may offer insights into decision making across contexts and may permit more effective comparison of case studies.

Tradeoffs are a common research heuristic in several academic disciplines involved in the study of adaptation, including psychology, economics, and ecosystem services (e.g. Jennings; Pfister; Howe et al., "Creating Win-Wins from Trade-Offs? Ecosystem Services for Human Well-Being: A Meta-Analysis of Ecosystem Service Trade-Offs and Synergies in the Real World"). Tradeoffs take different forms in each discipline, but the guiding principle remains the same and is well expressed by the Merriam-Webster dictionary entry for trade-off: "a balancing of factors all of which are not attainable at the same time" ("Trade-off | Definition of Trade-off by Merriam-

Webster")[6]. In other words, tradeoffs may be essentialized as a compromise between multiple values in achieving an acceptable outcome. Disciplinary differences in the conceptualization of tradeoffs rest primarily in the scale investigated and the factors at play in each case. For example, in ecosystem services studies, tradeoffs occur between outcomes in the form of environmental, economic, or social benefits at the scale of watersheds or another ecological unit, while in psychology, tradeoffs occur between choices imbued with value at the scale of the individual or deciding group.

In psychology, tradeoffs are most often used in the context of internal values; values are defined broadly as "internalized cognitive structures that guide choices by evoking a sense of right and wrong…, a sense of priorities…, and a willingness to make meaning" (Oyserman). Values are ascribed a wide variety of characteristics in psychology, many of which are relevant for their roles in decision making. Values can be both individual and collective; they can influence affective (feeling) and cognitive (thinking) process; they can be implicitly or explicitly associated with a choice (Oyserman). Of course, in any given situation, multiple values may play a role in decision making, thus resulting in synergies or conflict (i.e. tradeoffs) between values. Values are constructive in the sense that they shape the valence (positive or negative) associated with an object. Therefore, the primary contribution of the psychology literature is the conceptualization of tradeoffs as a compromise of values.

This foundation of a value-centered framework is then re-oriented with the integration of economic and ecosystem services conceptualizations of tradeoffs. Tradeoffs are an inherent component of economic analysis, seeing explicit engagement in the context of cost-benefit analysis (Maass); in association with exchanges of values (e.g. equity and efficiency) (Jennings); and in efforts to understand the nature of intertemporal tradeoffs (i.e. discounting effects) (Scholten and Read) among others. This conceptualization of values informs our "commodification" of values as an object of exchange within and across scales of adaptation decision making. Finally, the ecosystem service literature has engaged with tradeoffs of services across time, space, and scale; in doing so, researchers investigate the most efficient resource outcomes in terms of ecosystem services while also considering the implications for the service changes on individuals (Howe et al., "Creating Win-Wins from Trade-Offs? Ecosystem Services for Human Well-Being: A Meta-

[6] There is disagreement in the use of tradeoff and trade-off. For the purposes of this paper, we use the unhyphenated tradeoff, since this is most common in psychology, and this paper is most tied to that body of literature.

Analysis of Ecosystem Service Trade-Offs and Synergies in the Real World"; White et al.; Deng et al.). This third body of literature is in some ways an outgrowth of the first two. By conceptualizing value broadly, ecosystem services scholars are able to incorporate the breadth of services provided by an ecosystem (Daily). By operationalizing this value narrowly as economic value, they are then able to commodify these values in a way that allows for simple cross-comparison (Daily).

Therefore, we draw on a parallel line of thought to integrate these three lines of research into a cohesive framework of tradeoffs in adaptation. Combining tradeoffs conceptualizations from psychology and economics, we consider tradeoffs as a lens for understanding exchanges in values present in adaptation decision making. As described earlier, adaptation is an intertemporal, multi-scalar process that is influenced by interactions with adaptation actions at other times, place, and scales. Thus, by integrating some components of tradeoffs from ecosystem services, we are able to generate a conceptualization of tradeoffs across three axes relevant to the analysis of adaptation: space, time, and scale. As such, this conceptualization is applicable to decision making in any number of locations, on all relevant time horizons, at a variety of institutional and individual scales, and across environmental, social, and economic axes of value.

Employing this conceptualization, we invoke a synthesized analytical framework and apply it to a case study of adaptation to water scarcity in the Eastern Snake Plain of Idaho. In doing so, we ask the following research questions. First, what individual-scale and multi-scalar tradeoffs emerge in the context of adaptation to water scarcity in the Eastern Snake Plain? Further, to what degree do ESP farmers actively or passively engage with individual or collective tradeoffs in water use planning?

2.3 Methods

2.3.1 Case study context

The Eastern Snake Plain is a highly industrialized, highly productive agricultural valley running through the center of southern Idaho. The basin produces significant fractions of the potatoes, sugar beets, alfalfa, and dairy products in the United States (USDA National Agricultural Statistics Service, "USDA National Agricultural Statistics Service Cropland Data Layer"; USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"). Nearly three quarters of the productive acres in the basin rely on irrigation water, and nearly forty percent of this irrigation water is groundwater, most of which is from the Eastern Snake Plain Aquifer (ESPA) (USDA National Agricultural Statistics Service, *2012 Census of Agriculture: Farm and Ranch Irrigation Survey*; USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data").

The ESPA is a complex of hydraulically connected sedimentary and basaltic aquifers throughout the region (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). Water levels in the aquifer complex peaked in the mid-twentieth century following decades of flood irrigation throughout the plain and proceeded to drop back to and below pre-colonial levels as irrigation methods became more efficient and groundwater withdrawals intensified. In the mid-1980's, the state of Idaho undertook both an adjudication of water rights throughout the Eastern Snake Plain and an intensified modeling effort of the ESPA. At the same time, surface water streams fed by the aquifer complex began to dry up throughout the lower basin. Idaho water law is governed by the principle of prior appropriations, meaning that the oldest water rights have first claim to water; in general, surface water rights in the basin tend to be senior to groundwater.

These forces combined to result in a large-scale lawsuit leveed by senior surface water users against junior groundwater users, threatening to fallow more than a quarter million acres in the upper basin. In order to avoid what would have been a crippling blow to the region's economy, representatives of both sides worked to generate what would come to be known as the ESPA Comprehensive Aquifer Management Plan (CAMP). While this effort prevented the fallowing of the groundwater acreage, it required groundwater users throughout eight groundwater districts to cut or offset an average of 12.9% of their annual groundwater use. This policy-imposed water scarcity is the subject of this study, in which we seek to understand adaptation decision making in highly industrialized agriculture through the lens of multi-scalar tradeoffs.

2.3.2 Data collection

As an exploratory case study of adaptation dynamics across scales and across types of water users, this study employed a qualitative method of analysis supported by survey results from a previous survey of the study population (Hawes et al.; du Bray et al.; Running, Wardropper, et al.). Semi-structured interviews were conducted with 20 agricultural producers in the Eastern

Snake Plain, including farmers, dairy and livestock owners, and producers involved in some combination of these. Interviewees were identified through a combination of purposive sampling from an existing sampling frame and snowball sampling in which each interviewee was asked to identify other possible respondents (for more information on the existing sampling frame, see Chapter 3 of this document - Hawes, Burnham, Hillis, & Ma, 2019). Purposive sampling targeted agricultural producers with location, demographics, groundwater rights, and livelihood basis in mind. By purposively sampling from a diversity of areas, including both upper and lower Eastern Snake Plain, we aimed to examine variation across groundwater districts while also describing general trends in adaptation decision making in the basin. We also targeted farmers from a diversity of demographic groups, including variation in age, education level, and farm operation size. The other two requirements imposed were that producers had a non-trivial share of groundwater rights and that they farmed for a significant portion of their livelihood (extensive farming in support of dairy operations was considered to meet this criterion).

Each interview was conducted by the first author, lasted between one hour and two hours, and was composed of four sections.[7] The first section focused on a qualitative and quantitative characterization of the producer's operation. The second section moved to specific questions relating to the producer's decision-making practices. The third section focused on tradeoffs, digging deeper into producer decision making and engaging with the "selection of different types of benefits" (i.e. tradeoffs). The final section addressed the water rights settlement agreement[8] specifically, attempting to outline the impacts of the agreement on the producer. For more details, the interview protocol can be found in Appendix A. Thematic saturation was reached after 15 interviews, and 5 additional interviews were used to confirm saturation (Ando et al.).

2.3.3 Analytical framework

A preliminary analytical framework generated through the synthesis of interdisciplinary tradeoffs literature was used to outline the codebook prior to coding. That outline was then modified throughout the preliminary coding process, ultimately resulting in a theoretically-grounded, empirically-informed framework (Figure 1). This framework has three primary

[7] A subset of interviews contained a fifth section related to irrigation practices and land-use transitions. Though this section was designed for a secondary project, it was also coded as material for this study as irrigation transitions are highly relevant to water scarcity adaptation.

[8] In common speech through southeastern Idaho, the ESPA CAMP is referred to interchangeably as the "settlement agreement" or "water rights settlement." We adopt this custom as well.

dimensions: the scalar dimension (individual to landscape), the temporal dimension, and the "tradeoffs dimension" (from decision to (mal)adaptation [9] outcomes). Fundamentally, this framework conceptualizes tradeoffs as a disconnect between values and outcomes, most often due to exogenous (mediating) factors.

Important implications emerge from the framework. First, questions can and must be asked both within scales and across scales, both temporal and scalar (e.g. How do short-term adaptation actions influence long-term evolution of values? How do individual values translate to or impact public adaptation decisions (policies)?). Second, the framework generates a variety of internal questions on its conceptualization (e.g. conceptualization of objects like "landscape-scale values"; implied separation between cognition and "reality").

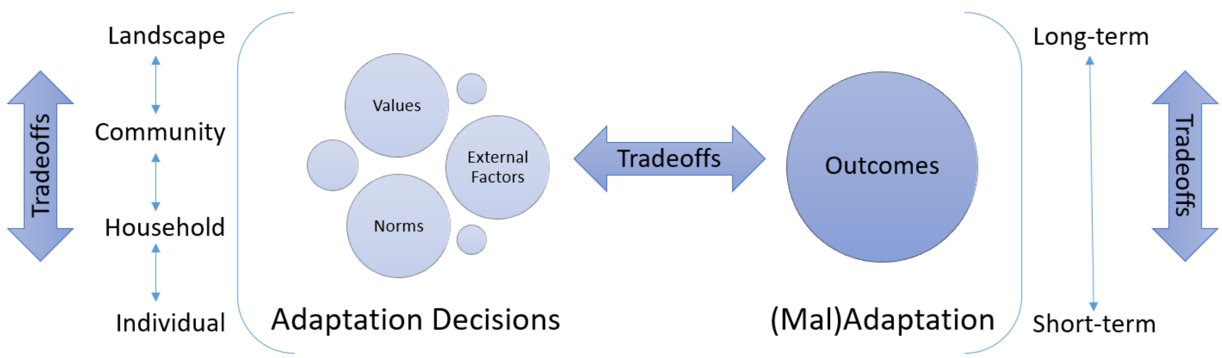


Figure 1 - The emergence of mutli-scalar, intertemporal tradeoffs in adaptation. Tradeoffs are conceptualized as emerging from decision making and adaptation actions, across spatial and temporal scales. In this work, we focus on individual farmers as the site of tradeoffs, attempting to understand how tradeoffs emerge at the individual level and at the regional level as a result of farmer value-sets mediated by external factors.

This paper does not seek to answer all of those questions, rather reserving them for the forthcoming work addressing the framework more generally (Nixon et al.). Instead, this analysis focuses on the role of values within the tradeoffs framework as a core component of decision making that can be operationalized across scales. This generates the following guiding questions.

[9] Recent research has observed that the success of adaptation outcomes is far from a foregone conclusion, and adaptive actions may either build or undermine capacity; thus, these actions are termed (mal)adaptation to denote their obscured valence (Fischer, "Pathways of Adaptation to External Stressors in Coastal Natural-Resource-Dependent Communities: Implications for Climate Change"; W. N. Adger; Mortreux and Barnett).

First, what tradeoffs are generated with respect to individual values in individual (mal)adaptation to water scarcity in southeastern Idaho? What mediating factors are most often cited as playing a role in these tradeoffs? Do certain values appear more or less often in tradeoff situations? Second, how are individual values reflected or obscured in public adaptation actions? Are certain individuals more or less likely to feel that their values are reflected? Finally, what implications do these observed tradeoffs have for future adaptation policy in the Eastern Snake Plain?

2.3.4 Data analysis

To address these questions, interviews were analyzed via inductive coding (Saldana; Ryan and Bernard). As described, theoretically informed categories were hypothesized before coding began and were ultimately informed by the structure of the data as coding progressed. The codebook and analytical framework evolved in parallel during the development of this first case study. Coding took place in two primary stages and took place in parallel in two case studies, the Eastern Snake Plain, Idaho and Khyber Pakhtunkhwa, Pakistan (Nixon and Ma). Preliminary coding employed the hypothesized structure, looking for patterns in the data and generating a variety of sub-codes and themes that fit within the structure. After preliminary coding, repetitive or uninformative codes were integrated into other codes and the first iterations of the current framework emerged. Using this new understanding of the data, the research team generated a refined analytical framework to be applied in both case studies. Secondary coding then occurred separately for each case study, focusing on more completely identifying and examining values, mediating factors, and mal/adaptation actions across scales. By partially coupling the coding process, the team ultimately hopes to be able to test the ability of the analytical lens to generalize across contexts. This case study serves as a preliminary, stand-alone work aimed at more completely understanding adaptation in the Eastern Snake Plain. Data analysis was conducted in NVivo by the first author. A copy of the completed codebook can be found in Appendix B.

More information on adaptation actions cited below can be found in a parallel effort describing the form and function of adaptation actions in the Eastern Snake Plain based on a household survey (Running, Wardropper, et al.). The survey was sent to a sampling frame composed of 1,131 groundwater farmers from several online databases, and the final response rate was 23.1% (Hawes et al.). Survey results were multiply imputed in R using the mice package before being analyzed in Stata (R Core Team; van Buuren and Groothuis-Oudshoorn; StataCorp).

2.4 Results and discussion

Our results are made up of four primary components. In the first three sections, we address the components of tradeoffs: values, mediating factors, and (mal)adaptation (Table 1). In the final section, we analyze the tradeoffs generated by this combination of values, mediation, and actions.

Table 1 - Values, mediating factors, and (mal)adaptation observed in the Eastern Snake Plain agricultural basin in the aftermath of the CAMP

Values (I – Indiv., C – Collective)	Mediating Factors	(Mal)Adaptation (C – Cropping, L – Lifestyle, I – Infra, M – Mgmt)
Efficiency (I)	Material Capital	Changing rotation (C)
Stability (I)	Livestock	Less water-intensive crop (C)
Tradition (I)	Rotations	Changing tilling strat. (C)
Steward (I)	Crop Health	Reduced spending (L)
Certainty (I)	Enforcement	New job/business (L)
Sustainability (C)	Social Influence	Irrigation infra. efficiency (I)
Equity (C)		Switch irrigation infra. (I)
Science-Based Policy (C)		Irrigate less land (M)
		Use canal water (M)
		Precision agriculture (M)

2.4.1 Values in the Eastern Snake Plain

2.4.1.1 Key values among farmers

At the core of our operationalization of the tradeoffs framework of adaptation is a set a values that drive behavior. Values have been a core focus of cross-cultural psychologists for nearly half a century, and we employ them as a first-step in a framework analyzing adaptation across cultures, contexts, and scales (Hills). Values and value orientation have also been a subject of frequent study in the context of agricultural sustainability, and this work builds on existing literature in identifying values core to the adoption of management practices (Roesch-McNally et al.; Small et al.). Analysis of farmer interviews revealed five key values of interest to adaptation planning in the Eastern Snake Plain.

2.4.1.1.1 Efficiency

A spirit of efficiency seems to pervade the farming community in Idaho. Given a specific set of resources, farmers try to forge the most productive path. This, of course, comes with its own set of tradeoffs, including frequent up-front investment in improved technology. When asked whether they would choose a less thirsty crop or a higher infrastructure investment, one respondent laid out the underlying driver plainly:

> *"I would think the efficiency would come in first, depending on whether you was growing grain … Efficiency is still efficiency. Really the only one that I can see that's gonna benefit [from less efficient water infrastructure] would be Idaho Power because your pumps have to run longer."*

This farmer, a second-generation man-of-many-hats, ran an assortment of side businesses with his wife while working alongside two farmers who managed his land. As both landlords and small-businesspeople, they spoke at length on the ways in which efficiency shaped their decision making. Within academic analysis of farm performance (e.g. agricultural economics), efficiency has long appeared as a central characteristic of study (Coelli). Efficiency has been theorized as a resource-specific measure of unit productivity per unit use (Ondersteijn et al.). Of course, in the conceptualization of Eastern Snake Plain farmers, efficiency is broader than the employment of any particular resource, and it is not necessarily connected to economic productivity. Rather, we see efficiency as a general interpretation of productive use of all resources available to the farmer, reminiscent in some ways of productive use mandates for water in the state (Harrington). Productivity in this case can be interpreted as the achieving of any number of goals pursued by the farmer.

For example, in the quote above, efficiency appears as a means to an end. By installing improved infrastructure, it is possible to accomplish three goals. First, the farmer can keep money out of the hands of the region's titans like the power company, a frequent rival for water. Second, they can raise a crop on the newly restricted water allocation. Finally, they can maximize their economic sustainability by opening up new crop choices and saving water for other fields. Of course, those investments are often intensive, and a balancing act is played in achieving efficient use of resources while also maintain economic sustainability.

2.4.1.1.2 Stability: Family and Economic sustainability

In many parts of Idaho, farming is still a family business. For some, land has been in families for generations, and management strategies were adopted from parents. For others, farming is about the current family, supporting those at home. No matter the driver, it's clear that one goal underlies the plans of nearly every farmer as they head for the end of a season: stay in business one more year. Acknowledging this, one farmer pointed out that the best laid plans are contingent on their ability to make ends meet at the end of the year:

> *"I always come back to - it has to work out financially on paper. If it does not, then is it a good thing? Yes, it's a good thing, but I just can't afford to do that good thing."*

One of the most thoroughly studied factors in farm management, the perceived profitability of an action is discussed in a variety of bodies of literature as a central component of farmer decision making (e.g. Miranowski & Hammes, 1984; Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008; Suri et al., 2019; Traore, Landry, & Amara, 1998). This perception of profitability is intimately related to a farmers' overall perception of the management action, and it is informed by social relationships and experience (Cary and Wilkinson).

Ultimately, this focus on profitability leads to a fundamental challenge for policy-makers interested in water conservation in an irrigated desert. Farming is a business of risk, and farmers face that risk every time they put a seed in the ground. Historically, those risks played out differently for groundwater and surface water farmers. While surface water farmers have always relied on the ditch-runner and canal company, groundwater users have always held their own water use firmly in hand, just a push of a button away from turning on a well:

> *"I [could] just go punch the button and turn it on. Don't have to mess with the canal. Heck with those guys. So, [people] did [switch]."*

This story, told by a canal manager, played out across the basin throughout the mid-twentieth century. This shift not only changed the balance of water withdrawals in the state, it ultimately shifted the relationship of farmers and water; while still always in focus, water no longer represented a significantly limiting resource for most farmers, as groundwater withdrawals have remained largely unregulated to present day. As we discuss later, this shift leaves policy-makers with a conundrum: when farmers are accustomed to doing whatever it takes to make ends meet, how can adaptation policy effectively enforce conservation of a supposedly plentiful resource?

2.4.1.1.3 Tradition: First in time, first in right

Policy that flies in the face of long-established norms is never a simple conflict, and water managers in Southeastern Idaho face this challenge on multiple fronts. Even as policymakers attempt to more strictly regulate groundwater pumping, the Comprehensive Aquifer Management

Plan challenges one of the American West's oldest rules to live by: the doctrine of prior appropriations. The doctrine, enshrined both in law and culture, establishes that water rights senior in age have first claim to water from a water source (Harrington). Under this body of law, water calls (such as those of the early 2000's that threatened to fallow much of the upper basin) were the most effective mechanism for ensuring water delivery (du Bray et al.; Harrington). In turn, the CAMP significantly challenges this doctrine (du Bray et al.). While acknowledging the seniority of lower basin surface water claims, the agreement requires cuts across the board from groundwater districts (ibid). Those districts, in turn, have not elected to fallow entire "junior" farms but rather to distribute cuts across water rights of all ages, a plan that doesn't abide by the long-established rules of the game. As the man-of-many-hats introduced earlier explained, when the rules of the game are known, everyone needs to play by them:

> *"I've got [water rights] anywhere from 1950 to 1981. The state of Idaho states that, you know, first in time/first in [right]. I think. I feel like they've gotten away from that. Well, let's help these other poor little guys out. And I'm one of 'em. That have a junior water right. I believe that somewhere along the line everybody knew the risk that they was getting into when they got into this game. If you have a priority date that falls into this line. I'm sorry to say. They should shut your water off."*

Law historians trace the origins of "first in time, first in right" norms in the American West back long before the establishment of large-scale colonial agriculture (Harrington). Along the same timeline, doctrines of productive use were handed down; thus, water users have developed customs of using their full allotment along with deference to seniority in right (ibid). This tradition of use to the fullest extent is tied closely to the value of efficiency described earlier, and it helps to provide some context for the sense of stewardship expressed by many farmers in the area.

2.4.1.1.4 Steward: Quality of farmer and appearance of farm

For many, farming is a vocation, one that requires considerable skill to stay in business. Each farmer has their own measures of a farmer's worth. For some, the primary measure is economic stability, for others, quality of product. More broadly, research has documented a "productivism" among primary producers, a combined role and set of social norms that play an important role in agricultural decision making (Burton). These measures of both self and other have important implications for farmers' decisions when faced with a fork in the road:

> *"I had one guy tell me there's no such thing as bad farm ground, just inadequate farmers."*

As academics have documented for decades, decision making rarely follows the rules of economic rationality (e.g. Ajzen, 2012; Bamberg & Schmidt, 2003; Feola & Binder, 2010). In a blooming desert, there is value in the pastoral landscape, value that cannot be equated to water or dollars. One farmer, a steward of thousands of acres, explained that the yearly process of planting, nurturing, and harvesting was grounded in years of tradition and experience. His annual routine outlined the patterns of his life:

> *"I enjoy growing these crops. I enjoy seeing that corn kind of like a wall there."*

Intimately related to the academic concept of place attachment, this connection to the pastoral landscape is neither unique to the intermountain west nor to the American farmer and has been documented widely by academics just as it is written on the landscape itself (Running, Burke, et al.; Harrison; Barillas). This, of course, leads to water use dynamics that are difficult to project. As that same farmer explained later, some things just can't come down to the balance sheet:

> *"This is one of my fields. You can kinda see how I've done these corners. It's a one-tire machine. Cost me $4,500 for that pivot. It doesn't pencil out [to a profit], but, you know. The only reason why I have [irrigation] pipe along the edge is I like it to look clean."*

This is deeply embedded in the legacy of the land, the desire to keep the desert green. Obstacles like rock patches and empty corners disrupt this landscape, and that shapes the decisions of farmers interested in preserving it. Their goals, then, extend beyond economic sustainability; many farmers in Idaho seek the sustainability of the greater pastoral landscape in Southeastern Idaho.

2.4.1.1.5 Certainty

This goal is thrown into jeopardy when large-scale transitions face the landscape. Prior to the CAMP, uncertainty around the future of groundwater farming generated widespread anxiety among farmers in the Plain. Though few farmers found themselves excited with how the Settlement Agreement turned out, many were happy that some sort of conclusion had been reached. With the end of negotiations came certainty in the political and economic landscape, at least in the near-term. As one man, a hay and grain farmer who had spent years paying off debt handed down by the previous generation of farmers, explained:

> *"The only good thing about the agreement now is that it's kind of set in stone. You know what is there. Hopefully, we are not going to be paying more lawyers millions of dollars."*

Like many farmers in the Snake Plain, this farmer's take on the settlement was two-fold: now we know what's coming, and now they'll quit giving my money to the lawyers.

Aversion to uncertainty translates beyond large-scale transitions to annual decisions, as well. For many farmers, a perennial stand of alfalfa represents some level of security, a crop that won't get blown out or frosted over before it even gets started. That same farmer explained how certainty impacts his year-to-year decisions, dismissing the risks of some of his fellow farmers as a good way to not last very long as a farmer:

> *"Well, with alfalfa, it's not a seasonal crop. It's a crop that you plant and expect to use for five to six years … We had several years ago when grain went up to $7 or $8. Actually, it went up to $15 for a while … I had a neighbor ask me if I was gonna plow up all my [alfalfa] and plant grain. I said no. I said I learned a long time ago if you stay consistent you might stay in business."*

It is well-documented in the economics literature that uncertainty and risk aversion play a critical role in decision making, and this has been studied extensively across contexts since early theorization of decision making under uncertainty (Von Neumann and Morgenstern; Menapace et al.; Moschini and Hennessy). This is of course also true in agriculture, a field intimately connected to a variety of forms of risk (Moschini and Hennessy). In keeping with this body of theory, we find that farmers vary in their general willingness to take on risk, and their perception of the riskiness of a practice also varies by individual (Moschini and Hennessy; Prokopy et al.).

2.4.1.1.6 In summary: Farmer value-sets in the Eastern Snake Plain

Farmer decisions in the Eastern Snake Plain are driven by a variety of factors, but by beginning with these five values, we can begin to understand the motivations of some farmers. While this caricature paints no individual in their entirety, it can help us to understand how some large-scale patterns may emerge from the reactions of individual farmers to a large-scale water rights shift. As policy-makers work to generate sustainable solutions to water scarcity in Eastern Snake Plain agriculture, efficiency, stability, tradition, stewardship, and certainty will all play important roles in determining how farmers react to new policies and ultimately in determining outcomes in the Plain.

2.4.1.2 Values visible in the Comprehensive Aquifer Management Plan

The driving question of tradeoffs in adaptation decision making is how values at the individual scale translate to higher scales and ultimately translate to action. To understand this, we must first look at the public adaptation policies in the Eastern Snake Plain. In this case, we focus on the Comprehensive Aquifer Management Plan. In analyzing such a policy, it is possible to analyze values from two directions. First, a top-down analysis would engage with the negotiators and policymakers who have supported the agreement, working to understand the values inherent in their work. Alternatively, it is possible to analyze the values ascribed to the agreement by agricultural producers in the region. We follow this second method, since the conflict in which we are interested is ultimately the conflict between farmers' internal values and the values they ascribe to the agreement. When possible, we draw parallels with the values professed by negotiators in public appearances.

2.4.1.2.1 Sustainability

There is general consensus across farmers and negotiators: the central theme of the CAMP was an effort to make farming in Idaho more sustainable for the long term. In this case, sustainability is two-fold (Idaho Department of Water Resources, *Idaho State Water Plan*). Negotiators believed that they simultaneous had to ensure that the water supply would last for the foreseeable future while also preventing repeated litigation that would eventually put large numbers of farmers out of business.

2.4.1.2.2 Equity

The second value identified by farmers is equity. Instead of simply putting farmers after a certain seniority date out of business, the agreement spreads the burden, as do most policies implemented by groundwater districts (Idaho Department of Water Resources, 2012; Personal correspondence and interviews). At its most extreme, entire districts have banded together to buy their way out of dodge, simply purchasing enough water from surface water users to offset their use in excess of the agreement. In other cases, this has results in policies with dozens of tiers by seniority date, with farmers at each tier cutting a certain percentage of their groundwater use.

2.4.1.2.3 Science-based policy

The third leg upon which the CAMP is perceived to stand is the current iteration of the Eastern Snake Plain Aquifer hydrologic model (Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). Though the model is an object of frequent critique among farmers (*"It's wrong… well, I shouldn't say it's wrong. It's just…"*), it has helped to validate the agreement in the eyes of legislators and was the point of jumping off for negotiators (*"And I will tell you, the model is imperfect … But it's the best model that we have. It's better than no tool at all."*). As with many environmental policies, models and projections of resource sustainability have an important role to play in determining the future of agricultural water in the Eastern Snake Plain. Simultaneously, the continued revision and reanalysis of the models can be expected to be a source of concern among farmers for whom a cut in groundwater is a cut in livelihood.

2.4.2 Core mediating factors

The second component of tradeoffs in adaptation decision making is the collection of mediating factors that stands between a value-set and adaptation action. Based on a farmer's value-set, we can visualize adaptation as a variety of paths available to them. Each path entails a unique set of "beliefs and practices," and each mediating factor opens or closes paths in a different way (Carr, 2008: 693). We draw on literature addressing adaptation in agriculture and identify six factors that have played and will play an important role in determining the adaptation outcomes of farmers in the Eastern Snake Plain.

2.4.2.1 Material Capital

The first mediating factor in adaptation to water scarcity is the infrastructure available to the farmer. Some farmers in the western half of the basin have been adapting to intense water scarcity for nearly three decades. Learning from those experiences, one farmer framed the options available to him in this way:

> *"I didn't have the water to farm it. I wasn't going through the cost of planting a crop and harvesting nothing. So, I thought, okay, we'll take 50 acres out of the [one] farm and 50 acres out of [the other]. So. And I just let it sit idle … Back then, it was all hand lines. I've put up all pivots now. Basically can get by with less water and I can move around. I mean, you know, you do a hand line field;*

> *you got a six-day rotation. It takes six days to get across. On a pivot, you can be across it twice with lesser application of water but still grow a crop."*

More broadly, farmers with a diversity of machinery and up-to-date infrastructure may have freedom to embrace cropping patterns unavailable to others. Material infrastructure has long been considered an important dimension of adaptive capacity (Burnham and Ma, "Climate Change Adaptation: Factors Influencing Chinese Smallholder Farmers' Perceived Self-Efficacy and Adaptation Intent"; Berman et al.), and irrigation infrastructure specifically plays an important role in determining farmer adaptive capacity (Sudan and McKay; Pérez et al.). Specifically, they have been identified both as an important component for success and as a challenge in irrigated agriculture under a changing climate (Elliott et al.; Sudan and McKay; Albizua et al.)

2.4.2.2 Livestock

Livestock require food whether the farmer has enough water or not. For farmers who rely on livestock for a portion of their income, this places consistent requirements on their cropping patterns. While most ranchers and dairies do not manage to grow their entire feedstock in-house, they often seek to produce as much hay and grain as is feasible in order to feed at cost of production rather than at market cost for as much of the year as possible. While recent literature has suggested income diversification in the form of livestock raising may serve as a mechanism of adaptation, livestock also place restrictions on a farmer's acceptable paths (Bloch et al.; Sudan and McKay; Paavola). Sitting at the dining room table in a home he'd called his for nearly eight decades, one farmer explained that some things take precedence when making annual plans:

> *"I gotta feed the cows. So, that's like feeding the family. You look at that and you decide what you have to do."*

The four-legged extension of his family had grown and shrunk in numbers since the 1960's when they first came to live on the farm, but he explained in detail the variety of ways in which those family members were managed and nurtured to sustain the herd and the farm. Each year, the first variable in the acreage equation was how many head of cattle needed fed through the winter. According to our recent survey of farmers in the area, about 28% of livestock owners have pursued additional livestock sales because of the CAMP, an indicator that farmers may be seeking to rid themselves of restrictions in light of the water cuts.

2.4.2.3 Rotations: Caring for the soil

Along with livestock, rotations are perhaps the most important variable in determining a farmer's year-to-year cropping patterns. Rotations both shape and are shaped by farm management. As rotations vary so might farmer investments in new irrigation or crop infrastructure, thereby shaping the material makeup of a farm. Inversely, obligations like livestock, contracts, and co-op memberships often shape rotations. Still, rotations serve important purposes independent of this bidirectional relationship (Bullock). Each crop has a unique impact on soil, and the proper combination of crops is critical to the prolonged health of a farm (Bullock; Stoate et al.; Ball et al.). Even small variations can lead to long-term impacts on a farm's productivity. One farmer, a younger man who thought of himself as an early-adopter who liked to test anything and everything cutting edge, explained that even he had limits to his experiments, often outlined by the needs of the ground. Describing one such experiment, which he considered a resounding failure, the farmer explained:

> *"Idaho Power did buyback programs. This was years ago when they were in trouble with electricity. One year I signed up my 500 horse power pump and I just shut it off for the year and they paid me to do that, and then I grew dryland crops basically on 400 acres … I'll never, like I said, it is hard to switch crops. It really affects the rotation. For the next couple years, the crops were affected … So I probably would never do that sort of thing again."*

In the long-term, some rotations have a larger water footprint than others, a consequence of their constituent crops. As rotations play a key role in determining a farmer's assignment of crops to each field, this has important implications for the differential impacts of water cuts on farmers (Dury et al.).

2.4.2.4 Crop health

Because of requirements like rotations and livestock, the prospect of cutting water use is a dire one for many irrigation farmers. But for different water sources, the execution of that idea varies dramatically. For those dependent on canals, the ditch rider has long held the keys to the water that made the desert bloom. In the words of one farmer:

> *"I've had some hardships over water but we always figure out a way. See, on the canal, there's a ditch rider that rides the ditch every day and he measures the headgate and turns the water in if you want, turns it out if you don't. I keep laughing when there's a short water year and say well when you get around*

> *the corner you can can't see down there that's how come I got my pickup full of buckets I'll just get busy and use the buckets when you're not watching."*

On the other hand, those keys to water have always been firmly in the hands of groundwater farmers who were little more than a button press away from water. As groundwater farmers face new restrictions on when and how much they can use their wells, this dichotomy becomes all the more apparent. Describing the early days of the settlement agreement, one farmer suggested that even in their infancy the cuts were being stretched and fudged. One of the key clauses of the agreement stipulates that farmers hold off on irrigation until April 1st and have water turned off by October 15th. On many farms, this didn't even survive the first year:

> *"Last year, it wasn't a problem. The year before, in March there was spring wheat. We had a really dry winter and spring and on the 15th of March there were some growers that turned their pivots on, I did too. I don't know if they caught them on satellite or if someone reported them, but they got a notice of violation and threats of penalties if they didn't shut their water off ... They just got notice, [no penalties]."*

As we see, when the rubber hits the road, not all farmers are willing to sacrifice the health of a crop for the sake of the settlement agreement. This willingness (or unwillingness) is intimately tied to the value of economic stability described earlier, but as we have seen documented both in interviews and in literature, farmer care for crop quality often extends beyond the economic value of the product (Norton; Zadoks). This, then, raises the next critical question in our analysis of mediating factors: what is the nature of enforcement?

2.4.2.5 Enforcement

Enforcement of any new law is likely to create cultural and legal conflict. In the words of the farmer who faced notice of violation:

> *"[The start date restriction has been in place for years], but it was really loosely held. I think these water permits that we have are from April 1 to November 1. But if somebody's got to water some beets to dig in November or they're watering some stubble between the gate … we've never had any problem. Or in the spring, if you needed to pre-water some ground to plant it or something. But now it's a problem."*

Rules long-held in legal code but not seen in practice are now subject to the gaze of the CAMP, and recent legislation in the Idaho legislature has enabled the levying of financial penalties by groundwater districts. Even before those were formally allowed, farmers expressed certainty that new rules would be held to a higher standard than before the CAMP. That same farmer explained the changes in social relations accompanying the enforcement:

> *"Oh yeah, [enforcement will change]. They're giving those water guys up there, they've always been just friendly people ready to help you. I mean I think they're still friendly people, but they've just kind of given them badges, a little more authority."*

What forms this takes in each district and what level of monitoring is feasible will play an important role in determining the short-term outcomes of the settlement agreement. In spring 2019, the first two bills intended to shape this enforcement were signed by the governor of Idaho (Idaho State Legislature, "Senate Bill 1041"; Idaho State Legislature, "Senate Bill 1056"). The bills, supported by water user associations and by the Idaho Department of Water Resources, give groundwater districts expanded authority to levy financial penalties on non-compliant farmers as well as to report them to IDWR for curtailment (Carlson; Idaho State Legislature, "Senate Bill 1041"; Idaho State Legislature, "Senate Bill 1056").

2.4.2.6 Social influence

As groundwater districts reflect on the most effective ways to operate within this new legal framework, they are faced with an array of possible enforcement mechanisms. Often though, the first course of action is not a financial or legal sanction, but rather a social one. For example, the Aberdeen/American Falls Groundwater District (AAF GWD) has laid out a four-year outline for sanctioning members out of compliance with their new water share:

Year 1. Letter written to noncompliant member

Year 2. Noncompliant member must come to meeting and publicly acknowledge the issue

Year 3. Noncompliant member must present a plan of action to the groundwater district

Year 4. An assessment of $100 per acre is leveled against the noncompliant member

By leaning first on social sanctions, AAF GWD demonstrated confidence in the power of social influence to impact farmer decision making. This, of course, is grounded in decades of history in tight-knit farming communities through the Plain. As farmers develop their own networks, the input and influence of their connections plays an important role in farm decision making. In the words of the man-of-many-hats who introduced us to many of the values in Eastern Snake Plain farming:

> *"Consulting. Consulting. Consulting. Consult my attorney. Consult my farmers. Communication is key."*

Both social network and the presence of professional advisors have been demonstrated as important in a variety of contexts for agricultural decision making (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"; Eanes et al.; Prokopy et al.).

2.4.3 (Mal)Adaptation in the ESP

The third component of tradeoffs in adaptation decision making is (mal)adaptation itself. To understand better what farmers in the Eastern Snake Plain are doing, we turn to a recent household survey of the farmers. Broadly, adaptation practices adopted in the Eastern Snake Plain fall into four categories (Table 2).

Table 2 - (Mal)Adaptation strategies adopted by groundwater farmers in ESP

Category	**% adopting category**	**Specific adaptation practice**	**% adopting practice**
Cropping Changes	71.9%	Changing rotation	53%
		Planting a less water-intensive crop	44%
		Changing tilling strategies	43%
Lifestyle Changes	73.7%	Reduced spending	68%
		Took off-farm job or started a new business	33%
Infrastructure Changes	80.8%	Improve irrigation infrastructure efficiency	78%
		Switch irrigation infrastructure	53%
Management Changes	83.8%	Irrigate less land	66%
		Use canal water	37%
		Adopting precision agriculture techniques	32%

Least popular among farmers are cropping changes, described as important but challenging and sometime risky adaptation options:

> *"Yeah, part of even looking at the canola too is the little bit of water savings that next year, because it is finished a lot sooner. So some guys I think are trying to do it with rotation, some guys are actually irrigating less acres. But if you can switch up your crop rotation a little bit, then you could maybe see some savings from year to year. … usually anything if you are going to water less, you will usually see a little less yield on the other end. … So cutting back 10%, if you think about it, it is like 2/3rds of a day in a week that you might not water. You put on 10% less or 12% less and depending on if it is a hot, dry summer, you are going to see a difference in yield. But if it is a cooler, wet summer, you won't see a difference."*

More often than cropping changes, farmers cited lifestyle adjustments in response to the ESPA CAMP's mandated reductions. Even among farmers who invested in a variety of income streams before the CAMP, the agreement has required revisiting of spending patterns. This becomes particularly relevant in light of increased groundwater district assessments (acreage fees) on groundwater-fed land:

> *"Like I was saying, it's like we had to write a blank check to them … I'm like I don't know how much it's gonna be. It's just suddenly I'm going to get a bill. Am I going to have enough money to pay it? … It has [changed our approach to our other business ventures]."*

The two most common structural changes to farms appear to be improved efficiency in irrigation infrastructure and the irrigation of less acres. Both of these can take a variety of forms. For instance, some farmers dry up corners of plots, citing low productivity along these edges; others have fallowed or turned to dryland crops for entire fields, focusing their irrigation efforts on more productive or profitable land.

2.4.4 Tradeoffs in Adaptation Decision Making in the ESP

2.4.4.1 Individual-level: Value vs. Adaptation action

2.4.4.1.1 Farming as a passion vs. Taking other jobs

As demonstrated, the "productivist" nature of farming has led many farmers to view the work as a vocation rather than as a job. Further, we demonstrate that some farmers in the Eastern Snake Plain are turning to other sources of income to support themselves. Although this is likely to be the most economically efficient solution, both for the individuals and at the macro-scale, it is also possible that this transition will come with a psychological and sociological cost for former farmers (Wheaton; Cooke and Rousseau). This possible stress is particularly problematic in light of continued evidence that farmers may be a particularly vulnerable population to chronic mental health struggles (McLaren and Challis; Armstrong and Schulman). Additionally, migration from this job displacement may re-up the burden on rapidly expanding urban areas throughout the Eastern Snake Plain (Dahal et al.). Both of these trends have important societal implications that may be a worthwhile focus of local and statewide policy moving forward.

2.4.4.1.2 Appearance of Farm vs. Irrigating less land

In much the same way that a workforce transition may be viewed as a consequence of value tradeoffs, it is clear that some sort of landscape transition is likely in groundwater districts where 12.9% of the dominant water source is suddenly curtailed. As is evident in our survey of groundwater users, this transition is already taking place, and in the words of one farmer, it is even impacting farms with a much less dramatic reduction in water availability:

> *"We went with the 5% reduction. Yet, it's still. I call 'em rock patches. Around here, we have little rock patches in the middle of our field that we are always trying to work with and everything else. When they done that, they put more rock patches and bald spots in my fields … [added] more weeds and made the farm ugly."*

While this may appear to have mostly superficial consequences, the impacts of a significant change in field appearance may be far-reaching. In the 2013 Farm and Ranch Irrigation Survey, over 71% of farmers reported using the condition of their crop as a measure of when to irrigate. For many farmers, these seemingly superficial changes to field appearance could have very real implications for irrigation timing; in turn, this can impact the among of water used on a field, thus producing a feedback to the regional policy.

2.4.4.1.3 Soil health vs. Crop choice

Perhaps the most important characteristic of a farm in the long-term is the health and quality of its soil. In recent decades, the use of rotations has reemerged and gained popularity as a mechanism for preserving soil quality (Bullock). Though still accompanied by fertilization and biocide application, rotations have proven uniquely useful for improving soil health and reducing crop disease. As described earlier, some farmers are shifting their cropping patterns as a result of the CAMP. This has the potential consequence of limiting the appeal of relatively thirsty rotational crops like alfalfa, which as a legume provides nitrogen fixation benefits. As overall cropping patterns change throughout the region, this is the first of several possible tradeoffs related to the agreement, the remainder of which appear as region-scale impacts.

2.4.4.2 Tradeoffs across scales (Individual Actions cause Impact)

2.4.4.2.1 Changing cropping and spending patterns cause economic shifts across the basin

As each individual farmer makes small changes to their rotation, these changes play out as large shifts in region-scale productivity. Agricultural processing facilities, dairies, and other industries dependent on row-crop productivity face new challenges in a changing "cropscape." One local farmer painted a picture of the direst possible scenario:

> *"Like let's say for instance. This is never going to happen. Let's say all of a sudden the farmers up here, something does happen and we don't have the water and so every farmer up here decided well, we can't grow potatoes. So nobody grew potatoes. I mean that is the cash crop of Idaho. That is where farmers. All of a sudden the farmers are not making money on spuds. They are not paying taxes. The value of ground. Ooo. This is even better. Let's say that they do just say we are curtailing everybody. The land value would go from $12,000 an acre to $1,000 an acre. Schools would shut down. I mean everything is based on property."*

Property values in rural Idaho have climbed nearly 275% in the last two decades; in some years, land appreciation is one of the few true money-making ventures in agriculture (USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"; USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"; USDA National Agricultural Statistics Service, "Volume 1, Geographic Area Series. Part 12, Idaho State and County Data"). As indicated by the farmer, land values in southeastern Idaho are directly tied to water rights, and both farmers and policymakers have expressed concern over the long-term trajectory of property value under the agreement. Therefore, we see a clear tradeoff between overall water savings in the basin and the total agricultural productivity of the region. While improvements in efficiency through technology and crop breeding can offset some of these losses, water in Idaho is ultimately a zero sum game, something that water managers of both surface water and groundwater have been reminded of under the settlement agreement.

2.4.4.2.2 Redirection of irrigation demand causes impacts on senior water rights holders

Many southeastern Snake Plain farmers hold dual water rights, both surface water and groundwater for the same plot of land. These farmers, by and large, have been using groundwater for much of the last few decades. As one watermaster in the area explained:

> *"So, we saw by the later 1960s folks started applying for groundwater rights and drilling wells. Most of those wells, the intent was probably for them to be supplemental … Then, of course, folks after a year or two, succumbed to the convenience of pushing a button and they stopped taking water from the canal and just used the well exclusively to irrigate land that still had the canal water right on it. Those folks kept their [canal water] assessments current, kept their shares in place. They just didn't use their water … With the settlement agreement … Well, when you have land on the canal system that has canal shares that are paid off and that water is available, it's kind of low-hanging fruit to shut off that well on the canal and call for your canal water. We can't say no …. We've seen a couple of thousand acres out of probably 15,000 potential come back on the system."*

This leads to parallel processes of groundwater shutoff and surface water re-upping. While to each individual farmer this may only make a difference on one or two of their fields, for the canal companies this is a significant growth in demand. To respond to this shift, several canal managers have indicated efforts to better line the bottom of their canals:

> *"We are lining reaches of our canal to conserve water … But I'm looking forward to working with my other partner canals to start looking at their systems and developing conservation practices for them … They're still in the 19th century and I'd like to drag them into the 20th century."*

While this allows more efficient delivery of water to stakeholders, it also limits incidental aquifer recharge out the bottom of the canal.

The redirection of demand to surface water canals has important implications for the aquifer, as well as for the water supply stability of the surface water supply. In the words of one stakeholder:

> *"I think the canal companies have been the unintended recipient of a lot of the effects of this agreement."*

In turn, as canal companies have been the unintended recipient, those receipts have been passed along to shareholders. This general redirecting of water seems to be a tradeoff between the full burden of water cuts resting on the shoulders of junior groundwater farmers and a general spread of burden across the farming population of the Eastern Snake Plain. This draws our attention to the final regional tradeoff of note.

2.4.4.2.3 Pursuit of equitable, sustainable solutions causes sacrifice of tradition

Until the Comprehensive Aquifer Management Plan, water in Southeastern Idaho was managed by the law of prior appropriations, a framework handed down in statute and culture since the earliest colonial settlement of what would later become Idaho (Harrington). With the introduction of the settlement agreement, the distinction faded between prior appropriations and a more collective form of water management:

> *"The agreement really kind of blurred the lines between prior appropriation and kind of the public trust administration of water. So … you know, conjunctive management of the whole system … This gives us an opportunity too. How do we begin to manage those together instead of still separately; because at this point groundwater is still managed in kind of a separate paradigm. It's in this quasi-public trust, everybody is all in the same boat kind of thing versus the river which is still managed solely on prior appropriation. How do we bring those two together and actually manage the whole system as one?"*

This collective "trust" form of management allows the burden of water cuts to be distributed among farmers across the Eastern Snake Plain, sometimes in unexpected ways (as described in the canal companies). This has the short-term benefit of allowing more farmers to stay in business and avoids the large-scale fallowing many feared before the settlement. However, it has the consequence of undermining one of the fundamental legal and cultural tenets of Idahoan water law, and this does not come without consequences for the public perception of the agreement:

> *"You know, you'll see all different opinions on prior appropriation. It's made the system work … There's also cultural and historic challenges with it too. The prior appropriation kind of preserves the way Idaho grew up. Again, if you want to change that, there's a whole lot of interests that would oppose something like that. All in all, I think the system works pretty well."*

This tradeoff in equity and tradition is an ongoing challenge for water managers throughout the American West.

2.4.4.3 Win-wins in multi-scalar adaptation?

Throughout the ecosystems services literature, tradeoffs are discussed hand-in-hand with the search for win-wins, a reflection of the desire of policymakers to create solutions that come without significant externalities (e.g. Howe et al., 2014). Therefore, our treatment of tradeoffs would be incomplete without some discussion of the potential for win-wins in multi-scalar adaptation. A variety of such win-wins may exist. For example, as farmers seek to improve the water-holding capacity of their soils, this may encourage more sustainable tillage practices or expand the use of biological fertilizers:

> *"And then we use the … biological fertilizers which help with the water penetration and some so I can run pivots slower, get the water in the ground and not have it evaporate."*

Further, as some conservationists have discovered, newly expanded water markets offer opportunities for water users outside of agriculture to creatively use some of the water previously reserved for crops:

> *"We're actually brokering some of the exchanges through the appropriate irrigation entities, but we are going out and finding the buyer and the seller and then we are getting it worked out. We are doing this to keep water in the river for fish. We never had the option to do this before because all you can do with these irrigator to irrigator exchanges and the age old problem of the conservation groups is that you irrigator A to not divert and all that happens is all of that water just goes down to the next junior user and that person takes it. But now with the managed recharge component, that water physically has to get to a recharge site and be diverted and metered and accounted for and so now we can actually get it where it needs to go."*

As with any policy, the settlement agreement has generated a system of winners and losers, and as we saw with the redirecting of demand to the canal companies, these win-wins may involve an unexpected cost for other stakeholders. With each change to the management of water in the Eastern Snake Plain, new opportunities and limitations are created, and tradeoffs, operationalized as the exchanges of values at the individual and regional scales, acts a lens through which to examine the opportunities and limitations.

2.4.4.4 Tradeoffs as an adaptation decision-making tool?

In addition to the identification of tradeoffs in multi-scalar adaptation, this work also sought to examine the willingness of farmers to acknowledge tradeoffs; we refer to this as the presence of implicit or explicit tradeoffs. Frequently referenced in agriculture and ecosystem services literature as a possible decision-making tool, explicit tradeoffs require the acknowledgment of the opportunity costs inherent in each decision a farmer makes (Rodriguez et al.; Meerow and Newell). Our findings suggest that most farmers are willing to make this acknowledgment (*"There's always a sacrifice every year."*), though there is often hesitance to describe specific instances in which one benefit is exchanged for another (*"That's kind of a tough question to be honest with you."*). Thus, we suggest that it may be possible to consider farmer value-sets as a lens by which to understand the implications of future adaptation policy. It is widely acknowledged that the interactions between adaptation policy and individual adaptation are poorly understood, and the ability to examine some of these outcomes through the projection of value tradeoffs may prove useful both in shaping adaptation policy and in supporting farmer decision making after such policies are implemented (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"; Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests"; Milman and Warner).

2.5 Conclusions

By examining the values (both social and material) exchanged at the individual level and across scales, it may be possible to better understand the interactions of private and public adaptation. In this first exploration of tradeoffs as an analytical tool in the study of tradeoffs, we have demonstrated the ways in which the examination of individual and collective values draws attention to unexpected and sometimes dramatic tradeoffs in water management in the Eastern Snake Plain. Additionally, we have shown that the ecosystem services framework of win-wins may also emphasize some of the new opportunities created by policy changes, and we have highlighted the potential use of tradeoffs as a decision support tool, both for policymakers and individuals engaged in adaptation.

Three important points remain to be addressed in future work. First, we propose tradeoffs as a framework for the analysis of adaptation across contexts, and this should be pursued through the employment of comparative case studies. As discussed in the methods section, a forthcoming partner project in Pakistan provides just such an opportunity. Second, considerable psychological literature exists describing the mechanisms by which to reveal values among individuals; an expanded engagement with this literature and the integration of quantitative measures of values across the population could improve the policy-relevance and generalizability of findings. And finally, as described upon introduction of the framework, a variety of questions come into focus when tradeoffs are laid out as a natural consequence of adaptation; this requires a more complete attempt at framing, a project which is undertaken by a forthcoming companion paper (Nixon et al.).

CHAPTER 3. SOCIAL VULNERABILITY IN THE EASTERN SNAKE PLAIN: INTERACTIONS AND FEEDBACKS IN MULTI-SCALAR ADAPTATION TO WATER SCARCITY

3.1 Abstract

Accelerating global environmental change will require agriculture in arid and semi-arid regions across the globe to adapt to shifts in water availability. Recent research recognizes that adaptation is not a single action in response to an individual stress, but rather takes the form of a "suite of beliefs and practices" shaped by social, institutional, and environmental context (Carr, 2008: 693). As water resources shift, it is expected that institutional context and policy landscapes will shift in parallel, changing the face of adaptation and farmer vulnerability in unexpected ways (H. M. Füssel; Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"). This paper surveys farmer vulnerability to just such a water resource policy change in the Eastern Snake Plain of Idaho (du Bray et al.). Using results from a household survey of impacted farmers, we examine vulnerability in two stages. The first stage, multimodel selection and inference, analyzes the primary predictors of vulnerability to water scarcity among this population of farmers, while the second stage, a segmentation analysis, investigates variation in adaptive capacity and the influence of vulnerability predictors across the population of farmers. Results indicate that key indicators of vulnerability include sensitivity to concurrent challenges and exposure to the water cuts. On the other hand, adaptive capacities including knowledge of alternatives, linking capacity, and access to other water sources are most strongly associated with lower vulnerability. Segmentation analysis highlights some nuance in these results, dividing farmers along the primary axes of farm size and specific capacity. Large and small farmers achieve high adaptive capacity by diversifying in different ways. Large farms diversify crops and farm investments, while small farms diversify sources of income through other jobs. Middle-sized farms prove the most vulnerable and divide into two groups along their respective strengths and weaknesses. The first group shows relatively low specific capacities (knowledge of actions, linking capacity, and adaptive management), high perception of challenges, and is the most vulnerable, while the other group has high specific capacity, low perception of challenges, and moderate vulnerability.

3.2 Introduction and Background

The future success of agriculture and agricultural livelihoods in groundwater-dependent systems hinges on the capacity of individuals and organizations to adapt to changing water resource availability caused by irrigation withdrawals, as well as climate and other social-ecological changes, including urbanization and attendant land-use change (Elliott et al.). As of 2012, irrigated land made up 66% of harvested acres in the United States, and groundwater provided approximately 55% of the water used for irrigated agriculture (USDA National Agricultural Statistics Service, *2012 Census of Agriculture: Farm and Ranch Irrigation Survey*). In particular, water shortages in interconnected groundwater and surface water systems throughout the US will make adaptation necessary both by water provisioning agencies and by farmers themselves (Burnham et al.; Garrote). The form and effectiveness of adaptation in these systems will be shaped by the vulnerabilities of stakeholders in those systems and by interactions between adaptation at individual and organizational scales. These interactions are poorly understood, particularly in industrialized agriculture (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"). Thus, this work seeks to translate lessons learned through extensive study of non-industrialized agriculture in the Global South to less-studied industrialized agriculture in the Global North and document the vulnerability of farmers to an ongoing, rapid policy shift.

While adaptation refers to response to change, vulnerability refers to the susceptibility of stakeholders to be negatively affected by that change. In this paper, we adopt the common conceptualization of vulnerability in social-ecological systems as being composed of three interacting components: exposure, sensitivity, and adaptive capacity (Berman et al.; Hovelsrud and Smit; Gallopín). Exposure is defined as the intensity and duration of change or impact experienced (W. Neil Adger). Sensitivity refers to the degree to which such exposure affects outcomes, particularly in reference to the relative dependency on a resource or the degree of connectedness to a system undergoing change (Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests"). Finally, adaptive capacity is taken to mean the ability of a system or individual to act (adapt) to reduce the harms resultant from exposure and sensitivity (Berman et al.; McCarthy et al.).

The scales of adaptation and vulnerability can be broadly divided into two categories: public and private. Public adaptation is that which is undertaken by governing institutions, most often at the regional or national scale but also at the local or resource scale (H. M. Füssel; Smit et al.). Private adaptation refers to the efforts of individuals to enact change to reduce the impact of environmental shifts (Fischer, "Pathways of Adaptation to External Stressors in Coastal Natural-Resource-Dependent Communities: Implications for Climate Change"; Eisenack; Forsyth and Evans). In some contexts, public and private adaptation are referred to interchangeably as planned and autonomous adaptation, respectively, but we choose to employ the public and private terminology in order to make clear the scalar dynamics at play and to highlight that level of planning is not necessarily correlated with scale. In this work, we study the vulnerability of farmers (private vulnerability/adaptation) in the Eastern Snake Plain of Idaho to water scarcity imposed by a regional water rights reorientation (public adaptation) that reduced average groundwater availability for irrigation by 12.9%. This builds on existing literature in three key ways.

First, this work seeks to evaluate the interactions between adaptation at individual and organizational scales. Recent work has shown that adaptation and vulnerability to one stressor at one scale do not occur independently of other social-ecological changes, such as development interventions in smallholder agriculture, and these changes themselves must be adapted to and may reshape household adaptive capacity (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"; Milman and Warner; Eakin and Lemos; Lemos et al.; Birkenholtz). In other words, actions taken at varying scales may interact in unexpected ways, and adaptation at one scale may have important implications for the production and reproduction of vulnerability across other scales. Therefore, it is critical that attention turns to the interaction between adaptation and vulnerability at varying scales.

Second, this work seeks to translate lessons learned through extensive study of non-industrialized agriculture in the Global South to less-studied industrialized agricultural system in the Global North (Burnham & Ma 2018). Previous literature suggests a variety of important predictors of vulnerability in agricultural systems, but most studies of agricultural producer adaptation and vulnerability have focused on smallholder farming systems in the Global South. In turn, we have little understanding of what shapes adaptive capacity and vulnerability in highly industrialized agricultural systems. This, then, has important implications for the first objective of this work, as we have little knowledge of what forms public and private adaptation will take in these systems, how they will interact to affect the collective well-being of agricultural production, and how they will interact to generate differential outcomes for individual producers (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation").

Finally, this work attempts to document the vulnerability of farmers to an ongoing, rapid policy shift. In both the Global North and South, most previous work has focused on anticipated vulnerability to anticipated stressors (H.-M. Füssel; Eakin and Luers; Welsh et al.). Because agricultural producers vary highly in their vulnerability to climate change and related policy changes and often react differently to these changes, it is critical to evaluate the impact of such changes on agricultural production and develop an understanding of the drivers of adaptive capacity and vulnerability in industrialized farming systems (Marshall et al.). By improving our understanding of the process by which actual stressors produce vulnerability, it may be possible to theorize more effectively about vulnerability in industrial systems and create better anticipatory models. This may help to prioritize policy interventions. Doing so in the context of public adaptation is particularly important because agricultural producers have been shown to be as concerned about the implications of climate change policy as about climate change itself (Niles et al.), and empirical understanding of the implications of policy-induced vulnerability is lacking.

In this paper, we employ a mixed-methods approach to investigate the drivers of vulnerability in the context of a policy-driven change in water availability. To do so, we seek to answer the following two research questions. First, what components of sensitivity, adaptive capacity, and exposure are most determinant of who is vulnerable to policy-driven reduced water availability? Second, how are the drivers of vulnerability distributed within the population, and to what degree does this distribution result in differential vulnerability among farmers?

To answer these questions, we employ a mixed-methods approach primarily reliant on quantitative analysis of a household survey. To ensure internal validity despite a low response rate, we integrate qualitative results from a series of interviews in the Eastern Snake Plain. The following sections lay out the methods by which we do this, our findings, and ultimately the implications of this work for the broader study of vulnerability to policy change in an era of climate change.

3.3 Methods

3.3.1 Study Context

The Eastern Snake Plain is a diverse and productive agricultural basin in the inter-mountain region of the American West, home to large outputs of potatoes, sugar beets, alfalfa, wheat, and other crops each year, as well as a significant volume of livestock dominated by dairy cattle (USDA National Agricultural Statistics Service, “USDA National Agricultural Statistics Service Cropland Data Layer”; USDA National Agricultural Statistics Service, “Volume 1, Geographic Area Series. Part 12, Idaho State and County Data”). More than 74% of this agricultural land is irrigated, inextricably tying both the future of agriculture and the future of the Idaho economy to water in the state (USDA National Agricultural Statistics Service, “Volume 1, Geographic Area Series. Part 12, Idaho State and County Data”). Nearly 40% of the water used for this irrigation is groundwater from the Eastern Snake Plain Aquifer (ESPA) complex, a collection of basaltic and sedimentary aquifers throughout the region (USDA National Agricultural Statistics Service, *2012 Census of Agriculture: Farm and Ranch Irrigation Survey*; Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). After rapid aquifer declines in recent decades, concerns emerged surrounding decreasing surface water flows in areas hydrologically dependent on the aquifer, and litigation ensued. This prompted a significant re-envisioning of Idaho water management, one that ultimately resulted in conjunctive groundwater and surface water management throughout the Eastern Snake Plain and led to the collective development of the ESPA Comprehensive Aquifer Management Plan (CAMP) (du Bray et al.). Most significantly, the CAMP requires a 12.9% reduction in groundwater use in each of eight participating groundwater districts (ibid). The agreement requires both individual farmers and district-level water organizations to meet the required water use reductions and adapt their governing rules and management strategies to ameliorate the impacts. Each groundwater district is required to lay out strategies for distributing water cuts among their stakeholders, ultimately achieving the 12.9% cut required of the district as a whole. This, then offers multiple opportunities to better understand farmer vulnerability to policy-driven water scarcity.

3.3.2 Household Survey of Groundwater Farmers

Data are from a mail survey sent to farm operators in the eight signatory groundwater districts subject to the terms of the water settlement agreement. We designed survey questions to collect information on a variety of subjects across eight sections. Those sections are: 1.) Farm Characteristics; 2.) Challenges to Your Farm Operation; 3.) Impact of Water Restriction on Your Farm Operation; 4.) Farm Operation Decision Making; 5.) Farm Practices; 6.) Farmer Perspectives on the Water Settlement Agreement; 7.) Resources for Farm Management; and 8.) Landowner

Information. This work relied on questions from Sections 1, 2, 3, 6, 7, and 8. Measures of vulnerability constructs were based on existing operationalizations in the literature (Eakin, York, et al.; Burnham and Ma, "Climate Change Adaptation: Factors Influencing Chinese Smallholder Farmers' Perceived Self-Efficacy and Adaptation Intent"; Colquitt and Rodell; Berman et al.). We inductively localized the survey through preliminary interviews with Eastern Snake Plain farmers and water managers. Finally, the survey was pre-tested with three farmers in the ESPA and refinements were made based on their feedback to improve question clarity and relevance.

Because we were unable to obtain a list of all farm operators who are members of each water district and thus required to cut their water use, our sample was constructed using two publicly available data sources. First, we identified water rights holders in each water district using the Idaho Department of Water Resources ARC GIS based online water rights locator tool. This process yielded 800 farm operator addresses. Importantly, the online tool states that the database of water rights it draws from may not include all water rights in the state. Second, to supplement the addresses collected using the water rights locator tool, we sampled addresses from an Idaho Department of Water Resources curtailment order sent on January 17, 2017 to water rights holders in the ESPA with rights junior to June 20, 1989. We crosschecked the addresses on this list with those obtained from the water rights locator tool and added unique addresses to our sample frame. In total, we obtained 1,398 addresses from this process. Following the Tailored Design Method, we sent the mail survey to each farm operator identified through this process (Dillman et al.). Each mailed item contained a web-link to an online version of the survey administered through Qualtrics. One hundred and seventy-nine survey packets were returned as undeliverable, and another 85 were returned with a note from the respondent stating they no longer owned or farmed their land, leaving an adjusted sample size of 1,133.

In total, we received a total of 265 completed surveys, for a 23.1% response rate. Non-response bias testing was conducted due to the relatively low response rate and the challenges in verifying the relationship of the sampling frame to the total groundwater farmer population. Overall, we conclude that any bias introduced does not affect the validity of the results and conclusions; we discuss the results of this non-response bias testing in detail later in this article.

As part of the survey, qualitative data were collected through a series of open-ended free response questions. Results from these questions were analyzed through qualitative text analysis, and the results of this analysis are used to complement the statistical analysis described below. Coding was conducted in MaxQDA, and the codebook can be found in the supplemental materials.

3.3.3 Analysis

Statistical analysis was conducted in R (R Core Team) and Stata (StataCorp) after data were digitalized in CSPro (US Census Bureau). We constructed the statistical analysis in two primary stages, preceded by multiple imputation and conducted in parallel with complementary qualitative analysis. The first stage of statistical analysis, multimodel selection and inference, was used to analyze the primary predictors of vulnerability to water scarcity among this population of farmers. The second stage, segmentation analysis, was developed to investigate variation in adaptive capacity and vulnerability across the population of farmers. From these segments, we can better understand how differential capacity across groups leads to differential outcomes for groups of farmers. The following sections details the analysis process, beginning with multiple imputation, followed by model development, and concluding with the two-stage statistical analysis.

3.3.3.1 Multiple Imputation

Preceding statistical analysis, we conducted multiple imputation of our data. Proposed originally by Rubin (1987), multiple imputation is a popular class of methods designed to enable unbiased analysis of datasets with significant levels of missingness. Complete case analysis (i.e. listwise deletion, standard in most statistical packages) assumes that data are “missing completely at random,” while real data almost never are (Rubin). The pattern of missingness observed in our survey was indicative of some level of randomness in missingness, but it is nearly impossible to assume complete randomness in missing survey data (ibid). Violation of this assumption introduces significant bias into analysis (Donders et al.).

Instead, of complete case analysis, we employ multiple imputation. Multiple imputation assumes that data are “missing at random,” meaning that the causes of missingness are captured in the known data (Rubin). In other words, another variable in the survey somehow captures the cause of non-response in one variable. We felt comfortable with this assumption because of the variation in missingness observed between variations. This variation meant that observations with more complete information on a particular variable could strongly inform the equations generated to impute the missing observations. In our data, item-level missingness was only 12% across the entire data set and 9% across variables used in the models we developed, but 183 of 264 observations were lost due to listwise deletion during the modeling process. This was due to a high level of variation in which variables experienced missingness between observations. We performed multiple imputation using the Multivariate Imputation by Chained Equations (mice) package in R (van Buuren and Groothuis-Oudshoorn); this allowed for significant flexibility in the methods of imputation.

The method of imputation used depended on the class of the variable being imputed: Continuous - Classification and Regression Trees, Categorical and Ordinal – Logit and Ordered Logit regression, Binary - Binomial regression. Additionally, in order to produce results as informative as possible, we imputed all variables in the dataset, including those not used in the final models. However, this led to prohibitively intensive simulations if we used all variables to impute all others, and we chose to use a correlation cutoff of 0.2 to limit the number of variables used to impute each variable. We describe imputation quality checking alongside nonresponse bias.

We imputed five data sets, which yields 97.65% on Rubin's score for relative efficiency (1987); additionally, five imputations is frequently suggested as a minimum threshold for effectively representing the variability in the prior distribution from which imputations are sampled (Lall). Each data set was analyzed and the results combined using updated versions of Rubin's combination rules (1987) to create a pooled point estimate. Traditionally, pooled point estimates are equal to the average of the separate estimates from each imputed data set, and their variance is equal to a weighted sum of the estimated variances between and within the imputed datasets (Lall). Since we employ two forms of statistical analysis that struggle with this definition of pooling, we employ variations prescribed by more recent advances on multiple imputation (Basagaña et al.; Schomaker and Heumann). This is examined in more detail as we explain each method of analysis.

3.3.3.2 Modeling Vulnerability to Water Cutbacks in Highly Industrialized Agriculture

Based on the framework of vulnerability as the result of interactions between exposure, sensitivity, and adaptive capacity, we constructed a theoretical model of vulnerability (Figure 2, Table 3) that we could then test through multimodel selection and inference (Berman et al.). Table 3 indicates the survey questions from which the model was drawn; the full survey is available upon request. In this case, we operationalize the model specifically at the farmer level and refer to the framework as individual vulnerability. However, it is important to acknowledge that similar measures of vulnerability can exist for organizations and other groups.

3.3.3.2.1 Sensitivity

Sensitivity is most often described as the external characteristics of an individual that make them more or less affected by a change (Eakin and Luers). In the case of environmental change, this refers to the dependence of an individual or system on the resource in flux; this is often broken down to the magnitude of the dependence and the diversity of acceptable substitutes available (Berman et al.). In the context of farmers in the Eastern Snake Plain, this can be conceptualized in three questions: to what degree are farmers dependent on groundwater for irrigation; to what degree are they dependent on crops for income; and to what degree are acceptable substitute sources of irrigation water or substitute sources of income available?

In this case, we break down sensitivity into three components to capture the spectrum of agricultural dependence on water: presence of certain crops (proxy for magnitude), diversification in farm operations (proxy for both magnitude and diversity), and size of farm (indirect, related to magnitude). To understand the relative impact of the use of water-intensive crops, we use binary variables indicating presence or absence of each crop of interest. Crops of interest are defined as those that constituted greater than 0.5% of the land cover in any of the eight groundwater districts in the 10 year period from 2007-2016 (USDA National Agricultural Statistics Service, "USDA National Agricultural Statistics Service Cropland Data Layer"). Diversification is broken down into three types of diversity: crop diversity, water right diversity, and income diversity. Crop diversity is defined as a simple scale indicating the number of crops of interest present on the farm. Water right diversity is included as the percent of each farmer's water rights portfolio composed of groundwater and surface water right. And finally, income diversity is measured by the presence or absence of off-farm income and the presence or absence of livestock on the farm. Farm size in acres is included to capture the relative scale of resource use on each farm (i.e. the magnitude of dependence); the value in acres was transformed prior to modeling to produce intelligible coefficients.

Table 3 – Vulnerability Model Variables

	Sub-component	Survey Prompt	Variable Scale	Factor values (-- for non-factors)		
				Eigenvalues	Loadings	Cronbachs α
Sensitivity	Crops Grown	Use the table below to indicate how many acres of each of the following crops were planted on your farm in 2016, your yield, and what percent of the crop you have contracted or in a co-op: Alfalfa, Barley, Potatoes, Sugar beets, Wheat	Free response integer transformed to presence/absence binary	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --
	Diversification	(Same as Crops Grown)	Free response integer transformed to count of total crops on farm	--	--	--
		In the following table, indicate what types of water rights you have (check all that apply) and what percentage of your total water portfolio that right makes up.	Percent of groundwater, percent of surface water in water rights profile	--	--	--
		How many head of [dairy cattle/beef cattle/other livestock] do you have on the land you own or manage?	Free response integer transformed to presence/absence binary	--	--	--
	Size of Farm	How many total acres do you farm (include leased land)?	Free response integer scaled for use in model (response / (2*standard deviation))	--	--	--

Table 3 Continued

Adaptive Capacity	Institutions and Entitlements	(Same as Crops Grown)	Free response integer transformed to presence/absence binary	--	--	--
		In an average year, what percentage of your crops are insured?	Percent of crops on operation insured	--	--	--
	Material and Financial Resources	In the table below, please indicate which of the following irrigation methods you use on your farm and approximately how many acres that irrigation system is on: Micro-sprinklers, Center pivot, Hand lines, Wheel lines, Drip, Furrow/flood, Other	Presence/absence of each irrigation form; wheel and hand lines combined, drip and micro-sprinkler combined	--	--	--
	Perception of other challenges	Please rate how challenging each of the following is when it comes to making a living from your farm.	5-point scale: Not a Challenge, Slight Challenge, Moderate Challenge, Major Challenge, Extreme Challenge	--	--	--
		Economic Challenges: • Low commodity prices • High input prices • Ability to obtain financing • Ability to find contracts • Unpredictable crop markets				
		Environmental Challenges: • Pest, weeds, and disease • Drought • Unpredictable weather • Not having enough water.				
		Exogenous Challenges: • Hiring and/or keeping labor • Government regulations • Availability of technical assistance.				

Table 3 Continued

Adaptive Capacity (cont.)	Specific Capacities	Please rate your level of agreement with the following statements.	7-point scale: Completely Disagree, Disagree, Somewhat Disagree, Neither Disagree nor Agree, Somewhat Agree, Agree, Completely Agree	--	--	--
		Social Capital • Helping other farmers in my community is important, even when it means making small sacrifices; • I seek the advice of other farmers; • I seek the advice of extension agents and other agricultural professionals; • My relationship with other farmers will help me find ways to deal with the settlement agreement				
		Adaptive Management • I regularly change my farm management practices to deal with new challenges; • I experiment with new ways to irrigate; • To comply with the agreement, I am willing to change how I manage my farm				
		Knowledge • I have the knowledge I need to solve water related challenges on my farm; • My current approach for dealing with water challenges will be sufficient for future water challenges				
		Linking Capacity • I was able to influence the decision-making process to the extent I wanted; • My interests were represented negotiations				

Table 3 Continued

Exposure	Groundwater Cut	What percentage of your total groundwater rights were you required to cut by your groundwater district?	Free response percentage, transformed to a proportion for modeling	--	--	--
Farmer Chars.	Demographics	Are you? (Male/Female)	Binary variable indicating whether a respondent is male.	--	--	--
		What year were you born?	Transformed measure of age (age / (2 * standard deviation))	--	--	--
		What is the highest level of formal education you have completed? Some high school or less, High school, Technical school/some college, College, Graduate degree (e.g. MS, MBA, PHD, MD)	Categorical variable of highest level of education reached	--	--	--
Vulnerability	Economic Vulnerability	In your estimation, what percentage of your typical farm income have you lost because of the water cut requirements?	Vulnerability measured as proportion of income lost after the settlement agreement went into effect.	--	--	--
	Perceived Vulnerability	How concerned are you about the following issues related to the water cuts? • Meeting the water reduction requirements of the settlement agreement • The impact of the settlement agreement on your farm operation • Your ability to make a living from your farm with the required water cuts	Composite of three measures of concern: simple average rounded to nearest integer 5-point scale: Not at all Concerned, Slightly Concerned, Moderately Concerned, Very Concerned, Extremely Concerned	--	--	--

3.3.3.2.2 Adaptive Capacity

Adaptive capacity is defined broadly as the ability of individuals under stress to enact change in behaviors, policies, institutions, or other governing dynamics to reduce stress or impact (Berman et al.; Engle). Adaptive capacity is typically conceptualized as being formed by four primary components, accounting for both external and internal "resources" available to farmers. Internal resources refer to a farmer's abilities or knowledge, while external resources refer to all resources external to the farmer, such as physical capital or social networks. In particular, we focus on: specific capacities (internal resources), institutions and entitlements (external resources), material and financial resources (external resources), and perception of past challenges (internal resources) (Eakin, York, et al.). Both specific capacities and perception of challenges were derived through factor analysis, employing the psych package in R to conduct minimum residual analysis with varimax rotation (Revelle). Specific capacities are the social connections or skills that individuals can apply to resist impact, and in our case, they factored out into four primary capacities: social capital, linking capacity, adaptive management, and knowledge (Eakin, York, et al.). This four-factor solution explained just over half of the variance (51.8% on average across 5 imputations) and was selected because of this high explanatory power and its theoretical significance. Social capital and linking capacity are both measures of networking, with social capital focused on relationships and linking capacity focused on the ability of the individual to influence policy or CAMP negotiations. Adaptive management is a measure of individuals' relative flexibility and willingness to experiment, while knowledge operationalizes individuals' understanding of the system. All four of these have been shown in past work to increase adaptive capacity and reduce vulnerability (Eakin, Lerner, et al.; Johnson et al.; Burnham and Ma, "Climate Change Adaptation: Factors Influencing Chinese Smallholder Farmers' Perceived Self-Efficacy and Adaptation Intent"; Engle). Institutions and entitlements refers to the engagement of farmers with other market resources. Specifically, we include the purchase of crop insurance and the presence or absence of contracts or co-op shares on a farm. Material and financial resources have important implications for an individuals' ability to enact change; in other words, these resources may act as a bottleneck for adaptation intentions. The central material resources of interest in this case are the irrigation infrastructures on each farm, and financial resources are included as a categorical variable of farm income. Perception of other challenges is similarly broken out into three sets of challenges using factor analysis: economic challenges, environmental challenges, and exogenous challenges. This three-factor solution explains 54.5% of the variation on average. Perception of other challenges may serve multiple roles in the development of adaptive capacity. On one hand, multiple stressors have been shown to intersect in ways that yield greater vulnerability among farmers (Burnham and Ma, "Linking Smallholder Farmer Climate Change Adaptation Decisions to Development"). On the other hand, recent work has shown that exposure to past shocks or challenges may build adaptive capacity in individuals, analogous to variability increasing resilience in ecosystems (Carpenter et al.; Burnham and Ma, "Climate Change Adaptation: Factors Influencing Chinese Smallholder Farmers' Perceived Self-Efficacy and Adaptation Intent"; Engle).

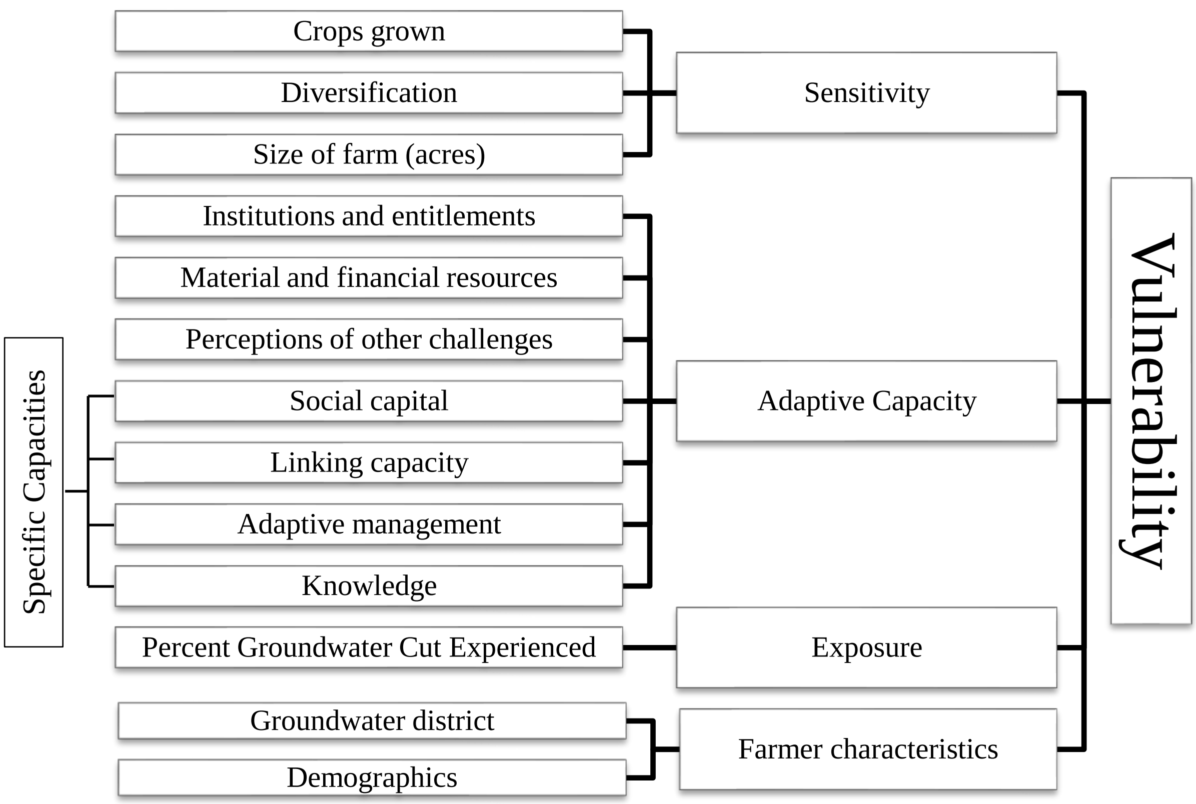


Figure 2 - Model of vulnerability as informed by existing literature. At right, vulnerability is measured in two ways, detailed below. At center, the four major components of vulnerability are sensitivity, adaptive capacity, exposure, and farmer characteristics. Each of these major components is composed of a number of sub-components, shown at left. More details on each component and subcomponent are available in Table 2.

3.3.3.2.3 Exposure

Exposure simply records the extent to which a shock or change is experienced (both in duration and magnitude) (Eakin and Luers). In the case of the ESPA CAMP, this is most effectively quantified as the proportion of a farmers' groundwater which is cut (du Bray et al.).

3.3.3.2.4 Farmer Characteristics

In this case, demographic data make up farmer characteristics. Demographic data are considered to ensure that exogenous contextual factors are not governing vulnerability dynamics. Specifically, farmers' gender, age, and level of education are considered.

3.3.3.2.5 Vulnerability

Two sets of response variables were developed to be tested. The first, percent of lost income, we refer to throughout the document as Economic Vulnerability. The second form of vulnerability modeled is a composite of farmer perceptions of their own vulnerability, referred to as Perceived Vulnerability. Recent research has suggested that vulnerability can be thought of both as concrete changes in condition and as perceived impacts on livelihoods (Callo-Concha and Ewert; Grothmann and Patt; Dang et al.). In fact, it seems likely that the perception of vulnerability is ultimately more important for adaptation decision making, since it is this perception that ultimately motivates individual-level action.

3.3.3.3 Two-Stage Statistical Analysis

We employ two methods of statistical analysis in this work: multimodel selection and inference followed by segmentation analysis. Model selection and other methods of regression analysis provide insight into the average predictors of vulnerability for the average farmer, a caricature with no equivalent in reality. To better understand how these key predictors of vulnerability vary across actual farmers, we implemented a clustering procedure to segment farmers by their adaptive capacity and demographics. Analysis of the characteristics of these groups show that adaptive capacity and vulnerability vary across farmer groups and farm types, and this results in different impacts across the population.

The first stage of analysis, multimodel selection and inference, was conducted using the glmulti package in R (Calcagno and Mazancourt; Calcagno). Multimodel selection and inference takes a larger theoretically-informed model as input and produces a refined model as output which explains the most variation in the independent variable. This modeling exercise employed our full vulnerability framework, employing all independent variables described with two forms of vulnerability as dependent variables. The refined version of this model may provide insight into which elements of the existing body of vulnerability literature are most relevant to highly industrialized agriculture in the context of policy change. The dependent variables were analyzed as separate modeling exercises, resulting in two different models of vulnerability. In accordance with Rubin's rules and specific guidelines suggested by Shomaker and Heumann (2014), estimates for coefficients were pooled across the five imputations, resulting in inferred estimates for the entire suite of data (Rubin; Schomaker and Heumann).

The second stage of analysis, segmentation analysis, utilized clustering capabilities in the base stats package in R. A kmeans approach was used to cluster the observations by Euclidean distance. Variables used in a segmentation analysis can be broken down into two categories, segmentation variables and profiling attributes. Segmentation variables are used to identify the groups, while profiling attributes are used to describe those groups. As segmentation variables, we included the three model components most directly related to a farmer typology. Those were: demographics, adaptive capacity, and crops grown. By segmenting along these three components, it is possible to examine how farmer characteristics and farm makeup affect differential vulnerability across the population. After establishing these clusters, we employ all model components as profiling attributes. It has previously been noted that cluster analysis does not naturally conform to Rubin's rules, and non-traditional methods of pooling are necessary. We used work by Basagaña et al. as inspiration for our method of pooling (2013). The only deviation from the prescribed framework occurred in the area of segmentation variable selection; rather than refining our list of segmentation variables used based on statistical significance, we retained all original variables due to their theoretical significance.

3.3.4 Interviews with Eastern Snake Plain Farmers and Qualitative Analysis

Qualitative data were collected through a series of interviews according to three semi-structured interview protocols. Each protocol was generated for the purposes of a specific sub-project analyzing the ESPA CAMP, and the data have been pooled here to supplement context and internal validity. To do so, we inductively coded a subset of interviews for discussion of adaptation, farmer values, and decision-making strategies, all of which are employed here (Ryan and Bernard; Saldana). Coding was conducted in NVivo by the lead author.

3.4 Results and Discussion

3.4.1 Non-response bias and multiple imputation results

Our respondent population is generally older, more likely to be male, and more land-rich than the overall farming population of the groundwater districts of interest (Table 4). This is generally unsurprising, given the typical limitations of household surveys (Dillman et al.). To attempt to correct for this, the research team conducted semi-random follow-up calls to survey non-respondents, offering to conduct the survey over the phone or send another survey if needed. This resulted in four surveys filled out online or over the phone and twenty surveys either resent and returned or simply returned after the prompt.

We made no statistical corrections for dissimilarities between our study population and the general population of farmers in the districts. As described in recent analyses of declining mail survey response rates, social scientists are faced with a conundrum of increasing expense and decreasing validity (Stedman et al.). In our case, we work to overcome this limitation by highlighting some high-level conclusions from qualitative analyses conducted in parallel with this statistical analysis. This sort of semi-narrative, mixed-methods analysis has been suggested by some scholars as a solution to questions of internal validity, though it falls short of generating solutions to questions of generalizability (Stedman et al.).

Table 4 - Analyzing non-response bias and results of imputation

Variable	**2012 Ag Census**	**Imputed Data**	**Unimputed Data**
Average Age of Farmer (years)	56.53	64.39	64.30
Gender (% female)	9.8%	6.8%	6.6%
Average Irrigated Farm Size (acres)	811.33	1248.00	1275.04
Average Farm Size (acres)	700.55	--	--
Net Farm Income (average)	$93,993.48	*Ordinal – See Figure 3*	
Own Cattle (%)	44.2%	45.8%	48.9%

Imputation did not change the descriptive profile of respondents significantly. Again, this is unsurprising, since nonresponse was scattered across observations; this provided ample data to support imputation, an indicator that the Missing at Random assumption is appropriate.

3.4.2 Profiling vulnerability to water scarcity – model selection results

A variety of differences exist between the predictors of economic and perceived vulnerability (Table 5). Evaluated at alpha = 0.05, five predictors were significant in both model selections, three predictors are only significant in the economic vulnerability model, four predictors were only significant in the perceived vulnerability model, and eight predictors were included in a model in at least one imputation but were not significant across imputations for either economic or perceived vulnerability.

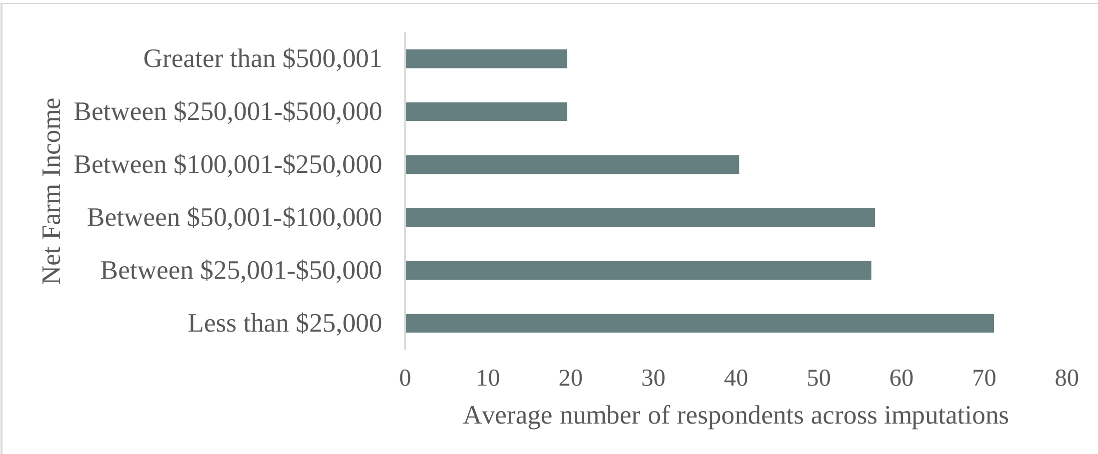


Figure 3 - Average number of respondents in each category across imputations. This suggests that a mean income of between $100,000 and $200,000 is appropriate for our population.

3.4.2.1 Key variables in both selected models

Five predictors were significant in both model selections. Perceptions of both economic and environmental challenges proved to be predictive of increased vulnerability in both models, economic and perceived. This may be related to vulnerability to past events and perceptions shaped by those events. The percent cut experienced by a groundwater user is correlated with vulnerability. We also found use of center pivot irrigation to be predictive of increased vulnerability. This is consistent with qualitative findings from interviews with farmers throughout the Eastern Snake Plain, in which farmers suggest that the five-year baseline used to set water consumption limits actually punishes farmers who had already sought water efficiency (e.g. through the use of center pivot irrigation). In the words of one farmer:

> *"I guess the biggest thing is my complaint is the ones that we'd had wheel lines and so we'd already converted from wheel lines to pivots and became more efficient but that was before the average in or whatever so I'm already being more efficient, being wiser about what I'm doing and you're penalizing me."*

Finally, linking capacity emerges as the specific capacity that has the most consistent, negative effect on vulnerability. This feature of adaptive capacity has not been widely tested as a predictor of vulnerability in other contexts. Observing its consistent role in this study, we suggest that linking capacity may have proven important in the development of curtailment rules at the groundwater district level. This indicates that such localized rule-making may privilege those with existing connections to local power structures.

Table 5 - Predictors of Economic and Perceived Vulnerability: Positive coefficients indicate and *increase* in vulnerability, while negative coefficients indicate a *decrease*. Variables are included in table if their coefficient is not equal to zero for either the economic or perceived model selection.

Predictor Variable	**Economic Coefficient Estimate**	**Significance (p-value)**	**Perceived Coefficient Estimate**	**Significance (p-value)**
Acres Farmed (transformed)	0.151329656	0.110912	--	--
Adaptive Management	-0.0795	0.207104	-0.045	0.105307948
Age of Farmer (transformed)	0.051	0.208504	--	--
Plants Alfalfa on Farm	0.123	0.212767	--	--
Plants Wheat on Farm	0.184	0.21023	--	--
Perception of Economic Challenges	0.440	0.014404	0.438	6.00929E-06
Perception of Environmental Challenges	0.499	3.89E-05	0.336	2.35911E-06
Perception of Exogenous Challenges	0.243	0.052934	0.223	0.000342558
Farm Income	0.038	0.207097	--	
Use of Center Pivot Irrigation	0.927	0.001432	0.376	9.81806E-06
Use of Line Irrigation	--	--	-0.135	0.049987545
Knowledge	-0.232	0.045633	-0.105	0.051665865
Linking Capacity	-0.413	0.000361	-0.330	5.47359E-06
Gender (male?)	--	--	0.121	0.107951188
Percent of Water Right from Groundwater	0.596	0.117575	0.156	0.106015882
Percent of Groundwater Cut	4.660	0.006604	0.731	0.000155873
Percent of Water Right from Surface Water	-1.380	0.003773	-0.360	0.054838441
Percent of Crops Insured	0.545	0.016965	--	--
Social Capital	0.068	0.207731	0.122	0.014835129
Intercept	-1.819	0.065239	2.857	8.61498E-06

3.4.2.2 Variables unique to Economic Vulnerability

Both knowledge and percent of water rights in surface water are found to predict lower economic vulnerability. Qualitative analysis suggest that farmers with significant surface water shares are avoiding the worst of the impacts by calling on previously unused canal shares:

> *"Well, we've had to make some adjustments … we've actually used a little more canal water. … we have one place that we can irrigate. It has both water rights: canal water rights and deep well water rights. So, when, in the spring when we are, when we have a natural flow, we try to utilize the maximum amount of canal water and save the well water."*

Percent of crops insured actually predicts higher economic vulnerability in this context. Some previous evidence suggests that expanded use of crop insurance may be associated with lower levels of adaptation to system-level drivers, so this behavior may also expand vulnerability (Bitterman et al.; Mase et al.).

3.4.2.3 Variables unique to Perceived Vulnerability

Perception of exogenous challenges and social capital are both correlated with higher perceived vulnerability. Use of line irrigation is associated with lower perceived vulnerability, a point that again falls in line with qualitative results that indicate that farmers perceive higher water use in the past as a relative advantage when coping with the policy.

3.4.2.4 Theoretically important variables do not always apply to industrialized ag in Idaho

An assortment of other variables included in our theoretical model did not prove to be significant in the modeling of either measure of vulnerability. These included variables such as adaptive management, size of farm, age of farmer, and gender, all of which have proven important in other contexts (e.g. Adger, 2006; Eakin, 2003; Eakin and Bojórquez-Tapia, 2008). The relative unimportance of these predictors suggests that existing theoretical models may require iterative revision to more effectively characterize drivers of vulnerability in highly industrialized agricultural systems in the United States. Though adaptive management does not prove significant in our statistical analysis, farmers who express more interest in learning new approaches and experimenting with new technologies perceive themselves as less vulnerable in interviews. This disconnect could suggest a misconception among farmers, but it could also suggest that a minority of farmers rely on experimentation as an adaptation strategy. Similarly, neither the number of acres farmed nor farm income were predictive of a change in vulnerability. While this may be indicative of the relatively weak connection between wealth and vulnerability to water scarcity in the context of industrialized agriculture, it may also be a symptom of the relative wealth of our average survey respondent. We expand upon this challenge in our Conclusions.

3.4.3 Segmentation of ESP farmers – cluster analysis results

Through the proliferation of irrigation, the high desert of the Eastern Snake Plain has been transformed into an agricultural basin as diverse and varied as any in the Unites States, and the people working that land are as diverse as the crops growing there. We were able to highlight this through cluster analysis, segmenting farmers into four primary groups, which we refer to as High-Capacity Farmers (Cluster A), Average Farmers (Cluster B), At-Risk Farmers (Cluster C), and Part-Time Farmers (Cluster D). Segmentation is used to highlight the dimensions along which groups within the population can be differentiated. However, as a consequence of different farm makeups and land-tenure histories, groups were also exposed to different levels of groundwater cuts. To more effectively compare vulnerability across groups, we normalize percent income loss by percent groundwater cut, producing a measure of the rate of income loss as water is removed.

Qualitative analysis suggests that each unique combination of farm characteristics can result in different availability of options for adaptation. For example, some methods of irrigation allow farmers to lower their irrigation flow rate while also slowing their movement speeds, while others are already slow enough crossing a field that extensions would endanger crop performance:

> *“I've put up all pivots now. Basically can get by with less water and I can move around. I mean, you know, you do a hand line field; you got a six day rotation. It takes six days to get across. On a pivot, you can be across it twice with lesser application of water but still grow a crop.”*

Therefore, quantitative segmentation should provide insight into the specific features of adaptive capacity and sensitivity that distribute unevenly across the population of farmers and yield inequalities.

Table 6 – Outcomes and demographics across clusters

Cluster Label	Cluster name	Average N (across imputations)	%Groundwater Cut Experienced	% Loss in Income	Normalized Vulnerability (Loss income / Loss Water)	% Income from Ag	% w/ income loss > 0	Acres farmed	Number of crops on farm
--	All respondents	264	16%	9%	0.56	53%	60%	1248	2.03
A	High-Capacity Farmer	27	19%	11%	0.66	56%	70%	5918	3.61
B	Average Farmers	76	12%	7%	0.59	66%	62%	1210	2.35
C	At-Risk Farmers	99	22%	9%	0.84	78%	79%	1022	2.02
D	Part-time Farmers	61	11%	5%	0.45	20%	28%	283	0.98

Clusters were identified using a bootstrapping algorithm designed to produce the most stable clusters from the available data. Each cluster returned an average Jaccard index between 0.65 and 0.75 (Hennig). Recent work has indicated that clusters at this stability level are indicative of patterns in the data and that descriptive analysis may yield insights; however, clusters with Jaccard indices below 0.75 are unlikely to perfectly identify which cluster each individual should be in. With this in mind, we focus this discussion on large-scale trends in the data and highlight potentially policy-relevant outcomes.

As shown in Table 6, only one cluster of the four shows disproportionate vulnerability to water cuts. In the following sections, we highlight the possible drivers of this. To do so, we divide our discussion into two parts that pair related clusters.

3.4.3.1 Clusters B and C: Average farms – not average outcomes

Cluster B and Cluster C farmers are the statistically typical Idaho farmers, managing between 1000 and 1200 acres with at least some college education and a mixed household income made up of between sixty and eighty percent income from the farm. However, they differ dramatically in their normalized vulnerability, with Cluster C exhibiting by far the highest average among the groups. A few variables appear to play a role in this difference. First, Cluster C experiences the highest groundwater cut among farmers, suggesting possible threshold effects in income loss. Second, farmers in Cluster C rely more heavily on income from agriculture and rely on a smaller number of crops, pointing to the role of diversification in determining sensitivity, a factor that is highlighted in Cluster A and D results. Third, Cluster C farmers tend to use center pivots on more of their land, something which qualitative results have indicated increases the short-term vulnerability of farmers. Finally, Cluster C farmers report the highest sensitivity to other challenges (economic, environmental, and exogenous), perhaps indicating that intersectional stressors play a role in their increased vulnerability. Interestingly, Cluster C reports mixed adaptive capacities; however, the greatest strength among this group, Social Capital, was not shown to have a significant relationship with vulnerability in our model selection exercise. On the other hand, Cluster B farmers report mostly high adaptive capacities, indicating that this difference may also play a role in the differential vulnerability.

Table 7 - Adaptive capacity across clusters

	Cluster name	**Economic Challenges**[10]	**Environmental Challenges**[10]	**Exogenous Challenges**[10]	**Social Capital**[10]	**Adaptive Management**[10]	**Linking Capacity**[10]	**Knowledge**[10]	**% who have crops insured**	**% who serve(d) as GWD Leader**
--	All respondents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34%	27%
Cluster A	High-Capacity Farmer	0.40	0.06	0.10	0.16	-0.24	-0.03	-0.17	53%	23%
Cluster B	Average Farmers	0.05	-0.05	-0.02	-0.04	0.34	0.19	0.17	40%	21%
Cluster C	At-Risk Farmers	0.44	0.17	0.21	0.29	-0.06	0.29	0.09	37%	30%
Cluster D	Part-time Farmers	-0.88	-0.18	-0.26	-0.31	-0.04	-0.30	0.01	17%	31%

3.4.3.2 Clusters A and D: Diversified farms

Cluster A and Cluster D farmers provide a foil to this typical Idaho farmer. Cluster D exhibits the lowest recorded normalized vulnerability, while Cluster A exhibits relatively low normalized vulnerability despite experiencing significant groundwater cutbacks. Analysis indicates that both clusters may rely on a related mechanism to reduce sensitivity to water cuts: diversification. Cluster A farmers have large farms where they plant a variety of crops, while Cluster B farmers manage mostly small farms and bring in a high percentage of off-farm income.

[10] By their nature, the population average of each factor is approximately zero when averaged across imputations.

In both cases, the impacts of the groundwater cut are diluted. Both clusters exhibit somewhat mixed adaptive capacity. Cluster A farmers possess below average specific capacities, while also reporting the greatest perception of intersectional challenges. Cluster B farmers report being largely insulated from intersectional challenges but also exhibit the lowest specific capacities across the board. These mixed capacities indicate that the major contributor to vulnerability reduction for these groups comes in the form of reduced sensitivity. In this case, that seems primarily attributable to diversification of income sources.

3.4.3.3 Implications of clusters

This four-cluster solution indicates that, by and large, many combinations of characteristics exist to ensure that farmers are resilient to changing water availability. This could be as a result of diversification, something that has been discussed at length in the livelihoods literature (Osbahr et al.). It could also be a result of generally high adaptive capacity among farmers in the region, something that could be viewed as a consequence of the relative wealth of the area. Finally, qualitative results have suggested that most farmers were only cursorily managing groundwater withdrawals to this point, and most acknowledged that a certain degree of improved efficiency was not overly burdensome. The clusters suggest that potential threshold effects are being seen among farmers, with most able to adapt to relatively tolerable cuts but seeing accelerating income loss after a certain percent of water loss.

3.5 Conclusions

Our analysis indicates that components of adaptive capacity like linking capacity and exposure to other challenges may prove particularly important in determining vulnerability to water supply changes in highly industrialized, irrigated agriculture. Differential vulnerability across the population indicates that differences in initial conditions can result in dramatically different outcomes for farmers undergoing these sort of policy-driven water supply changes. This has important implications for policymakers as they seek to create just, effective policies. This is particularly important in the western US and other industrialized agricultural systems where this sort of policy-induced water scarcity is likely to be the dominant form of water scarcity in the near future and where climate change adaptation policy has been shown to be of greater concern to farmers than climate change itself (Niles et al.). Even as climate change intensifies, it is highly likely that water management agencies of various forms will play an important role in governing the distribution of water cuts necessitated by a drying climate.

This study is faced with what is becoming a common challenge in the natural resource social sciences: low response rate and some indication of response bias. For this reason, some of our discussion of the study's results is tempered. In our case, we work to overcome this limitation by highlighting some high-level conclusions from qualitative analyses conducted in parallel with this statistical analysis. Future work should continue to pursue analysis of the drivers of vulnerability in the context of highly industrialized agriculture and interactions between public and private adaptation.

As new policies take effect, specific capacities like knowledge of alternatives may prove key in differentiating those farmers who either successfully make changes to their farms or navigate around the need to make such changes. This indicates that the funding of training programs could prove important in allowing farmers to establish a plan for adapting to changes in water availability. Additionally, the emergence of linking capacity as an important predictor of vulnerability in this context suggests that policy makers may be faced with a tradeoff when distributing rulemaking to local governing boards. While this sort of localization may allow rules to be better customized to local conditions, the relative importance of linking capacity in reducing vulnerability may indicate that this sort of decentralization favors those with strong connections to the local policy-making process.

This study points to important gaps in our understanding of actual vulnerability of industrialized agriculture to real-time stressors, gaps that may be expected to prove increasingly problematic as climate change adaptation policies roll out globally. While the extensive body of knowledge from studies focused on the Global South or on projected vulnerability provide a robust launch-point, our work highlights the importance of applying that knowledge to new contexts as opportunities for study continue to emerge.

CHAPTER 4. THEORY-DRIVEN AGENT BASED MODELING FOR EXPLORATORY PREDICTIVE ANALYSIS OF ADAPTATION DECISION MAKING

4.1 Abstract

Climate change will require agricultural adaptation at multiple scales, and effective policy-scale adaptation will require rapid, accurate modeling of this process. This work outlines the core components of a coupled natural-human systems model that was developed to create a more effective simulation mechanism for adaptation in American agriculture. The primary motivation for the development of a new model was the creation and integration of three social science theory-based decision-making modules. This chapter is focused on three outcomes: 1.) Describing the development of the model; 2.) Highlighting the significance of decision-making rules for outcomes in models of this type; and 3.) Comparing model outcomes to empirical data describing cropping patterns and adaptation in a case study of Eastern Idaho. This work sets the stage for future efforts towards refining the model and lays out some guidance on future development of agent decision-making rules in ABM.

4.2 Software Details

Program title: Industrialized Agriculture Adaptation Model (Farm-Adapt)
Developer: Jason K Hawes
Contact address: jasonkhawes@gmail.com
Software access: Farm-Adapt free through GitHub. NetLogo, AquaCrop, and R free through original publishers
Software required: NetLogo, AquaCrop, and R
Program Languages: NetLogo, R
Availability: The program and all accompanying platforms are free and available to use for non-commercial purposes. Software and data for the case study herein are available through the case study public GitHub: https://github.com/jkhawes/FarmAdaptESPA
License: GNU General Public License v3.0

4.3 Introduction

As climate change and increasingly globalized markets change the face of agriculture globally, agricultural adaptation to interacting stressors will determine food, water, and economic (in)security outcomes in many regions (IPCC). These modern food systems are tremendously complex, relying on vast networks of formal and informal institutions (governing organizations, social structures, economic frameworks, etc.) while striving to meet an exploding global demand (Godfray et al.). This complexity, combined with continued population growth and accelerating change, means that our collective ability to project and understand future outcomes in agriculture is central to long-term global sustainability (Bazilian et al.; Godfray et al.). Such projections are only expected to grow more difficult under a rapidly changing global climate and as human systems seek to adapt to changing conditions (Irwin et al.).

Adaptation has been documented as a multi-scalar, intertemporal process that occurs at both the organizational and individual levels (Burnham and Ma, "Linking Smallholder Farmer Climate Change Adaptation Decisions to Development"). In this context, adaptation at the organizational level refers to interventions from government or collective agencies, often in the form of policy; this is also referred to as planned adaptation (Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests"). Individual-level adaptation refers to long-term, fundamental changes to an individual's beliefs or practices relating to a resource; this is also referred to as autonomous adaptation (Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests"). Empirical research has shown that agricultural adaptation efforts at these different levels often interact in unexpected ways, creating both synergies and tradeoffs that can result in enhanced adaptive capacity or increased vulnerability of farmers (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"; Rasul and Sharma).

As global environmental change accelerates in the coming decades, it will become increasingly important that planned adaptation initiatives be designed with these interactions in mind (Burnham and Ma, "Multi-Scalar Pathways to Smallholder Adaptation"). This requires the ability to effectively project these interactions and their impacts, and this, in turn, requires more effective mechanisms of modeling adaptation at multiple scales. Such models would be required to incorporate spatial and temporal effects, social-ecological dynamics, and heterogeneity among actors. To accomplish this, we turn to agent-based modeling.

ABM is a simulation methodology built on the dual foundations of cellular automata and heterogenous, independent agents (de Marchi and Page). Both the social and biophysical environment can be customized to simulate the desired context, and agents can take on a variety of internal qualities. Each independent agent is governed by a set of decision-making rules laid out by the modeler; these rules can include limitations on perception, goals, values, social influence, behavior options, and a variety of other parameters (Schlüter et al.).

Most often, these rules have been based on economically rational behaviors (profit-seeking, bounded or unbounded) or built around localized decision-making heuristics derived from intense fieldwork (Smajgl and Barreteau, "Volume 1, The Characterisation and Parameterisation of Empirical Agent-Based Models"). Both of these strategies have produced valuable models, underlying significant advances in our collective understanding of complex social-ecological systems (see An, 2012; Bell, 2017; Groeneveld et al., 2017 for more complete discussions of this legacy). These two veins of research reflect two generally separate drivers in the development of ABMs. The first is the drive to generate simple, generalizable models that inform our general understanding of a complex social-ecological systems problem; this has underlain many of the models employing economically rational frameworks (Sun et al.). Requiring minimal knowledge of the actual agents in context, these models are relatively quick to implement and can often represent a significant improvement from resource dynamics models that ignore or generalize human factors (An; Abebe et al.). Still, they lack the nuance and detail of decision-making rules more accurately reflecting reality. Thus, the second driver is an impetus to generate realistic models that provide insight into the resilience or sustainability or a particular social-ecological system (Pérez and Janssen; Smajgl and Barreteau, "Framing Options for Characterising and Parameterising Human Agents in Empirical ABM"). Most often, models driven by this impetus use extremely localized heuristic models of decision making. Such models draw their strength from the modeler's in-depth knowledge of the system being modeled, but they can be extraordinarily time-consuming to implement.

Acknowledging this conflict between intensely localized and overly simple rule-making methods, recent discussions of the state of agent-based modeling suggest that a compromise is needed; in turn, some discussions suggest that descriptive decision theory in the social sciences may provide such a compromise (Schlüter et al.; An; Müller et al.). Further, it has been suggested that the general failure of agent-based modelers to broadly invoke social descriptive decision-making theories may be the most important weakness of ABM for informing policy (Schlüter et al.). Conversely, this is a charge to the social science community writ-large to engage with models and modelers in this effort to invoke such decision-making theories. As models become increasingly important for policy generation in a changing world, overly time-demanding or overly simplified representations of the human system pose a clear risk to stakeholders affected by potentially misinformed policies. Therefore, we seek to build on recent work attempting to bridge this gap in our understanding of ABM in social-ecological systems. To do so, we test a selection of descriptive decision theories in a model of agricultural adaptation to policy-imposed water scarcity. In the process, we develop a new model of agricultural adaptation, the Industrialized Agriculture Adaptation Model Version 1 (Farm-Adapt).

4.4 Model Development

Beginning with the goal to improve the collective understanding of modeling informed by social-psychological theory, we developed Farm-Adapt between May 2017 and March 2019. The model was designed with three general principles in mind: Modularity, Portability, and Couplability.

The model is designed in modules, both as a mechanism for simplifying code and as a tool for allowing user customization. Though most of the programs utilized so far are considered part of the minimum acceptable infrastructure, it is theoretically possible to add or remove modules with minimal code modification, allowing for relatively quick development of advanced functionality.

Portability in this case is taken in both the traditional sense of software portability and in a more niche sense to designate the ability to simulate adaptation in varied geographies. Designed using open-source software and intended to run on standard power computers, the model and associated documentation are expected to be portable to a variety of machines and environments. In the second sense of the term, the model is initially instantiated in the Eastern Snake Plain of Idaho, USA, but inputs and modules are designed to be easily reoriented to a new location or adaptation situation.

Finally, the model is designed with couplability in mind. Though the model itself does not integrate an explicit interface like the Community Surface Dynamics Modeling System's Basic Model Interface (Peckham et al.), the model is designed to couple easily with, for example, crop or climatic modules. This sort of model coupling is generally considered the most effective mechanism for creating holistic systems models, and the first example of this in the Farm-Adapt Model is the integration of AquaCrop crop modeling (Steduto et al.; Peckham et al.; Foster et al.). The model is designed to integrate with models operating at any time scale between daily and annual iterations.

This discussion is divided into three sections to facilitate the description of the Farm-Adapt Model development. Model Concept and Flow focuses on the structure of the model, highlighting noteworthy design decisions designated as key to system function. Model Software and Deployment describes the user interaction and simulation process, identifying the key variables determined by the user and describing the method by which the simulation can be run. Finally, Background and Parameterization describes the primary sources of information for model development as well as how this information is integrated into the model. This, then, leads us to a discussion of the Eastern Snake Plain case study.

4.4.1 Model Concept and Flow

The Farm-Adapt Model is made up of 33 modules, each divided into procedures and controlling one or several aspects of the simulation. This section provides an outline of module types (System setup, Annual Simulation, and Analysis and experimentation) and describes the primary functions of each collection of modules.

4.4.1.1 System setup

The first series of modules parameterize and initialize the simulation environment. The dominant portion of this is the generation of the groundwater district to be studied, including landscape, agents, and social networks. Each groundwater district is imported as a vector file, and the NetLogo simulation world is sized to fit the district. Farmers, including their demographics, are randomly generated based on averages identified in secondary data. Finally, a random social network is used to connect farmer and consultant agents. These relatively large, semi-random worlds take considerable time to generate on standard power computers; for that reason, most simulations employ an “Experimental” setup strategy, which imports a previously generated world and reparametrizes it. Experimental simulations must be run through the R code included in the model repository (R Core Team).

4.4.1.2 Annual simulation

Upon completion of setup, the model simulates a number of years determined by user input. Each year of simulation is divided into four seasons: Planning Season, Crop Season, Harvest Season (Reconcile), and Offseason (Knowledge Sharing). Modules are organized by season, and each season plays a distinct role in the Farm-Adapt process. Planning Season is the core of the Farm-Adapt Model. It incorporates season initialization for each farmer as well as the decision-making modules. The decision-making modules ask farmers to select a combined land use/management portfolio that best fits each field they manage. For the initial case study, this is operationalized as the selection of a crop for each field and an irrigation method (hardware) to go along with it. This basic framework could be expanded to any number of agricultural adaptation questions; for example, early extensions of the operationalization in the Eastern Snake Plain are expected to integrate non-crop land uses, “software” or planning changes to irrigation, and soil management strategies that can impact both crop performance and irrigation efficacy.

After the Planning Season, crop performance is simulated during the Crop Season. Crop Season is the first season to integrate model coupling, employing weak[11] coupling that relies on text files passed back and forth between NetLogo and AquaCrop, the United Nations’ Food and Agriculture Organization irrigated agriculture simulation tool (Raes et al.). At the time of writing, this coupling is time-prohibitive for large-scale simulation and thus was not used for simulations in this early analysis. Improved efficiency is a goal of future model releases.

Harvest Season, also referred to as Reconcile, is the period in which both the farmers and the model take stock of what transpired the previous year. This includes recalculation of wealth and adjustment of attitudes according to outcomes. Finally, Offseason, or Knowledge Sharing, simulates farmer and consultant exchange of information and updating of attitudes and subjective norms. This is conducted through the social networks constructed during setup.

4.4.1.3 Analysis and experimentation

Farm-Adapt is designed to produce a variety of plain-English outputs to facilitate early-stage analysis of model performance. Additionally, an assortment of BehaviorSpace experiments and associated R scripts are integrated into Farm-Adapt and stored in the Farm-Adapt GitHub

[11] Weak coupling here is used here in the software engineering sense. Text files (data) are passed back and forth between the programs, but no direct interaction occurs. This is generally referred to as “weak” coupling.

repository for rapid analysis of updates. Finally, in order to facilitate in-situ analysis, an R script integrating the R-NetLogo package is available through the Farm-Adapt GitHub repository (Thiele). For experiments to be run through the Experimental Setup process (a significant time savings), NetLogo must be called through R. It is impossible to simultaneously employ the Experimental Setup functions in native NetLogo while also varying inputs for experimentation.

4.4.2 Model Software and Deployment

As described, our team developed the Farm-Adapt Model in NetLogo, an open source agent-based modeling platform developed at Northwestern University (Wilensky). We chose NetLogo for three primary reasons. First, two authors were already familiar with the software. Second, the open-source system and easy-to-use Graphic User Interface (GUI) make NetLogo a popular platform for projects considering participatory work, experimental games, or workshops requiring direct engagement with the model. Finally, the growing community around NetLogo has developed a robust array of add-ons that enable coupled modeling through systems like MATLAB (The MathWorks Inc.), R (R Core Team), and ModFlow (Jaxa-Rozen et al.).

The user can interact with Farm-Adapt through one of two programs: NetLogo or R. The NetLogo interface is recommended for initial use of the program and for familiarization with the model (Figure 8). Within the NetLogo program, the user has access to an assortment of functionality beyond the basic simulation. For instance, it is possible to generate input files for new experiments from within the software, allowing the user to identify the variables of interest and to import this into a new BehaviorSpace experiment. However, as the pseudo-random setup process takes an extended period of time, it is likely that the user would prefer to employ the experimental setup whereby previously generated worlds are imported for simulation. While a powerful tool, this does not allow for extended variation within simulation, making it necessary for the user to employ R as the primary interface during extended experimental runs.

When employing coupled crop modeling, the primary role of the user is to cue the use of AquaCrop when needed. Messages indicating the appropriate time are displayed by NetLogo, along with a request to resume the simulation once AquaCrop has finished. Data are imported and exported between programs independently through text files, but NetLogo has no built-in mechanism for triggering AquaCrop simulations. For those with access to MATLAB, it is theoretically possible to use the coupling platform designed for NetLogo and MATLAB to more strongly couple Farm-Adapt with the open source version of AquaCrop designed for deployment in MATLAB (Foster et al.; The MathWorks Inc.; Biggs and Papin). To maintain open access to all model components, this has not been integrated into Farm-Adapt V1. As noted before, coupled crop modeling has been limited to date due to the time-intensive nature of the simulations and the limitations to running models in parallel.

4.4.3 Background and Parameterization

Once instantiated in a case, Farm-Adapt is an empirically-grounded, theory-informed model of agricultural adaptation. To create such a model, our team drew from a variety of primary and secondary data sources and engaged with several bodies of literature. Generally, the model can be described as relying on the parameterization of three separate components: social/economic environment, biophysical environment, and agent decision-making environment. Parameterization data for each of these components are systematically catalogued and parameterization methods are written generically to allow for relatively easy integration of other locations. More specifically, each district (or other simulation setting) is parameterized primarily using two file types: GIS files for geospatial configuration and text files for describing key social and biophysical qualities of the district (e.g. demographics, weather, economy). Decision-making parameterizations are currently embedded in the model, but future updates are expected to improve modularization of decision making.

Farm-Adapt V1 is implemented in the Eastern Snake Plain of Idaho in keeping with the case study described here. The goal of a portable model, however, is that it can be implemented in other settings. Relocation of the model can be conducted in stages. The replacement of location-specific inputs (GIS and text inputs) is the only explicit requirement of relocation, but a variety of localized parameters should be revisited in the event of a large-scale study outside the Eastern Snake Plain. These include, but are not limited to, crop yield and price patterns, irrigation strategies, and the decision-making theories themselves.

4.5 Descriptive Decision Theory and ABM

Within the planning season, Farm-Adapt Model V1 employs and allows comparison of three models of decision making. Each model is based on a general framework derived from broader theories of adaptation. Recent scholarship suggests the analysis of adaptation as a “suite of beliefs and practices" instead of individual, standalone decisions (Carr, 2008: 693). Correspondingly, we broadly conceptualize the choices of farmers as an integrated package of water management technology and land use; this, then, is the overarching framework that structures the conceptualization and operationalization of each decision-making model in-context. In other words, these decisions are interdependent and are modeled as such. Farmers consider land uses and adaptation strategies together, rather than on their individual merits.

The first model of decision making available in Farm-Adapt invokes a boundedly-rational, profit-seeking agent; this was designed as the control condition and closely resembles early models of rational behavior in ABM. The second model employs Azjen's Theory of Planned Behavior, a social psychological theory that has been used widely in the natural resource social sciences (Ajzen, "The Theory of Planned Behavior"; Floress, Akamani, et al.). The third model is based on the Integrative Agent-Centered Framework proposed as an updated model of farmer behavior by Feola and Binder (2010). Each of these models is implemented via a series of algorithms that roughly correlates to the theory. The algorithms are localized via existing literature and results from semi-structured interviews. Semi-localized conceptualization, operationalization, and "alogrithmization" are discussed below, followed by presentation and analysis of the results of these models. Within the discussion of each model, Figures 4, 6, and 7 employ the recently laid out Modeling Human Behavior (MoHuB) framework to describe the scope of the decision-making model (Schlüter et al.).

4.5.1 Rational Actor

Referred to hereafter simply as Rational Actor, the first model of decision making is conceptualized as profit maximization under boundedly rational conditions. Though not a decision-making theory in the truest sense, this serves as the "control" framework in this work. A derivative of early *Homo economicus* models of human behavior, bounded rationality owes its roots to the work of Herbert Simon and his interest in the impacts of limited information on human decision-making (Simon, "A Behavioral Model of Rational Choice"; Simon, "Simon-H=Theoriesof Bounded Rationality"). Simon was the first to argue that rationality was context-dependent and that even utility-maximizing decisions in a world of limited knowledge and limited cognitive capacity could be ultimately irrational and/or lead to undesirable outcomes (Klaes). Since then, bounded rationality has become a cornerstone of most models of human behavior; in even the most complex theories of decision-making, bounded rationality is often considered an underlying principle, describing both the limited decision-making space of the actor and the satisficing nature of utility calculations (Simon, "Bounded Rationality and Organizational Learning"). In agent-based modeling, simple profit maximization under bounded rationality has served as the default decision-making theory, presenting an easy-to-operationalize step between basic rational choice and modern social theory (An).

Under the Rational Actor framework in the Farm-Adapt Model, farmers calculate the utility of a land use (Rational Actor Utility - RAU) by employing a crop budget calculation derived from the University of Idaho's extension materials (University of Idaho Extension). This approach estimates the net expected returns (*NER*) of a crop by subtracting operating and ownership expenses from the gross expected returns (*GER*), given by:

$$RAU = NER = GER - Operating\ Exp. - Ownership\ Exp. \tag{1}$$

It is assumed that farmers are quite accurate at estimating their own expenses, including maintenance costs. On the other hand, variability is built into the yield and price functions for each crop, yielding a bounded decision-making space. Thus, gross expected returns are given by:

$$Gross\ Expected\ Returns = Estimated\ Market\ Price * Estimated\ Yield \tag{2}$$

Farmers' estimation of their expenses is broken down into two components, Operating Expenses (*OpEx*) and Ownership Expenses (*OwnEx*), given by:

$$OpEx = Seed + Fertilizer + Pesticide + Custom\ Costs + Irrigation + Machinery + Labor + Misc.Costs \tag{3}$$

$$OwnEx = Land + General\ Overhead + Capital\ Recovery \tag{4}$$

Details of each component are located in the model Read-Me (available via GitHub).

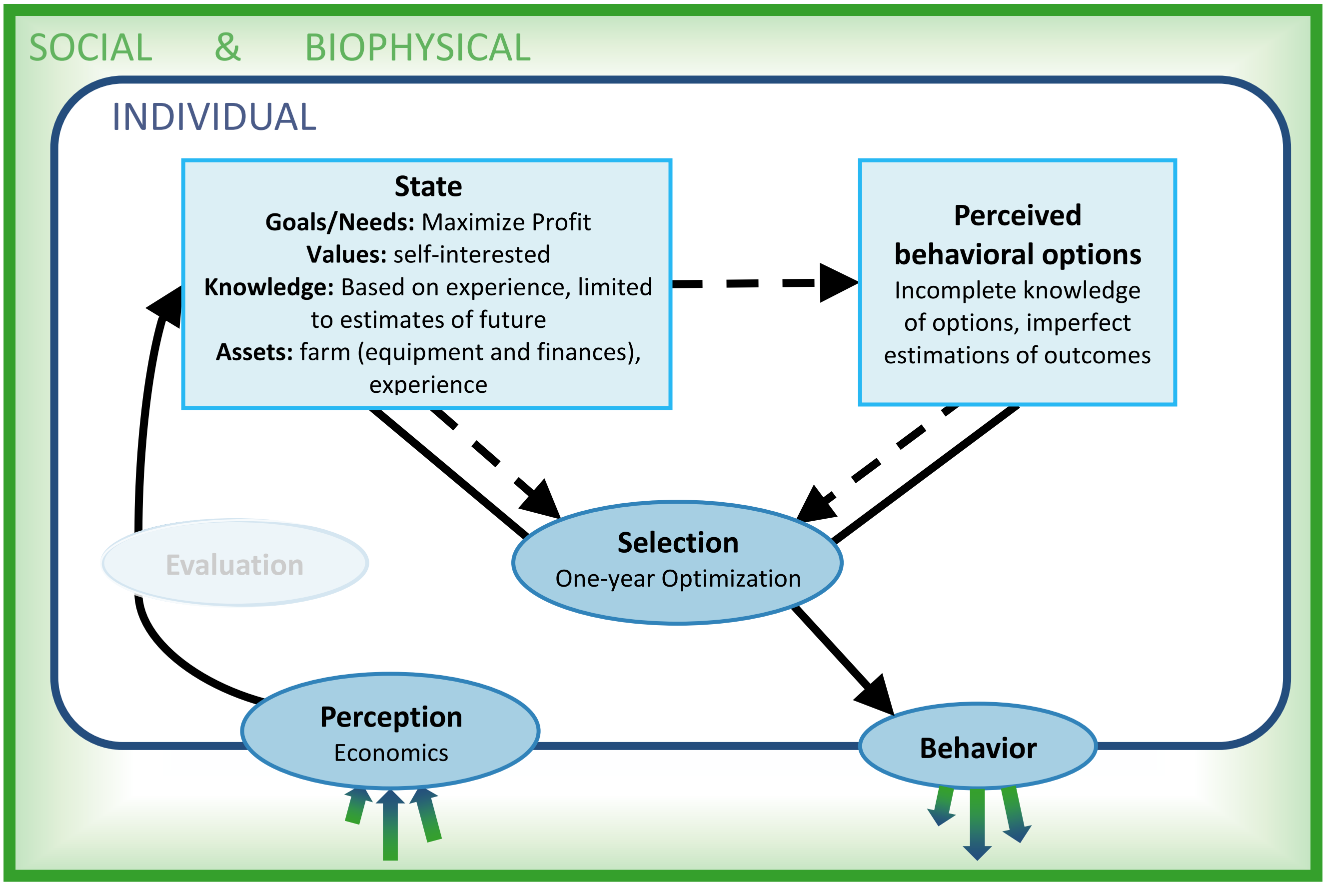


Figure 4 - MoHuB Framework - Boundedly Rational Actor. Each individual interacts with the environment through their perceptions and through their behaviors. Their perceptions inform their state through their knowledge of markets. Selection occurs from among the perceived behavioral options according to a one-year maximization of profit. This selection is then translated to behavior. Adapted from Schlüter et al., 2017.

4.5.2 Theory of Planned Behavior

The Theory of Planned Behavior (TPB) is a social psychological decision-making theory extensively operationalized across the social sciences; the theory was selected for this work because of its preeminent status among scholars of the human dimensions of natural resources (Floress, Akamani, et al.). This is due in part to its simplicity, a feature that also makes TPB a good candidate for operationalization in ABM (Schlüter et al.). First proposed by Icek Ajzen, TPB integrates internal and external factors in decision-making, identifying norms, attitudes, and perceived behavioral control as the central factors in development of an intention (Ajzen, "The Theory of Planned Behavior"). This intention is then measured against actual behavioral control, at which point it would be acted upon (Figure 5). Newer iterations of the theory integrate feedback loops into the system, introducing the opportunity for actors to learn from the results and consequences of their decisions; this learning is characteristic of the shifting decision-making space in adaptive capacity.

For our work, each component of Behavioral Intention (*BI*) is calculated independently and then combined. Thus, farmer utility for the TPB decision-making framework (*TPBU*) is given by:

$$TPBU = BI * ABC = (AC + SNC + PBC) * ABC \quad (5)$$

where *AC* refers to Attitude Consistency, *SNC* refers to Subjective Norms Compliance, *PBC* refers to Perceived Behavioral Control, and *ABC* refers to Actual Behavioral Control.

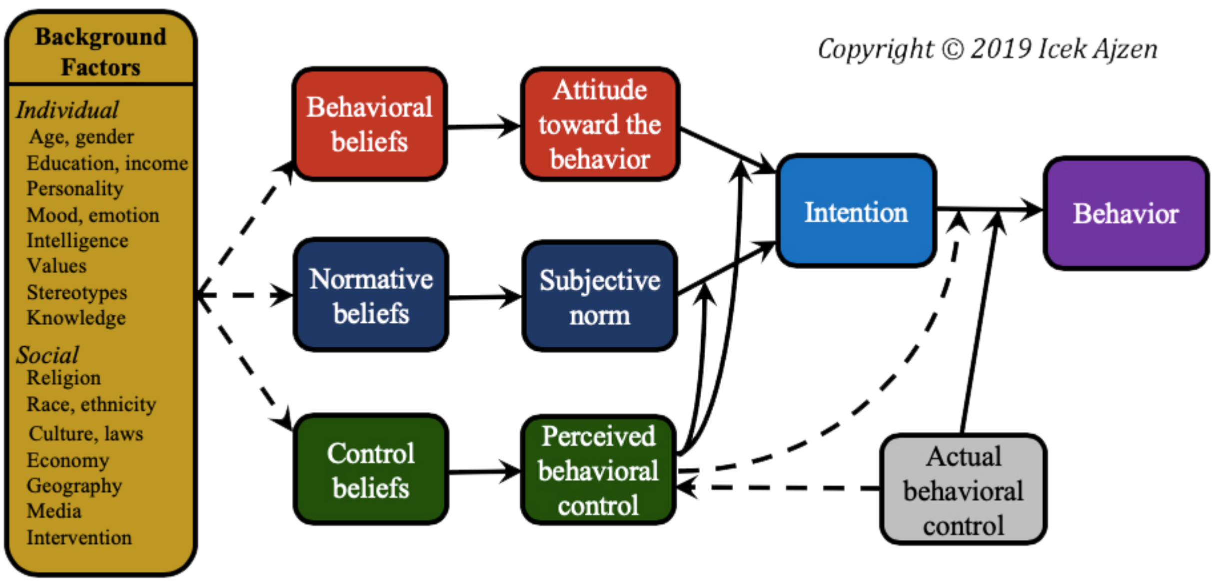


Figure 5 – The Theory of Planned Behavior. Since its original publication in 1991, the Theory of Planned Behavior has undergone frequent revision. Updated information and descriptions can be found online (Ajzen, 2019). Recent additions to the model incorporate beliefs about the action in question, which in turn are influenced by background factors. Neither of these extensions is considered in our operationalization of the theory, although this could be an important extension of the Farm-Adapt algorithms.

The breakdown of each component is based on the localization described above, employing information from literature and results from semi-structured interviews with farmers across the Eastern Snake Plain (Ajzen, "The Theory of Planned Behavior"; Poppenborg and Koellner; Floress, Jalón, et al.). All subfunctions are on a range of [0,1]. *AC* is conceptualized as four such sub-functions: the farmer's perceptions of profitability (*PP*), the crop of interest (*PC*), and the water management strategy of interest (*PWM*), and the consistency of the crop in question with the farmer's rotation (*CR*). This, then, is given by:

$$AC = \frac{PP + PC + PWM + CR}{4} \tag{6}$$

Subjective Norm Compliance (*SNC)* is conceptualized in two stages. In the first stage, farmers check their actions against two subjective norms: compliance with the ESPA CAMP ($ESPA_{Comp}$) and active use of their lands (not leasing) (*Active Farmer* - *AF*). In the second stage, this is scaled by an efficiency norm that penalizes plans that would plow out fields of alfalfa before the perennial crop loses its vigor. In total, this is given by:

$$SNC = \begin{cases} if\ Previous\ Year's\ Crop \neq Alfalfa\text{: } \dfrac{ESPA_{Comp} + AF}{2} \\ else\text{: } \left(\dfrac{ESPA_{Comp} + AF}{2}\right) * \dfrac{AlfalfaAge}{6} \end{cases} \tag{7}$$

Perceived Behavioral Control (*PBC*) is made up of three components. Perceived information available (*PIA*) is a measure of the farmer's ability to find information about crops and water management strategies; past experience (*PE*) is a measure of the farmer's familiarity with a crop; and economic feasibility (*EF*) is a secondary measure of profitability.

$$PBC = \frac{PIA + PE + EF}{3} \tag{8}$$

Actual Behavioral Control (*ABC*) is conceptualized as the economic feasibility of a plan. If the net expected losses are more severe than a threshold identified by the farmer as the amount they are willing to lose (*AWTL*), actual behavioral control becomes zero. This is given by:

$$ABC = \begin{cases} if\ NER < (0 - AWTL)\text{: } ABC = 0 \\ else\text{: } ABC = 1 \end{cases} \tag{9}$$

Thus, internal and external social drivers as well as the farmer's perception of the economic success of the plan of interest determine utility under the Theory of Planned Behavior framework.

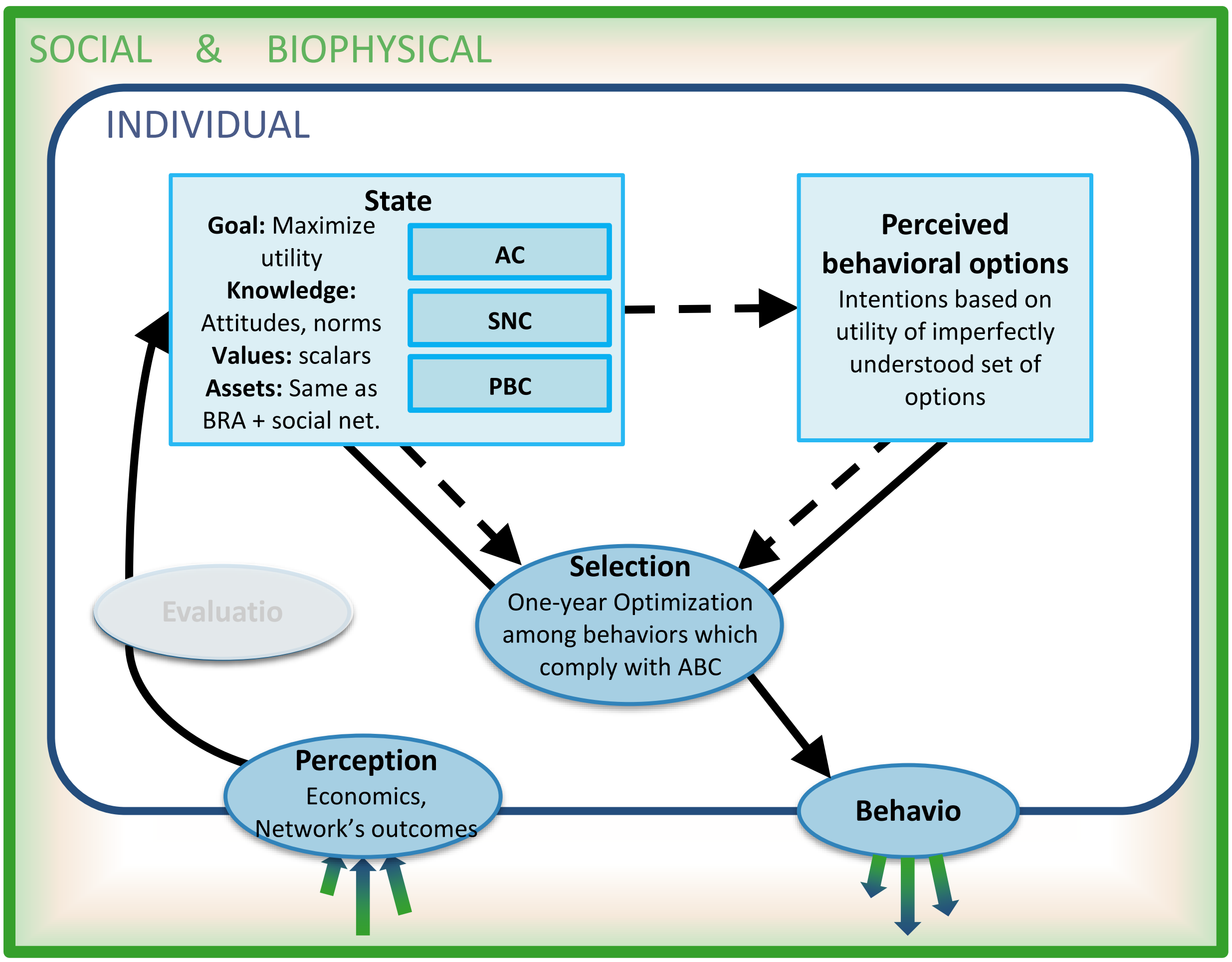


Figure 6 - MoHuB Framework – Theory of Planned Behavior. Each individual perceives their network's attitudes, in addition to all of the economic information known to a boundedly rational agent. Their perceptions inform their state through their knowledge of markets and norms, and they are used to update agents' own attitudes. Selection occurs from among the perceived behavioral options according to a one-year maximization of utility. Utility is calculated as a composition of Attitude Consistency (AC), Subjective Norm Compliance (SNC), and Perceived Behavioral Control (PBC), and actions are further regulated as feasible or infeasible through a check of Actual Behavioral Control (defined as compliance with a maximum allowable loss). This selection is then translated to behavior. Adapted from Schlüter et al.

4.5.3 Integrative Agent-Centered Framework

The Integrative Agent-Centered framework (IAC) was proposed in 2010 as a new way of describing decision-making among farmers in the United States (Feola and Binder). The work integrates two widely applied theories of decision-making and social systems, Triandis' Theory of Interpersonal Behavior (1980) and Giddens' Structuration Theory (1984). IAC framework was developed to draw together the large-scale socially-constructive forces described by Giddens and the small-scale perception-constructive forces of Triandis. The framework was selected for this work because it was created with both farmer adaptation and modeling operationalization in mind, allowing for minimal reorienting in translation to model rules (Feola and Binder).

In the Farm-Adapt Model, IAC relies on many of the same conceptualizations as TPB. This is a simplifying assumption that is demonstrated as mostly valid by the literature but is also recognized as a key area of potential improvement for later versions of Farm-Adapt (Boazar et al.; Bamberg and Schmidt). For instance, a farmer's Expectations (*Expect*) are conceptualized as equivalent to their Perceived Behavioral Control, Affect (*Aff*) as equivalent to Attitude Consistency, and Subjective Culture (*SubjCult*) as equivalent to Subjective Norm Compliance. IAC expands on this framework by explicitly considering the importance of habit and including a measure of Physiological Arousal in decision making. Habit Consistency (*HC*) is conceptualized as the consistency of a crop with a farmer's rotation and the consistency of an irrigation practice with what they were doing previously, and it is given by:

$$HC = \begin{cases} if\ Crop = Rotation\ AND\ Water\ Mgmt = Installed,\ 1 \\ if\ Crop = Rotation\ OR\ Water\ Mgmt = Installed,\ but\ NOT\ both,\ 0.5 \\ if\ Crop \neq Rotation\ AND\ Water\ Mgmt \neq Installed,\ 0 \end{cases} \quad (10)$$

Physiological Arousal (*PA*) is mostly absent from the model, as it is theorized as mostly relevant to rapid decision making and not long-term planning (Feola and Binder). It is therefore considered only relevant in situations where the financial hardship imposed by a plan is viewed as extreme by the farmer. This is determined by incorporating a scalar to grow the willingness to lose threshold (*AWTL*) described in Theory of Planned Behavior. Since the negative condition (a score of zero) is equivalent to a farmer being physiologically aroused, this can be considered an "inverse" scoring system, which is given by:

$$PA = \begin{cases} if\ Deficit < (Phys\ Arousal\ Scalar\ * AWTL),\ 1 \\ if\ Deficit > (Phys\ Arousal\ Scalar\ * AWTL),\ 0 \end{cases} \tag{11}$$

Through these mechanisms, IAC builds on the TPB framework to more completely incorporate two important components of farmer decision making: the psychological and practical inertia of a rotation and irrigation system, and the ability of farmers to take temporary losses in the name of longer-term gains. This yields the final IAC Framework utility function (*IACU*), given by:\

$$IACU = BI * HC * PA = (Aff + SubjCult + Expect) * HC * PA \tag{12}$$

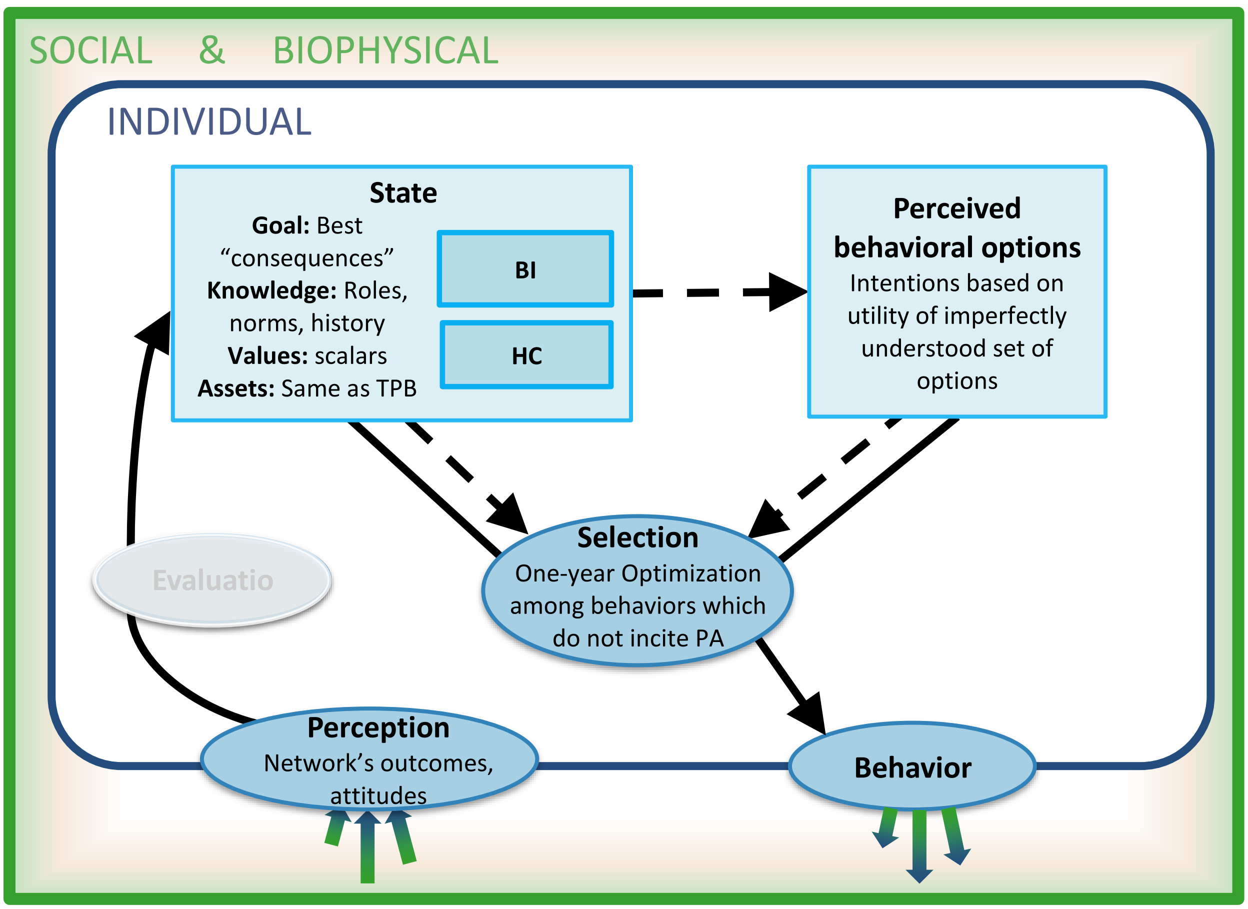


Figure 7- MoHuB Framework – Integrative Agent-Centered Framework. Perception is equivalent to TPB. Selection occurs from among the perceived behavioral options according to a one-year optimization of utility. Behavioral Intention (BI) and Habit Consistency (HC) make up the optimization formula, and any action that does not initiate physiological arousal is permitted. This selection translates to behavior. Adapted from Schlüter et al., 2017.

4.6 Case Study

This work is two-pronged. First and foremost, it is intended to contribute to the ongoing discussion of social-psychologically informed agent-based models. In doing so, however, it is introducing a new model of farmer adaptation. As both a structure for analysis of decision-making rules and a first test of the model, a case study of the Idahoan Eastern Snake Plain Aquifer Comprehensive Aquifer Management Plan (CAMP) has been implemented. The CAMP is a settlement agreement between groundwater users, surface water users, and the state of Idaho that dictated approximately a 13% cut to groundwater use across the Eastern Snake Plain (ESP) (du Bray et al.). This agreement came in response to nearly three decades of water rights adjudication, hydrological modeling, and litigation, and it places a profound strain on an agricultural basin in which 74% of agricultural land is irrigated (USDA National Agricultural Statistics Service, *2012 Census of Agriculture: Farm and Ranch Irrigation Survey*; Idaho Department of Water Resources, *Enhanced Snake Plain Aquifer Model Version 2 . 1*). This modeling effort is part of a larger initiative to understand the form and framing of agricultural adaptation to this sort of imposed water scarcity (e.g. DuBray & Burnham, 2018). The Eastern Snake Plain of Idaho makes an ideal test bed for theoretically-informed agent-based modeling. As a long-time home of irrigated agriculture, its agricultural system has been the subject of extended study, and the area can be considered a tremendously information-rich environment for simulation. Information-rich in this case refers to the variety of data available from academic literature and from local, state, and national agencies examining the makeup, performance, and drivers of agriculture in the Eastern Snake Plain (e.g. Chance, Cobourn, & Thomas, 2018; DuBray & Burnham, 2018; Idaho Department of Water Resources, 2012, 2013; USDA & NASS, 2011). This information-rich environment not only allows for effective characterization and parametrization, it enables extensive calibration of the model and allows for the comparison of each decision-making theory's performance to real-world outcomes (USDA National Agricultural Statistics Service, "USDA National Agricultural Statistics Service Cropland Data Layer"). For this analysis, calibration was conducted for three groundwater districts in the Eastern Snake Plain, Magic Valley Groundwater District, Aberdeen-American Falls Groundwater District, and North Snake Groundwater District (Figure 8). By testing three districts, we are able to analyze model performance in multiple sub-cases, and each district was selected as part of the initial case study to test some aspect of the modeling initiative. Magic Valley (MV) was selected due to its diverse crop base that is relatively representative of southeastern Idaho more generally; other districts specialize in certain crops to a greater degree. Since the focus of this paper is on the deployment and predictive power of descriptive decision making theory, we elected to focus on a district that required extremely heterogeneous decisions of agents to effectively predict real-world outcomes. On the other hand, the North Snake (NS) district was selected because of its intensive specialization in dairy-related agricultural products. While dairies are mostly excluded from the simulation, these sort of external drivers prove key in determining the crop portfolio of a region, and it is important to test the model's ability to capture this variation in the absence of explicit inclusion. Aberdeen-American Falls (AAF) is included as another generalist district that is rich in surface water. Also ignored in this operationalization of the ESP is the presence of surface water rights on farms. This has been proposed as a near-term improvement of the model, and by testing performance in AAF, it may be possible to determine the importance of surface water presence in model performance.

4.6.1 Simulation

To assess the performance of each decision-making framework in each district, statistical tests focused on two key outcomes: the percent of agricultural land taken up by each crop over the course of a simulation (i.e. the "cropscape") and the percent of farmers who shifted their irrigation practices in response to the ESPA CAMP (i.e. structural adaption). Table 8 indicates the land uses and irrigation practices from which the farmers chose.

Table 8 - Land Use and Water Management strategies available to farmers (in any combination)

Land Use	**Water Management Strategy**
Alfalfa establishment (correspondingly, alfalfa perennial maintenance)	Center Pivot Mid Elevation Spray Application
Barley	Center Pivot Low Elevation Spray App.
Corn	Center Pivot Low Elevation Precision App.
Potatoes	Furrow/Gravity irrigation
Spring Wheat	Drip/Precision Irrigation
Sugarbeets	
Winter Wheat	

In each season, farmers were expected to select one land use and one irrigation practice for each field. Although decisions occurred at the micro-scale, only macro-level outcomes are discussed here. Farm-Adapt does not seek to predict farmer behavior. Rather, it seeks to describe macro-level patterns emerging from the interactions of micro-level decision-making and shifts in macro-level conditions such as policy and economic trends (in this case, the interaction of farmer decision making and a public adaptation effort focusing on groundwater scarcity). This preliminary analysis simply seeks to understand how well the operationalization of Farm-Adapt in the Eastern Snake Plain replicates patterns of crops and farmer adaptation decision-making in the three districts of interest. From this, we attempt to draw some conclusion about the role of social-psychological decision theory in agent-based modeling.

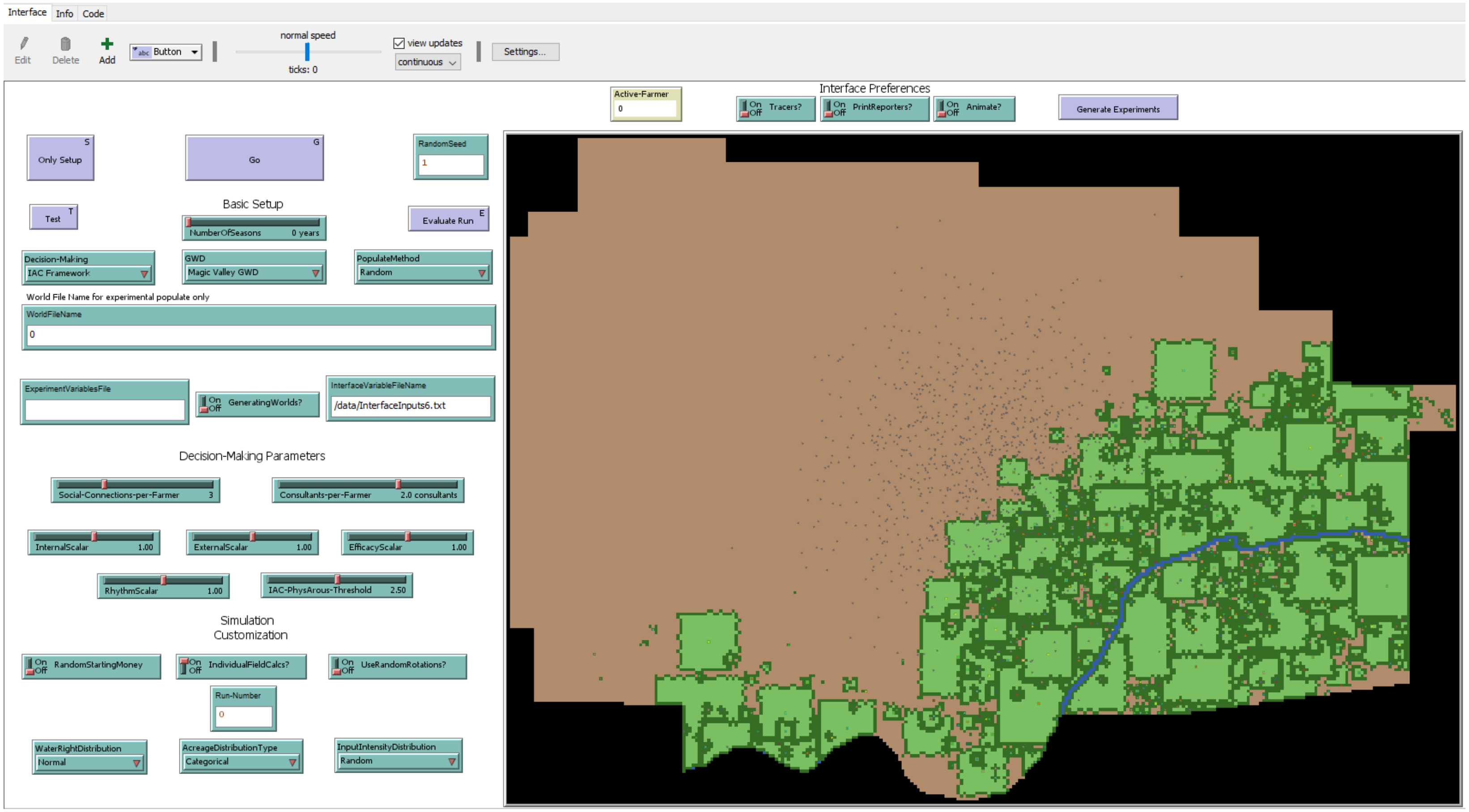


Figure 8 - Farm-Adapt Model V1, Magic Valley Groundwater District simulation world. Farm-Adapt can be run directly from NetLogo, where the user can either use BehaviorSpace experimental controls to dictate the inputs or they can use the GUI to designate the values of interest. As worlds are randomly generated, five changes appear on the screen. First, the district appears and the simulation frame is resized to fit the scale and shape of the district (brown patches). Second, surface water streams appear (blue patches). Third, farmers select a seed patch for their farm (multi-color dots at center of green patches). Farmers may either ignore surface water or seek land near to it depending on simulation settings. Fourth, farmers grow their farm to the size dictated by the random distribution set out at the beginning of the simulation (light green patches outlined with dark green). Finally, consultants appear randomly near the center of the district (gray dots), and links are drawn between farmers and consultants (invisible).

4.6.2 Results and Discussion

4.6.2.1 Cropscapes

The percent composition of each cropscape is described in Table 9 USDA NASS stands for the United States Department of Agriculture National Agricultural Statistical Service, and it is being used to describe the empirical data sourced from NASS' online Cropscape service. The results indicate that differential predictive power exists both within and between each decision-making model. For example, theories perform differently across districts and even across crops. Looking closely at AAF, we see that the TPB model effectively predicts both Alfalfa and Potato land use coverage but fails to project the other three crops with as much precision. On the other hand, in the MV district, TPB is very effective at projecting nearly all the crops.

Table 9 - Average Cropscape Across Decision-Making Frameworks

Aberdeen-American Falls Groundwater District (AAF)					
	Alfalfa	**Barley**	**Grain**	**Potatoes**	**Sugarbeets**
USDA NASS	12.5%	2.8%	51.6%	21.4%	11.7%
TPB	10.2%	27.7%	21.3%	18.4%	22.5%
IAC	23.1%	10.1%	22.0%	27.5%	17.3%
RA	0.0%	0.0%	0.0%	96.4%	3.6%
TPB + IAC	16.6%	18.9%	21.6%	23.0%	19.9%
Magic Valley Groundwater District (MV)					
USDA NASS	27.1%	17.1%	21.8%	12.9%	19.1%
TPB	37.8%	16.9%	15.7%	13.9%	15.7%
IAC	39.9%	8.4%	29.2%	11.4%	11.1%
RA	0.0%	0.0%	0.4%	91.3%	8.4%
TPB + IAC	38.8%	12.7%	22.4%	12.7%	13.4%
North Snake Groundwater District (NS)					
USDA NASS	34.1%	8.8%	43.7%	7.1%	6.4%
TPB	25.5%	17.5%	10.6%	20.6%	25.8%
IAC	44.8%	10.0%	21.6%	11.8%	11.8%
RA	0.0%	0.0%	30.2%	59.4%	10.4%
TPB + IAC	35.1%	13.7%	16.1%	16.2%	18.8%

In general, it is quite clear that, on average, the social-psychological models are better are projecting the macro-scale cropscape trends than a profit-seeking boundedly rational actor. To break down these findings further, we calculate the Euclidean distance between each cropscape.

This distance is described in Figure 9; the lower the distance, the more accurate the prediction. As the figure shows, both Theory of Planned Behavior and the Integrated Agent-Centered Framework provide reasonably useful projections, and there is variance across districts in which one is most precise in its predictions. Based on this variation between districts, we hypothesized that some combination of theories may perform best across locations. As a preliminary test of this, we take the simple average of the IAC and TPB projections and include it in all of the results tables. When we do this, we see a cropscape that is more consistent across districts and nearly outperforms all three models on average.

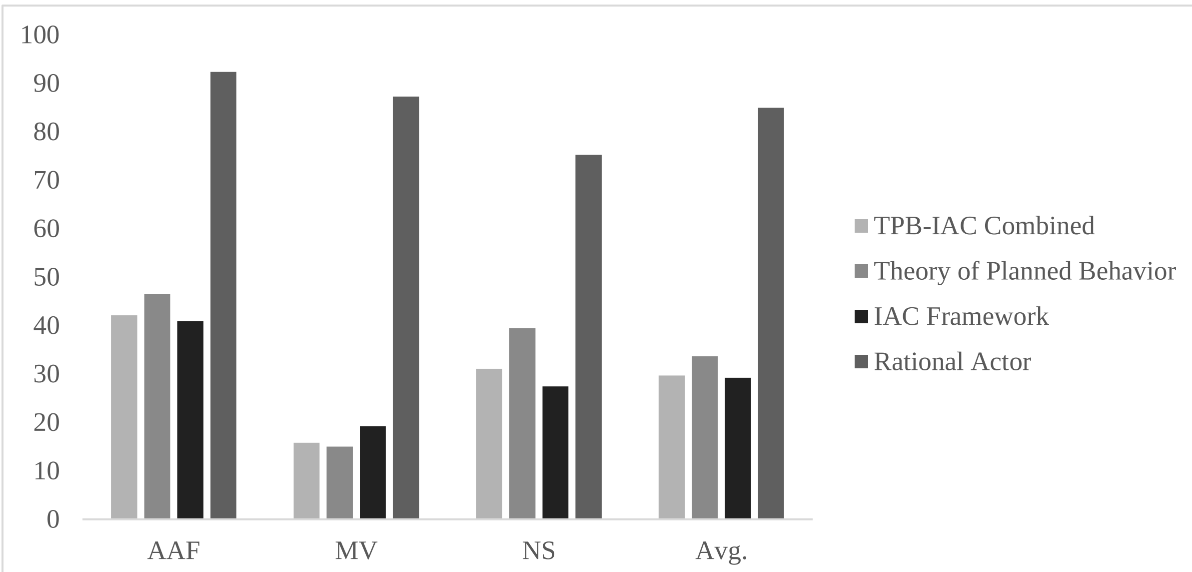


Figure 9 - Euclidean distance from each theory (or combination of theories) to the actual cropscape in each district, as well as the average distance across districts. A smaller distance indicates a more accurate model. In each case, both social psychological theories far outperform rational actor modelling, but there is inconsistency across districts in which social psychological theory performs best.

4.6.2.2 Farmer Adaptation – Structural changes to irrigation

Although empirical evidence has shown that adaptation can occur in a variety of forms, we focus specifically on one type of adaptation in this analysis. Comparing results to a household survey of farmers, we are able to examine how effectively each decision-making framework projects at what rate farmers adapt to changing conditions in water availability through structural changes to irrigation technology. We find widely variable projections, shown in Table 10. Of the three models of decision making, the Theory of Planned Behavior performs the best in projecting this adaptation rate. Again, we see significant variation between districts, indicating that the decision making algorithms are sensitive to the characteristics of each location.

Table 10 - Average Rate of Irrigation Adaptation

	Aberdeen-American Falls	**Magic Valley**	**North Snake**
Farmer Survey	40.9%	58.4%	63.4%
TPB	58%	40%	52%
IAC	3%	2%	4%
RA	27%	14%	76%
TPB + IAC	30%	21%	28%

4.6.3 Discussion

Our results draw attention to two key findings. First, relatively small differences between decision-making models can result in significant divergence of macro-scale patterns. This is consistent with recent calls in the literature for a renewed emphasis on theoretical grounding of decision-making rules in agent-based modeling (Müller et al.; Schlüter et al.). For example, the relatively minor additions of Habit Consistency and Physiological Arousal lead to dramatically different cropscapes between TPB and IAC simulations. This is consistent with the findings of complex systems theory that suggest that small changes in initial conditions can play an important role in outcomes (Mitchell). This, in turn, suggests that the precise operationalization of decision-making theories is quite important for the performance of a model, for the outcomes generated, and ultimately for the conclusion reached and possible policies recommended. This is further evidence that considerably more work is needed to continue to refine algorithms as generated in exploratory analyses such as this one. Additionally, it is a call for detailed documentation of decision-making theories as they are operationalized. In keeping with this, the decision-making algorithms used in this work are documented in detail in the ODD+D protocol in Appendix D.

Second, employing a general starting framework of decision making in agricultural adaptation, we were able to generate cropscape results from two social psychological models of decision making that resemble reality in the three groundwater districts of the Eastern Snake Plain. In particular, we find that the models were effective at predicting the cropscape in the Magic Valley groundwater district, indicating that further revision may be necessary in areas like the North Snake district that specialize in certain products. Further, we find that a decision-making model based on the Theory of Planned Behavior produces a reasonable approximation of the rate at which farmers adopt new irrigation technologies. This is encouraging and suggests that further exploration of adaptation modeling in this context is warranted. Several dimensions of this model deserve further attention and testing. For example, it is worth revisiting the assumption that farmers' year-to-year decisions about land use (crops) play an important role in their decisions about water management or other adaptation (and vice-versa). While such a link has been indicated in the literature, it is possible that the results could be improved further by separating those two decisions (Dury et al.). Additionally, is possible that other types of adaptation (e.g. "software" or management practices) differently under each decision-making model; by providing farmer with additional options, it may be possible to even more effectively project their reactions to increasing water scarcity.

4.7 Conclusions

This manuscript introduces Farm-Adapt, a new model of farmer adaptation employing micro-level social-psychological decision-making theories to replicate macro-level cropping and adaptation patterns among farmers in highly industrialized agricultural settings. Though still in the early stages of rollout, our results have important implications for the integration of social-psychological decision-making theory into ABMs.

Our results indicate that models of decision-making not only show differential fitness from each other, they show differential ability within a model to predict different types of outcomes (e.g. TPB predicts adaptation better than IAC, while IAC better predicts planting and maintenance of perennial alfalfa than TPB). Even more, we show that these models may predict certain outcomes in some contexts better than in others (e.g. best cropscape prediction in Magic Valley). A strength of agent-based modeling lies in the heterogeneity of agents, and this should be considered not only in the implementation of individual decision-making models but *across* decision-making models as well. In other words, a mixture of agents employing the IAC and TPB models may have led to a general population that more clearly resembled the empirical data. While our direct averaging of models did improve the consistency of cropscape predictions, the failure of IAC to predict the adaptation rate of farmers meant that the averaged values for adaptation were not as good as TPB. A second illustrative example of this can be found in the general failure of our model to project farmer adaptation efforts. While one social-psychological model dramatically overpredicted adaptation, the other dramatically underpredicted, as did a rational actor framework. However, a mixture of decision-making strategies among agents could lead to a more moderated result and more effectively project adaptation overall.

Given the continued popularity of agent-based modeling and the growing interest in integrating social-psychological theories of decision making into those models, we expect that this work and the Farm-Adapt model will be only one of many such works focused on theory-driven decision making in the coming years. As this body of literature expands, we suggest that it is critical to think about the decision-making model as a dynamic part of a larger simulation tool. Particularly in agent-based modeling, the internal workings of an agent can be so intertwined with the workings of a model that it is difficult, if not impossible, to revisit or replace those decision-making rules after initial implementation. As the body of knowledge on theory-based decision-making rules expands, this could be a critical handicap for models that would be better served with a different set of decision-making algorithms. Alongside calls for modularity in geophysical models, we join those calling for conscious modularity in decision-making rules. We acknowledge that the bidirectional relationship between social-biophysical simulation environments and the decision-making rules necessitates that models cannot simply plug and play any set of rules. However, through this work we have demonstrated both the importance of the rules employed and the relative sensitivity of models to these rules; therefore, future ABM projects could take steps to ensure the widest possible impact of their efforts by consciously designing for flexibility in the very center of the model – within the minds of the agents themselves.

CHAPTER 5. CONCLUSIONS

This project takes a multi-methods approach to understand agricultural adaptation to water scarcity in the Eastern Snake Plain of Idaho. The work sought to address eight research questions. Below, we summarize the findings and conclusions relevant to each question.

5.1 Paper 1

5.1.1 RQ1: What individual-scale and multi-scalar tradeoffs emerge in the context of adaptation to water scarcity in the Eastern Snake Plain?

In this preliminary analysis of tradeoffs as a method of analyzing adaptation, we identify three individual-level tradeoffs and three cross-scale tradeoffs with important implications for future policy in the area (Table 11). While it is likely that a variety of tradeoffs could be identified with further study, we focus on these six as evidence of the utility of this framework and as an opportunity to identify policy-relevant implications proceeding form a values-driven lens in the context of adaptation.

Table 11 - Tradeoffs across the Eastern Snake Plain as a result of the Settlement Agreement

Individual-level Tradeoff	**Cross-scalar tradeoff**
Farming as a passion vs. Taking other jobs	Changing cropping and spending patterns cause economic shifts across the basin
Appearance of Farm vs. Irrigating less land	Redirection of irrigation demand causes impacts on senior water rights holders
Soil health vs. Crop choice	Pursuit of equitable, sustainable solutions causes sacrifice of tradition

5.1.2 RQ2: To what degree do ESP farmers actively or passively engage with individual or collective tradeoffs in water use planning?

For the most part, farmers do not actively engage with tradeoffs as a decision-making tool. However, most are willing to acknowledge the existence of such tradeoffs. As a result, we suggest that tradeoffs may indeed prove a useful framework for adaptation decision support both at the individual and at the organizational/policy level. By identifying individual and collective values at play in adaptation decision making, it may be possible to more effectively project the outcomes of interactions at the individual and organizational levels.

5.2 Paper 2

5.2.1 RQ1: What components of sensitivity, adaptive capacity, and exposure are most determinate of who is vulnerable to policy-driven reduced water availability?

We identify five variables that significantly predict both economic and perceived measures of vulnerability in the ESP (Perception of Econ. Challenges [+], Perception of Env. Challenges [+], Use of Center Pivot Irrigation [+], Linking Capacity [-], and % of Groundwater Cut [+]). We also identify six variables that are significant in predicting either economic (Farmer Knowledge [-], % of Water from Surface Water [-], and % of Crops Insured [+]) or perceived vulnerability (Perception of Exogenous Challenges [+], Use of Line Irrigation [-], Social Capital [+]). This assortment of predictors is similar to but not entirely in line with existing literature, suggesting that further study of vulnerability to policy-induced water scarcity is necessary in the context of highly industrialized, irrigated agriculture.

5.2.2 RQ2: How are the drivers of vulnerability distributed within the population, and to what degree does this distribution result in differential vulnerability among farmers?

The breakdown of these predictors among ESP farmers suggest four groups of farmers who are likely to react differently to policy-induced water scarcity. Two groups, high-capacity farmers and part-time farmers, use diversification to limit their vulnerability to income loss as a result of the settlement agreement. A third group, the average farmers, show low vulnerability and also rely on relatively high specific capacities to limit this. The final group, at-risk farmers, exhibit the highest vulnerability among ESP farmers; this seems to be tied to their dependence on a small number of crops and their relatively high exposure to other challenges. This intersectional stress undermines their ability to limit their own vulnerability.

5.3 Paper 3

5.3.1 RQ1: Of the theories selected, which most effectively predicts crop patterns among Idaho farmers? Which most effectively predicts crop patterns adaptation?

Overall, the Theory of Planned Behavior (TPB) most effectively predicts crop patterns at the macro-scale. The Intergrated Agent-Centered Framework (IAC) also provides relatively accurate projections. The boundedly rational actor (RA) resoundingly fails to make such projections, although a more complete inclusions of rational risk assessment may prove useful in improving those projections. TPB is the only theory to reasonably project adaptation rates among farmers. We suggest that this should be explored further through the expansion of “software” or management practice adaptation in the model. Additionally, a basic investigation into “mixing” decision-making theories appear to show some promise in the projection of crop and adaptation outcomes. This should also be explored further.

5.3.2 RQ2: What limitations exist in translating social theory to model operationalization?

Qualitative, elegant social theories do not always translate well to algorithms for the implementation of models. However, there exists a large body of literature employing these theories in quantitative surveys; this is a resource that acts as a convenient bridge to operationalization in agent-based models. Therefore, we suggest that agent-based modeling can and should emphasize those models which have proven useful in the quantitative natural resources social science literature as a tool for understanding individual behavior. This, though, highlights another significant limitation of ABM operationalization in this context. If extensive survey data sets employing each theoretical framework are not available to the user, it is necessary to randomize many of the key values in a descriptive decision-making theory. Still, as our results demonstrate, theory-informed ABM may prove useful even in the context of highly randomized decision-making parameters.

5.3.3 RQ3: To what degree can theory-driven agent-based models be parameterized with secondary data to support rapid, exploratory assessment of adaptation in novel contexts?

In the context of the Eastern Snake Plain, the results here seem to be mostly positive. The model, with minimal localization from qualitative interview data, performs reasonably well at replicating long-term, district-level crop patterns. As addressed above, relying on secondary data is a significant limitation in parameterization of decision-making rules; otherwise, however, it seems to be mostly sufficient for the development of these models.

5.4 Overall conclusions

At the turn of the century, FAO estimated that irrigated land made up about a fifth of the arable land globally, but noted that it produced about two-fifths of all crops and about three-fifths of all grain products (Food and Agriculture Administration of the United Nations). Further, they expected this role to grow considerably by 2030, including an expansion of nearly 40 million hectares in developing regions (ibid). According the latest OECD data, the OECD member countries and the BRICS block (Brazil, Russia, India, China, and South Africa) dominate global agricultural production, an indicator that mechanized farming continues to underlay the global food supply (OECD and Food and Agriculture Administration of the United Nations). Yet, to date, most of our understanding of agricultural adaptation and vulnerability is built on case studies in developing, smallholder contexts and focuses on hypothetical vulnerability to forecasted change. Therefore, it is acutely important that we develop a clearer understanding of agricultural adaptation to actual water scarcity in the context of highly industrialized, irrigated agriculture. This work seeks to lay the foundation for that pursuit. In our analysis of the Eastern Snake Plain, we find that novel methods may offer an opportunity to more effectively study adaptation to resource change. We also find that, while some lessons learned in smallholder agriculture in developing regions translate to our case study, important differences exist, highlighting the need for further study in areas like the American West. Further, we find that novel methods may hold particular promise in information-rich environments like the American West, where agent-based modelling and other projection exercises can be informed by a wealth of contextual information collected by government administrations, extension agencies, and past researchers.

APPENDIX A - INTERVIEW GUIDE

Farming decision making, tradeoffs, and adaptation to New Water Restrictions in Idaho

Interviewer:

Location:

Time:

Opening:

Thank you for taking the time to talk with us today. We are a team of researchers from Idaho State University and Purdue University in Indiana. We are doing a study to better understand how farmers makes decisions about their farms in the Snake River Plain, as well as trying to examine how folks are adapting to the aquifer recharge program.

The interview should take about 60 minutes. Everything you tell us during the interview will be kept strictly confidential, and your name will not be revealed to anyone beyond the research team. You may discontinue the interview at any time.

For the purpose of data analysis, we would like to record this conversation. Do you feel comfortable with this? If not, please let me know now.

Turn on recording device now if allowed.

Again, thank you for your willingness to participate. Unless you have any questions, we'll go ahead and get started, but feel free to ask questions throughout the interview.

Section 1: Farm operation
First of all, I would like to ask you a few questions about your farm operation.

1. How much land do you own? How much do you lease?

2. What crops do you usually grow? Approximately how many acres of each?

3. Are your crops contracted or in a co-op?

4. What type of irrigation do you use currently? When did you start using that?

5. What kind of water rights do you have currently? *(They should comment on both surface vs. ground and age – if they do not, prompt)*

6. What types of risks or challenges are you dealing with on your farm?

- What have you done to address these risks or challenges?

Section 2: Decision-making and adaptation
We're interested in how you and other farmers manage your farms. To understand that, we would like to talk about your farm management and decision-making processes.
To start, I'd like you to walk me through how you make decisions on your farm.

7. In any given year, what's the process of deciding which crops to plant where and when? What are the key factors that you consider in making such decisions?
   - If they mention contracting …
     - How do you decide who to or not to contract with?
     - How do you decide when to or not to contract?
   - If they mention irrigating …
     - How do you decide how often to irrigate?
     - How do you decide whether to update/install new irrigation infrastructure?
   - If they mention fallowing …
     - How do you decide whether to fallow in a particular year or not?
     - How do you decide how much land to fallow?
   - If they mention their rotation …
     - How do you decide if and when to change that?
   - If they mention gov't programs…
     - How do you decide whether/when to participate?
   - If they mention leasing land …
     - How do you decide how much land to lease?
     - How do you decide who to lease your land to?

8. Have the ways you make your farming decisions changed during your time as a farmer?
   - Did how you make those decisions after the settlement agreement? If yes, how?

9. Compared to most farmers in the area, do you think your way of making farming decisions is fairly typical or rather different? If different, could you briefly describe what you do differently?

Section 3: Tradeoffs in decision-making and farm management
We'd like to ask some follow-up questions about the decision-making factors you mentioned earlier.

10. Can you start off by telling us about a time you faced a major decision in your farm operation, a major fork in the road? What was the decision or fork in the road?

11. How did you resolve that?

12. In general, is that your approach to major decisions on your farm?

Let's take a different example … One of the farming challenges facing many farmers is the long-term nature of infrastructure investments such as new machinery or irrigation infrastructure. *(If* *they mention infrastructure as their "major decision" above, skip this introduction + question 13 – retain question 14)*

13. How do you decide when to invest in farm-scale implements like new machinery or irrigation infrastructure?

14. How do you think about short-term and long-term benefits of such investments? Is one more important than the other?

Beyond infrastructure investments, when you make decisions about your farm options, I imagine you are faced with different decisions you could make. These different decisions may produce different types of potential benefits, for example, *improved soil health* vs. *higher yield from planting a more profitable crop that is less beneficial to the soil*.

15. When faced with different types of possible benefits like these, how do you weigh them against each other?

16. Do you feel like you're forced to sacrifice some types of benefits more often than others?
    - In other words, do you think that some types of benefits always come at the expense of another type of benefits? *If they seem confused:* For example, does soil preservation always come at the expense of using farming techniques you're comfortable with?
    - Are there other examples of this?

17. Are there some things you can't or won't sacrifice? Are there some that are the first to go?

Ok, so let's think about some other types of benefits … for example, *planting a less water-intensive crop* vs. *installing more efficient infrastructure*.

18. When faced with different options like that, how do you weigh them against each other?

19. When facing that kind of challenging decision, do you talk to other farmers in the area?

20. What about crop consultants? Extension agents?

21. Does the lending agent have an impact on your decision?

Ok, so let's think about one more example you mentioned earlier, ____*(to be customized to things each farmer noted as particularly important)*______.

22. When faced with different categories like that, how do you weigh them against each other?

23. Can you think of other situations in which you have to decide between different types of benefits? Any particularly challenging ones?

Section 4: Water Management and the 2015 Settlement Agreement

We've touched on water throughout the conversation, but we do want to take a minute to talk a little more specifically about the settlement agreement. So thinking first about your farm …

24. Do you have a cut requirement? What is it? Has that been the same every year?
25. What changes have you made or are you making on your farm to deal with the settlement agreement?
    - How did you decide on those changes?
    - Do you think what you have done / are doing is fairly similar or different to what other farmers are doing?
    - How are these changes affecting you and your operation?

26. Were you prepared to make the cuts required of you?
    - Do you remember being concerned about water before the agreement? When and why?
    - Were your rights ever curtailed before the agreement? Were you unable to irrigate for other reasons? What happened? How did you react?
    - [*If they mentioned prior experience with water shortage]* Do you think past experiences with [drought/water curtailments/water conservation/water shortage] helped prepare you for the settlement cuts? How so?
    - How did you/do you learn about different options for using less water?

27. Now that the agreement is being implemented, do you feel you had a say in it?
    - Do you trust the people who were involved?

28. How do you feel about the process?
    - Do you think the negotiations were sufficiently transparent?
    - Was the outcome of the negotiation fair?

29. Did farmers have input into the implementation of the agreement at the local level?
    - What did that look like?

Section 5: Plat Maps and Land-Use Change

So we are almost done, but we have one last section that we want to run through, and hopefully it'll be kind of an interesting change of pace. For this section, we're working with some folks over at Boise to conduct some exploratory work trying to understand how satellite imagery corresponds to what's actually going on on the ground, particularly thinking about land use transition and irrigation changes. In preparation, we went through and found parcels with your name on them in the ___________ County database, and we've printed out those maps here. If you're comfortable with it, we'd like to look over these and talk about the land and its story a bit. We have our own smaller copies, so you can keep these bigger copies if you'd like.

30. What percentage of your land did we capture with this/these map(s)?

31. What is the agricultural history on these parcels, as far back as you can remember?

32. What type of irrigation has been used on this land through its history? And today?
    - What year did you change irrigation type? (particularly center pivot transitions)

33. What made you change your irrigation strategies?

- What factors played into the decision to change over to the new method?

34. Has changing irrigation strategies ever changed the type of crops you grow? When and why?
    - I know you mentioned _______ earlier, but what other factors have impacted the type of crops you grow on these parcels? Any specific examples?

35. Last thing on the water front - what water rights are associated with these parcels?
    - Have you changed whether you use groundwater or surface water for irrigation? Where?

36. And then the last topic we wanted to cover – in the vein of land use change and transition, we've heard some folks talk about the adoption of precision ag as one of the new trends that is causing some transition. Is that something you've seen around here? Have you adopted any precision ag strategies on your land? What types do you use?
    - What caused you to start implementing precision ag technology?

Section 6: Socio-demographics
Before we finish, I would just like to ask you a couple of quick questions about yourself:

37. Including yourself, how many people live in your household? And how many work on the farm?

38. In terms of how your family makes a living, I know this is a bit uncomfortable to talk about, but would you roughly give us an understanding of the different sources of income for your household?

Source	Percentage
Agricultural production (not including livestock)	
Livestock production	
Off-farm work	
Conservation easements or programs	

39. In the simplest terms, how would you describe your political views?

40. What is your educational background?

41. What religious tradition are you affiliated with?

Section 7: Concluding question for general comments

42. Is there anything else you would like to share with us about farming in southeastern Idaho, especially in the aftermath of this water curtailment agreement, we have missed?

All right, thank you very much. We really appreciate the time you’ve taken to participate in this research. It helps us understand what issues you are facing and how steps could be taken to help you do your work, which is work we know benefits this community and others.

Turn off recording device now.

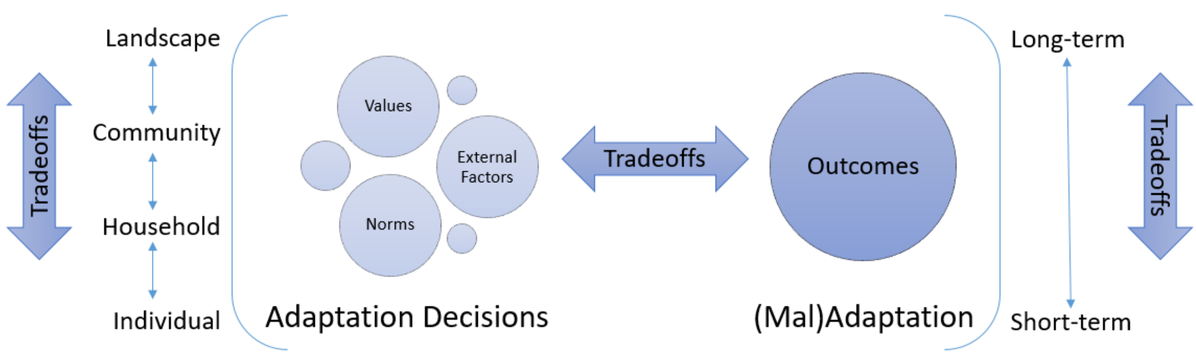
APPENDIX B – CODEBOOK: TRADEOFFS AND ADAPTATION

This codebook has been constructed by Jason Hawes for use in understanding the appearance of tradeoffs in adaptation.

The codebook was prepared as a theory-informed, inductive coding strategy. A broad conceptualization of the sections was developed in preparation for coding, and individual codes were developed from participants' discussions. The section headings were developed in this piece to differentiate bodies of literature and topics of focus. Each section heading contains a number of codes, and each code may contain several sub-codes. This three-level organizational system allows the author to differentiate between areas of emphasis during coding and during literature review.

A couple important concept run through this analysis:

1. Values are moderated by context, management strategies, and decision-making parameters, and the adaptation that we see coming out may not always reflect these values. We can infer that tradeoffs are occurring in the decision-making process when that mismatch occurs.



2. Factors, management strategies, and values (Fac-MS-Val) are treated as a trio of factors influencing adaptation outcomes. The three reside on a spectrum of tangible to intangible and external to internal. Factors sits on the far left of that scale, with those codes representing very tangible, external factors influencing decision. Values lie on the far right side, very internal to the decision maker and intangible by nature. Management strategies split the two – these often take the form of broader heuristics that are informed by experience.

Each section is introduced beginning on page 5. From there, sections are presented in alphabetical order with extended code descriptions prepared for each code. See below for an example.

Sample Codebook entry:

Code:	SAMPLE
Brief Definition:	5-10 word reference definition
Full Definition:	Extended definition explaining the contextual significance and expected occurrences
When to use:	Explicitly identify cases in which this is relevant. Use this code when …. []
When not to use:	Do not use this code when … [another, more specific code is applicable] or []
Sub-codes	- Listing of sub-categories to be coded
Example:	"Quote extracted to demonstrate the occurrence of the code"

Last update: 2019-07-26 JKH

Section Definitions

Adaptation

- The adaptation section is designed to capture the actual actions that people take. This list of adaptation strategies was inductively generated and each was found in the literature to be relevant in other contexts as well.
- This section really places an emphasis on tangible actions. By collecting these, the author hopes to be able to accomplish two things. First, it should be possible to compile a list of descriptions of what farmers are doing to cope with or adapt to water stress. This is useful in several parts of the project. Second, it may be possible to compare adaptation strategies to the values identified in the last section and examine the interceding space for tradeoffs.

Descriptive

- Descriptive codes are used as catalogs for describing the interviewees and farmers in the Plain more broadly. They can be thought of as similar to descriptive statistics in quantitative work.

Factors

- In the Fac-MS-Val trio, 'factors' is the most applied. This section aims to highlight the tangible components of decision making. This is useful in two contexts. First, it can be equated to constructing a rough cognitive map of farmers in the area, identifying the variables that make up their decision-making space. Second, it gives us some additional points of reference for what factors may be mediating the space between values and adaptation actions.

Land-Cover Interview

- The land-cover interview is a collaboration with Jodi Brandt and others at Boise State who are interested in ground-truthing land-cover transitions in the Eastern Snake Plain.
- This section is not fully filled in yet, since I have not yet taken the time to code the parts of the interviews where I did this work.

Management Strategies

- As discussed above, in the Fac-MS-Val trio, 'management strategies' is the component that sits in the grey middle ground. It is mostly composed of heuristics or experience-based decision-making parameters that sit somewhere between the tangible factors of 'decision making' and the more internal 'values' section.

Settlement Agreement

- The settlement agreement section is looking for descriptive features of the settlement agreement, in particular details about local implementation and farmer reactions to that. It's a fairly basic section that is more looking at the context of the project than any of the research questions.

Tradeoffs

- The tradeoffs section is used as two things. First, it is a collection of a couple ideas that just don't fit anywhere but in a tradeoffs framework. Second, it is serving as a placeholder for multi-scalar tradeoffs yet-to-be-implemented.

Values

- The values section, as described before, is really interested in the internal norms and attitudes that shape decisions for a farmer. Based on social psychology, we would argue that these components are the core drivers of decision making; however, we also know that behavioral control and perceived behavioral control play an important part, and I am arguing that it is this disconnect between values and adaptation actions that is causing the tradeoffs at the individual level.

Section 1: Adaptation

Section notes:

Items coded in this section should be past or present actions. Speculation will be coded in its own section if it appears too often to ignore. Short-term plans may be considered for this section, but otherwise things should already be in place rather than hypotheticals.

Code:	Coping strategies
Brief Definition:	Short-term behavior change in response to stress
Full Definition:	Coping strategies are an important part of the adaptation process, often forming the first level of defense against social-ecological stessors. Importantly, they are NOT actual adaptation, but they coded in this section because we're more interested in the actions than perfect replication of the theory. (Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests")
When to use:	Use in cases when a specific short-term solution is mentioned.
When not to use:	Do not use in cases where fundamental or large-scale transitions are discussed – these will most likely qualify as actual adaptation to environmental change
Sub-codes:	N/A
Example:	"That's why we made the water call. Everybody was going along pumping and being able to raise a crop, where I had to convert from hay to grain and actually there a couple years had to idle about 100 acres because I just didn't have the water for it."

Code:	Diversification
Brief Definition:	Diversifying income sources in any of a variety of ways
Full Definition:	This fairly broad code is used to capture any number of practices that can expand or change a farmer's income sources. This could be new crops, new livestock, a new job, or any number of other things. (Burnham and Ma, "Linking Smallholder Farmer Climate Change Adaptation Decisions to Development")
When to use:	This is most often going to be used in response to questions about their reactions to challenges, but it is to be used as a broad sink for discussions of taking on new projects as a way to get through hard times.
When not to use:	--
Sub-codes:	N/A
Example:	"We ended up doing a lot of custom trucking and custom hay baling and that kind of stuff to make it all work."

Code:	Finding new water sources
Brief Definition:	Various strategies to find new water sources and cut groundwater use
Full Definition:	A variety of farmers found a way to have a new legal right to water. This allowed them to reduce their groundwater withdrawals while minimally reducing their actual water use.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"Yeah. We actually traded some ground to the canal company and they put in a recharge pond and then with that I was able to pump, I am able to pump all the spill water, so that took care of my mitigation so I'm in great shape right now, actually have surplus."

Code:	Learning New Approaches
Brief Definition:	Trying something entirely new or attending trainings
Full Definition:	This is specifically focused on farmers who respond to a crisis by seeking out some new skill. The most obvious instances may refer to formal training, but it can also be in combination with seeking advice of peers or learning by doing. An emphasis is placed on the actual learning, rather than just experimentation with something new. (Tschakert and Dietrich)
When to use:	Use when the interviewee specifically refers to expanding their skillset or trying to learn something new in relation to their work or management practices.
When not to use:	Do not use this code in place of diversification. Something can be both diversification and learning, but they will not always be and in some cases it may be tempting to conflate the two.
Sub-codes:	N/A
Example:	"…"

Code:	Luck
Brief Definition:	Farmer references successful navigation of challenges as luck or fortune
Full Definition:	This is relevant to adaptation because it speaks to their perception of their own actions. This is most often seen in cases where farmers are referencing great success but would rather downplay the actions they took to get there. It seems likely that this may be integrated into another code at a later time when I have a feel for what they're really talking about when they say luck. (Garner)
When to use:	Use when a farmer explicitly mentions luck or good fortune (or some other synonym).

When not to use:	Do not use when the farmer talks about not knowing how they made it through something or in other circumstances where they refer to Mother Nature or the universe or God – only explicit mentions of luck.
Sub-codes:	N/A
Example:	"We doubled the size of the farm in the process. But it was a little luck and a little of this and a little of that. That's the way it went."

Code:	Quit Farming
Brief Definition:	Farmers retire or switch jobs in response to water/social-ecological stress
Full Definition:	This is a broad category for farmers who quit farming or retire in response to an intense stress – to qualify, the person must stop farming full-time for at least one year. For example, some nearing retirement age will just hand over the farm, while younger folks might find a new job. Leasing out the entire farm would count – it may not be a permanent retirement (and they may still act as farm-hand occasionally), but they have quit the full-time job of farming. (Burnham and Ma, "Linking Smallholder Farmer Climate Change Adaptation Decisions to Development")
When to use:	Use anytime someone mentions that they or someone they know quit farming in response to the settlement or other stress.
When not to use:	Do not use this code when a farmer mentions that they considered retiring or "would" retire in response to some stress.
Sub-codes:	N/A
Example:	"He was getting old enough and I think because of the settlement I think that's one of the reason he decided to give it up."

Code:	Reducing Water Use
Brief Definition:	Actions reducing water use on the farm
Full Definition:	This is the section explicitly oriented towards capturing the adaptation actions people have taken. It will look very similar to coping strategies, but it should represent more long-term solutions or investments or true behavior changes, rather than short-term reactions. (Fischer, "Characterizing Behavioral Adaptation to Climate Change in Temperate Forests")
When to use:	Use this code to capture instances of actual adaptation to the settlement agreement that involve reducing water use. It is reasonable to use this as a code for lack of action as well – in other words, if a farmer mentions a form of adaptation and says they have not or will not do that, that's also relevant and could be considered maladaptation.
When not to use:	Do not use when farmers discuss their short-term solutions or something they "did that one year" to get by.

Sub-codes: N/A

Example: “We have wheat. We have the potatoes - Or they grow some onions too. So, there's just enough flexibility in cropping that I can farm that groundwater farm with my surface water.”

Section 2: Descriptive

Section notes:

This section is designed to capture descriptive characteristics of farms and farmers that might prove useful in the model or in description sections of papers.

It is expected that much of the content here will be coded elsewhere as well, since the discussion of "what" a farmer did is a natural time to also discuss "why." The why is the subject of interest for the decision-making study, but the what can be useful both on its own and as a cue to look closer at a section.

Code:	Crops
Brief Definition:	Discussions of various characteristics of crops on the farm
Full Definition:	The main crops code is designed to capture commentary on crops that is not common enough to deserve its own category. The sub-codes are the primary information storage system here, capturing specific descriptive characteristics that might prove particularly useful.
When to use:	If you use this main code or any sub-codes while an interviewee is discussing the role that certain crops or crop characteristics play in decision making, make sure to also code in the decision making section (or other section, depending on the context). Sub-codes: Alfalfa length is used to capture when farmers discuss how long they leave alfalfa in the length. The amount of each crop code is used to capture how much of each crop a farmer has in the ground that year. The contract or co-op code tracks when a farmer mentions having one or the other for some crop. Finally, the rotation code follows what rotations farmers have, and it tracks past rotations or "I used to do…" as well.
When not to use:	…
Sub-codes:	Alfalfa length Amount of each crop Contract or co-op Rotation
Example:	…

Code:	Dairy Descriptives
Brief Definition:	Excerpts from interviews with dairymen that describe their operations
Full Definition:	This code is used to keep dairymen from cluttering livestock and other feed codes that farmers also inhabit.
When to use:	The main code is unlikely to be used much, unless there's some sort of really unusual descriptor that needs documenting. Food and water captures the feeding practices and water system for each dairy. The herd

	sub-code captures both the size and dynamics of the farmer's herd. The milking sub-code captures milking practices.
When not to use:	Do not use this for livestock outside of dairy interviews. Also do not use when dairymen are describing how their dairy impacts operation of their crop farms – that part is the relationship we're really interested in, so we want to code that with all the normal farmers.
Sub-codes:	Food and Water Herd Milking
Example:	…

Code:	Farm size
Brief Definition:	Literally describing the size of the farm
Full Definition:	Captures, in general, how much land a farmer works. This should include both leased and owned ground.
When to use:	Use when a farmer gives a quantitative figure for how much ground they own, lease, or work.
When not to use:	Do not use when a farmer is just talking qualitatively about growth or scale.
Sub-codes:	N/A
Example:	"F: You want to be right down the acre? J: Sure. F: It's 1,127."

Code:	Household size
Brief Definition:	Captures the number of people living in the household.
Full Definition:	Used to document the demographic question of how many folks live under one roof. There is some chance that this may play into decision making, especially when multiple generations cohabitate.
When to use:	…
When not to use:	…
Sub-codes:	N/A
Example:	"F: Right now, just me and my wife. Used to be two boys, but they are 22 and 21. They left when they were 18."

Code:	Irrigation
Brief Definition:	Specifically looking at methods or hardware of irrigation
Full Definition:	Specifically, this is interested in hearing what kind of equipment people use or have previously used to irrigate on their farms. This is fairly well documented in surveys, it doesn't hurt to hear how people talk about it,

	and it is likely to play into decision making at some level, so it's good to capture. Also, if we want to compare our sample to the population, we could compare things like this and age.
When to use:	Use in cases where infrastructure or equipment is specifically mentioned. Irrigation transitions should specifically capture discussion of changing to a new hardware system. This is used to capture some of the contextual factors around those decisions (it may also be captured in Big Changes or other codes if the farmer speaks at length about why they did something.)
When not to use:	Do not focus on time when methods or timing is discussed.
Sub-codes:	Irrigation transitions
Example:	"F: Most of the grassland, well not all of it. I'd say 3/4 of the grassland is shovel irrigated out of a ditch. See. I'm an old irrigation. I'm under the Aberdeen-Springfield Canal, which was flood irrigation. That's what got it here. Then there's some sprinkler that like the way out here is too rocky to farm and that's sprinkler irrigated cause it fits in nice but it isn't all that way. Some of the others is just cause I haven't changed and some of it cause it's kind of impossible to change it."

Code:	Leasing ground
Brief Definition:	Discussing how much ground is leased in or out and when
Full Definition:	This code is looking for both quantitative and qualitative descriptions of farmers' leasing practices. This means we're interested in how much land they rent but also when, where, and from whom.
When to use:	This can and often will be used in conjunction with adaptation or decision making codes, perhaps even some values codes.
When not to use:	…
Sub-codes:	N/A
Example:	"F: 6,500 acres. I: How much of that is owned and leased? F: Well, course that's what we farm. We own about 7,000 acres. I lease out about 1,500. But I rent out about 800."

Code:	Livestock
Brief Definition:	Discussing how many livestock are owned
Full Definition:	The general code is a purely quantitative code, trying to capture how many head of cattle are being kept (all livestock discussed was cattle). The sub-code is far more general, capturing when people discuss the logistics or the leasing patterns of feeding and watering the cattle.
When to use:	Food or water for livestock should be used quite generally, as each farmer's approach is different.

When not to use:	Do not use when dairymen are being interviewed, and do not use the general code unless some quantitative or near-quantitative value is offered.
Sub-codes:	Food or water for livestock
Example:	"F: There's like 120 cows and then heifers and calves. I think it's around 210."

Code:	Religion
Brief Definition:	Capturing demographic question that tracks religion. Only asked in some interviews.
Full Definition:	This is purely a documentation for when someone mentions their religion. It doesn't have to be in direct response to the religion question, but I would expect it to appear there most frequently.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	(None yet)

Code:	Water rights
Brief Definition:	Description of the water rights owned by the farmer
Full Definition:	Several attributes of water rights will end up under here, including seniority, type, and source. Seniority and type are common enough to merit their own sub-codes and they'll be sub-coded then collected into the broader code as well.
When to use:	Use when a farmer describes their current water rights.
When not to use:	Do not use when a farmer is just discussing their general perspective on water rights in the West or if they are talking about other water-related issues.
Sub-codes:	Seniority Type
Example:	"J: What kind of water rights do you guys have on the land? F: We have some canal rights. We have some deep well rights. … J: Are those mostly junior or senior deep well rights? F: Most of them are senior. We have one junior."

Code:	Years Experience
Brief Definition:	Capturing farmers' discussion of how many years experience they have
Full Definition:	This is just for documentation of experience, and it can be qualitative or quantitative discussion of this. It should not be used when a farmer

	discusses experience broadly as a tool, but rather when they refer in some way to their amount of experience
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"I: Oh, okay. Got some of those big planes. Yeah. I know. That makes sense. So, how long have you been farming? F: All my life. I: How long have you owned your own place? F: It's been. Well, 35 years I guess you might say. I didn't start out with this much but then worked into it."

Section 3: Factors

Section notes:

This section is designed to capture the tangible variables and factors cited as components of decision making. For instance, practices like consulting others or drawing on experience are coded in this section as they relate to specific things or actions more than the heuristics or values driving them. With the three-pronged coding approach, this is the piece most closely tied to *actions* and *things*.

Code:	Consulting Others
Brief Definition:	Farmer discusses consulting with experts or peers on farming decisions
Full Definition:	Agricultural advisors have been identified as important communicators of risk and environmental change (Haigh et al.). Additionally, it is broadly recognized that subjective norms and internal and external roles play an important part in shaping agricultural decision making. Both peer and expert input are likely to shape these norms and roles (Feola et al.).
When to use:	Use this when an interviewee specifically mentions talking over an issue or challenge with another person. In most cases, you will use the sub-code(s) that are named according to the person they are speaking with. If the sub-code does not exist, determine whether this is an outlier or if the sub-code should be created. If you determine that it is an outlier, use the general Consulting Others code (all results get aggregated anyway).
When not to use:	…
Sub-codes:	Agronomists, Crop consultants, Irrigation consultants, etc. Banker or lending agent Extension Agents Family Lawyer Other farmers
Example:	"F: Let's put it this way. It comes to my pivots, I you know have I guess you call supporting cast, people that I. My pivot guy. Him and I grew up

together. You can tell him. He doesn't try to BS me. It is what it is. My attorneys, you know, I have an excellent accountant. Yeah.

J: The supporting cast is important.

F: Let's put it this way. If I didn't have a supporting cast, if I didn't have a good accountant, if I didn't have my good attorney, and I didn't have my pivot guy, I would be in. I lose any three of them I'm in trouble."

Code:	Experience
Brief Definition:	References to changes in decision making over time or relying on experience and history to make decisions
Full Definition:	Two primary concepts will be embedded in here, both engaging with the idea that farmers rely on their own personal experience to support their decisions. This is fairly fundamental in most social psychological theories of decision making, from the prevalence of decision heuristics to the importance of attitudes and attitude formation (Ajzen, "Values, Attitudes, and Behavior"; Feola and Binder).
When to use:	Use in particular in response to question about decisions changing over career. Other than that, most often appears in discussion of day-to-day decisions or general management practices on farm.
When not to use:	
Sub-codes:	N/A
Example:	"When you're young and foolish you don't think all those things out really good you know. I'm not saying that that's the way or isn't the way. My decisions more are based on my past history and what worked and didn't work."

Code:	Filling contracts or co-ops
Brief Definition:	Indication that fulfilling commitments is priority in planning
Full Definition:	Since this is a traditional legal obligation, the presence of this as a decision-making parameter is actually rather a foregone conclusion, and it will often appear as kind of an implicit statement that "this contract is our starting point" and from there we figure out what the rest of the fields will look like. Capturing it to see if there are circumstances under which this falls through. We're also interested in seeing if this is tightly linked to other decisions like expansion or equipment and irrigation.
When to use:	Use in any circumstance where an interviewee describes the size of their contract or co-op requirements in the context of determining what to plant or what to purchase or what to do next on the farm.
When not to use:	Do not use …

Sub-codes:	N/A
Example:	"Then, when you have contracts like the malt barley, where you have so many acres, then you can vary that a little bit. But I gotta have 300 acres of malt barley. It isn't usually acres the way they go. It's so many bushels. That's the way you do it, you know. Then start figuring things out a little."

Code:	Finances
Brief Definition:	Discussion of finances as a decision driver
Full Definition:	As above, the presence of financial factors in decision making is a foregone conclusion. In this case, we are interested in capturing the circumstances under which it is mentioned, the relationship to other drivers, and the long-term/short-term dynamics of financial consideration.
When to use:	Use in any circumstance that the interviewee suggests that a decision was motivated by a financial factor. Use Taxes when taxes are mentioned.
When not to use:	Do not use when an interviewee is describing finances in other ways, such as money management or risk and challenges. Instead, focus on instances where finances are a motivating factor for other decisions on the farm.
Sub-codes:	Taxes
Example:	

Code:	Generational Transition, Inheritance, Passing it on
Brief Definition:	Discussion of generational transition as a decision or decision-making factor
Full Definition:	Code as a broad take on generational transition – ideally, we will capture some discussion of this as a driver of decisions, but people are also really interested in talking about the process itself and this will hopefully bring to light some intersection with other decision-making factors. Generational transition is defined as any instance in which a farm is being passed from one family member to another (so this may occasionally be intra-generational rather than inter).
When to use:	…
When not to use:	…
Sub-codes:	N/A
Example:	"F: About a year ago my dad decided to retire and I pretty much bought it from him, everything from him. We had to kind of. That was some big decisions on how to navigate and make everything work. J: That's a big transition. What kind of led you to making that decision?

F: It was kinda him and I come to that decision together to. My dad is 87. He had a will and he figured rather than. Because I was the executor to the estate and everything. It was all supposed to come to me eventually. I got a very good attorney and a very smart attorney that counseled us through that and walked us through that. It was pretty much his thinking on that."

Code:	Goal setting
Brief Definition:	Discussion of goals in the farm management process
Full Definition:	This code is interested in looking at attitudes and values in farmer decision making. In a way, it is a long-term take on some of the ideas embedded in theory of planned behavior – the goal is to understand how a farmer setting a goal (an intended action) impacts their decision making to get to that action.
When to use:	Farmers will discuss their goal in a variety of terms, including dreams, plans, transitions. This code allows for broad interpretation and is an attempt to collect these.
When not to use:	Do not use when a farmer is describing the short-term motivation that led them to a particular action in one year. Instead, we're interested in looking at how they set long term objectives and how short term decisions play out in pursuit of those.
Sub-codes:	N/A
Example:	"My dad started out. He was in college, trying to be an accountant. Actually, he went to the University of Idaho. His dad was killed in a gun accident and so he came home. Out of what his dad had, they only managed to salvage 120 acres. They lost everything else. He and the lender agreed. He took the 120 acres with this $40,000 debt against it. That's where he started. When I got involved in, my goal was to one day have a farm without a mortgage. Took me 65 years but I did it."

Code:	Growth
Brief Definition:	Discussing farm growth (in acres) as a standard trend or pattern
Full Definition:	This is specifically geared towards the idea that there is intertia in growth. Many farmers describe that once they start the process of growing the farm, it becomes an inexorable trend.
When to use:	--
When not to use:	Do not use this when farmers are discussing …
Sub-codes:	N/A
Example:	"F: Yeah and then expansion, once you get in the mode of expanding then you almost need to keep expanding or else pretty soon the tax might get you. That's the way it works."

Code:	Importance of Scale
Brief Definition:	Mention of farm size as a driver of decision making
Full Definition:	This will only be used when farmers explicitly mention that the size of a farm impacts their decisions or other farmers' decisions.
When to use:	…
When not to use:	Do not use this in regard to growing or shrinking the farm. This is only intended to capture the actual impacts of size.
Sub-codes:	N/A
Example:	"J: [Discussing inheriting 900 acres after only managing 300] What has that meant for you guys over the last year or so? How have you kind of changed your patterns or your? F: Because of the settlement or because of. J: Because of the retirement, your dad's retirement. F2: We had to think a lot bigger. F: We gotta think a lot bigger. It definitely made the picture, if you will. It definitely made the picture bigger. It's. There's a few more decisions to be made."

Code:	Irrigation
Brief Definition:	Irrigation as a driver or object of decision making
Full Definition:	This is expected to be a rather popular code describing the influence of irrigation, irrigation water, and irrigation methods on farm decision making. This can include decisions related to crop types, acre fallowing, leasing, and many other relevant ideas.
When to use:	This is to be used when farmers explicitly mention some component of their irrigation plan, irrigation infrastructure, or irrigation water as a driver of their short term or long term decision making.
When not to use:	Do not use when a farmer mentions …
Sub-codes:	N/A
Example:	"F: …I keep laughing when there's a short water year and say well when you get around the corner you can can't see down there that's how come I got my pickup full of buckets I'll just get busy and use the buckets when you're not watching. J: Do what you gotta do. I'm sure he's.

F: No. That would be. Actually, I've never really changed the cropping situation because of that, because so far I've always managed to get by."

Code:	Leasing out land
Brief Definition:	Discussion of factors considered in leasing out land
Full Definition:	This will primarily be a code for moments in which leasing land is the object of decision making, although it also applies to moments in which leasing out land is a driver of decision making.
When to use:	Any time a farmer is discussing the act of leasing land or leasing it out, this code applies. This is likely to be pretty extensively used.
When not to use:	…
Sub-codes:	N/A
Example:	"We've had the same renters for I bet ya the last ten years or longer. J: You kind of at some point you mentioned that you try to keep the best farmers in the fields that you can. Is it kind of competitive around here to get the? F: I have a waiting list."

Code:	Livestock
Brief Definition:	Discussion of livestock as both drivers and objects of decisions
Full Definition:	Livestock play an important role in determining both what a farmer needs out of their crops and what a farmer can do with their crops. They were a frequent topic of discussion, especially since a lot of farmers keep at least a small herd of beef cattle or heifers around or have done so at some point in their career.
When to use:	Use any time a farmer is discussing cattle. Although there are other livestock in the ESPA, none have a significant presence, so we're going to focus in on cattle as part of adaptation decision making. Use the feed sub-code when the discussion is centered specifically on feeding the cattle in one way or another; this may be a majority of occurrences, since most of the folks we spoke to thought of cattle as a compliment to their crops and land-holdings.
When not to use:	Do not use if a farmer simply mentions having cattle without discussing their implications for the rest of the farm or his management practices regarding the cattle. Do not use during dairy interviews – this will mute the signal of predominantly crop farmers with cattle.
Sub-codes:	Feed
Example:	"F: I lease it for a whole year, but it's summer grazing. It's irrigated grass. It's marginal land that you can't farm, lava rocks and things that way. But it's good grazing land."

Code:	Risks and Challenges
Brief Definition:	Moments of reflection on the risks and challenges faced by farmers
Full Definition:	This code is intended to capture the types of things farmers talk about when they think about risks and challenges.
When to use:	Code will predominantly be used with relation to the risks and challenges question asked, but it can also be invoked in any situation where a farmer reflects on risk or challenges as drivers or components in a decision. Use sub-codes when one applies to the challenge. These will be used both for counts and for context when considering variables in the model and values in the tradeoffs framework. It is worth noting specifically the Water sub-code includes the settlement agreement. This may change, but my feeling is that those risks aren't separate for people.
When not to use:	Do not use with respect to risk aversion – this may be a tricky line, but we're interested in the concrete risks and challenges faced rather than the idea of risk or gambles more generally. Risk aversion is being coded separately as part of the value category.
Sub-codes:	Costs or balanced budget Labor Other regulatory restrictions Water Weather Weeds, Fungus, Insects, Etc.
Example:	"F: What kind of challenges don't we face? J: That may be the better question, but we'll stick with this one for now. F: Weather probably is the biggest challenge. It's the one thing we depend on the most that we have no control over."

Code:	Rotation
Brief Definition:	Rotation as a determinant of crops or variables influencing rotation changes
Full Definition:	This code is intended to capture two things – the moments in which rotation is the steadfast, immutable object that farming sits on and the moments in which rotations are perhaps variable in the face of some force. We are interested in capturing both this dichotomy and the forces that appear in it.
When to use:	Use this code anytime rotation is discussed as a driver of farming decisions or as an object of decisions.
When not to use:	Do not use when the conversation is simply regarding what rotation is in use on a particular farm.

Sub-codes:	N/A
Example:	"So, on any of these fields, did changing irrigation strategies change your rotation or the crops that you could or would grow on them? F: No. I put pivots on them. I just rented it out once, or a couple times to somebody, for corn. I: Really? F: Couldn't have done that with wheel lines. I: Yeah. What made you do that? F: Just economics of it. Wheat prices were bad at the time. So. Rented out to a guy for corn. Worked out good."

Code:	What to plant
Brief Definition:	Discussion of the factors that drive planting decisions
Full Definition:	This is very simply a question of what factors drive what crops go in the ground. While the inverse may be relevant (crops planted may drive other decisions), this will be a big enough category in one direction that we'll look for the other idea in other places. I do explicitly ask about what the process of deciding this in any given year looks like, so that will probably be a key player here.
When to use:	Use this code anytime someone describes the factors that make them plant a crop in a certain year.
When not to use:	Do not use this when someone describes what they did that year, what made them set their rotation, or what their crops mean for their farming operation.
Sub-codes:	N/A
Example:	"So, in any given year, what is your process of deciding what crops to plant? Where and when and what are the key factors that you think about when you are making those decisions? F: Generally, I try to - The hay is our main cash crop. So, anything else is basically a rotational crop to get back to hay. If we have some ground that's not too rocky that they can put potatoes in, we'll let 'em put potatoes in. It helps build up the ground. Our main goal is to raise alfalfa. Everything else is basically a rotational crop."

Section 4: Management Strategies

Section notes:

This section is designed to capture what I would call guiding heuristics in farm management. In the three-pronged coding approach, this takes the middle ground between values and decision making parameters. While the parameters are tangible components of the farm and values are the attitude and norms playing into decision making, these management strategies sit as the middle ground between the two.

Code:	Best for the farm
Brief Definition:	Farmers make decisions because the action is what is best for the farm
Full Definition:	This example of a heuristic is best embodied in discussions of taking economic hits because it was more important to keep the fields in good working order. Other moments include discussions of "reinvesting every nickel" or "buying a new tractor instead of a new pickup." The idea here is that the farm is kind of an entity unto itself that is deserving of attention and care.
When to use:	Use this when a farmer explains their decisions as motivated by a desire to maintain and improve the farm as best possible.
When not to use:	Do not use this when a farmer talks about specific aspects of the farm, like irrigation maintenance or soil health – these should be coded in more specific codes. Rather, this is interested in capturing the idea of "the farm" as a more general concept.
Sub-codes:	N/A
Example:	None yet – I know this occurred, haven't found it yet.

Code:	Big Changes
Brief Definition:	General discussions of big changes on the farm
Full Definition:	This is used to collect farmers' reflections on big changes on the farm. An emphasis is placed on collecting excerpts that provide some sort of commentary on the challenges and advantages that come with making big changes of any sort. This is intimately related to the tension between incremental and transformational adaptation to water scarcity (Kates et al.).
When to use:	This can be used broadly to capture conversations about transformational changes on the farm. These need not be adaptation in the traditional sense – rather, we are trying to capture the intellectual space in which large changes on the farm reside.
When not to use:	Do not use when someone mentions something they have considered doing – this code is intended to capture historic or current thoughts on big changes, not speculation.

Sub-codes:	N/A
Example:	"I was born in 1937. This house was five years old, the first part of this house. My dad got a son, his first rubber tired tractor, and his first crop of potatoes all in one year. And we grew potatoes absolutely every year until 1969. Then we made the decision. I was involved in it then directly. We're not making any money growing potatoes. Let's go over this other way and have more cattle and grow grain and we'll do better. You know, the potato market back there would go this way depending on supply and demand heavily. The very first year we didn't grow potatoes, it got to $10 and my dad just turned green. But you know, year in and year out it was a good decision. It was a little hard at first to fill the hole and cover the gap but it was. I look back at that and I think about that when you want to make a major change cause one thing changes another thing changes another thing. I think you have to look at the future and where you are going and what you hope will happen."

Code:	Deciding what to fix or purchase first
Brief Definition:	Discussions of when and why to invest in particular things
Full Definition:	This is geared toward the question of "when to invest in new farm-scale implements or equipment." It is intended to capture the driving forces behind those sorts of large investments. It is not necessarily theoretically motivated.
When to use:	Use in almost every interview after the "when to invest" question, and more broadly use when farmers are talking about making improvements to the farm or to their large-scale infrastructure. This could also relate to land purchases, but this will probably be infrequent.
When not to use:	Do not code sections where interviewees discuss year-to-year expenses like types of seeds. Instead, focus on investments in the farm or the operation. There may be circumstances in which a farmer compares an annual expense with a large investment (like a custom baler vs. buying your own) – this is an exception and SHOULD be coded.
Sub-codes:	N/A
Example:	"Usually the squeaky wheel gets the grease. There's some pivots that are getting a little older, will take a little more repair. We try to address that. I have a real good friend of mine that I go through on all my pivot stuff. He keeps pretty close tabs on 'em and knows what's what and where everything is. Usually, it all depends on what crop's in the field. If it's hay, then usually if the pivot needs some work done, will work on the pivot. Just all depends on where, what the priority is."

Code:	Diverse Strategies
Brief Definition:	Farmers strive for balance between approaches

Full Definition:	This can be a balance between crops, between farm and other jobs, between risk and conservative strategies. The general theme is just that farmers are interested in maintain some diversity in how they make a living as a safeguard against failure.
When to use:	--
When not to use:	Do not use this when farmers are discussing …
Sub-codes:	N/A
Example:	"F: Let's put it this way, I have one guy that rents and he raises the hay and the barley and that. The other one I got, he rents and raises grain and sugar beets. We like to keep two different farmers in our management process so we don't have. You know if one has difficulties we're not relying on just one. So, we don't like putting all of our eggs in one basket with one farmer."

Code:	Financial and Infrastructural Foundation
Brief Definition:	Farmers discuss the importance of keeping the underlying pieces strong
Full Definition:	Essentially, as with many endeavors, one management heuristic is that certain "infrastructures" (defined broadly) should be kept up at a high level in order to allow for continued functionality through the tough times. The implications of this heuristic are effectively that farmers invest money in certain underlying characteristics of the farm whenever they can (thus, this is closely related to "Best for the farm").
When to use:	--
When not to use:	Do not use this when farmers are discussing …
Sub-codes:	N/A
Example:	"F: I do think about that way. I got another good friend of mine that I also grew up with and they also actually farm. I find his dad also very interesting to talk to. I get a lot of my insight from them. They're the ones that clued me in on keeping everything up to snuff. Keeping your payments up. Keeping everything else up. Because when things, you have bad economic times, if you don't keep these things all up to snuff he says everything is broke down and you have no money. So, if you keep everything up to snuff. That's kind of how we base our decisions."

Code:	Having a plan or system
Brief Definition:	Heuristic highlighting the importance of consistency or stability
Full Definition:	This heuristic is sculpted around the idea that some farmers believe that finding a system and sticking with it is the best way to manage a farm. In some ways, this is the opposite of adaptive management, but one doesn't necessarily have to come at the sole expense of the other – rather, a farmer could emphasize consistency in one domain while adaptively

	managing others. They also could emphasize slow transitions – this is relevant and should be coded here. For instance, if a farmer is slowly lowering the number of cattle in their herd, this would be relevant, but if they sell off the entire herd every decade and then buy more 5 years later, that's not.
When to use:	Use when farmers discuss "sticking with it" or "keeping to the plan" or "avoiding jumping around" – there are lots of ways of saying that they strive for consistency, so just watch for that sentiment.
When not to use:	Do not use when farmers are describing experience alone. "I did this, so I still do that" is related to consistency, but it's more a statement of experience – code for that.
Sub-codes:	N/A
Example:	"F: Yep. You know. Mostly was growing potatoes. I started out in potatoes and then I started buying land and we started growing other crops. Actually, my spud acres are down versus what they were 15 years ago. I: Gotcha. Why was that? F: I farmed the other crops. Contracts are hard to come by now a day. Feel comfortable with the 500 acres we grow. That's just part of the puzzle, you know. I don't jump around much. I don't follow markets. I stay pretty constant with same-cropping."

Code:	Making use of everything
Brief Definition:	Farmers describe methods for using less valuable resources or waste
Full Definition:	This is highly related to the value code of efficiency, but it's a bit more action oriented (as the whole section suggests). Really what we're looking for here is when farmers attempt to use resources that might otherwise be wasted, like ground that can't be cropped being cattle ground or the building of ponds to catch runoff.
When to use:	--
When not to use:	Do not use this when farmers are discussing efficiency alone as a concept. If they are discussing efficiency and provide examples, those examples may fit in here, but maybe not.
Sub-codes:	N/A
Example:	"F: I lease it for a whole year, but it's summer grazing. It's irrigated grass. It's marginal land that you can't farm, lava rocks and things that way. But it's good grazing land. My cows stay right here. They don't go up to the mountains or anything like that. They all stay right here on the farm. We try to farm the good part and the cows eat off the bad part. That's how come they're here."

Code:	Path dependence
Brief Definition:	Indicating that history governs present outcomes
Full Definition:	This is interested in anecdotes or descriptions of path dependence in farm makeup or farm management. This is perhaps not best described as a heuristic, but will have to think more about where it might fit
When to use:	--
When not to use:	Do not use this when farmers are discussing …
Sub-codes:	N/A
Example:	"F: Most of the grassland, well not all of it. I'd say 3/4 of the grassland is shovel irrigated out of a ditch. See. I'm an old irrigation. I'm under the Aberdeen-Springfield Canal, which was flood irrigation. That's what got it here. Then there's some sprinkler that like the way out here is too rocky to farm and that's sprinkler irrigated cause it fits in nice but it isn't all that way. Some of the others is just cause I haven't changed and some of it cause it's kind of impossible to change it."

Section 5: Settlement Agreement

Section notes:

This section is designed to capture the logistical components of the settlement agreement as well as the responses recorded in this set of interviews. If this section starts to look really interesting, we could apply it to the

Code:	District policies
Brief Definition:	Discussion of their understanding of district policies
Full Definition:	This is both to capture more information about the district policies and to compare their understandings against what we already know from the districts.
When to use:	Use this anytime someone either qualitatively or quantitatively discusses the rules laid out by the groundwater district.
When not to use:	--
Sub-codes:	N/A
Example:	"F: Before we had the meters, as I understand it, the settlement deal says we had to cut back 13% on our farm ground. We could do it, which in my opinion was a joke. We could do it in one of two ways. We could take 5% reduction and buy water, which is the option the biggest percent. Or we could transfer surface water, which my dad had some, about enough to do his, but I didn't have enough to do mine."

Code:	Impacts of the agreement
Brief Definition:	Descriptions of impacts of the agreement as the farmer views it
Full Definition:	This is a very general code, and it may get quite large and require sub-dividing. For now, since we didn't talk in depth about the agreement with most people, just code everything that they describe as an impact or outcome on their farm in this section. Certain things I'm interested in get sub-codes, like assessments. For assessments, this is a general code intended to capture both the quantitative and qualitative discussion of the assessments resulting from the settlement agreement.
When to use:	Use in any case the farmer discusses "impacts" or "outcomes" or "because of…" the settlement agreement.
When not to use:	Do not use when….
Sub-codes:	Assessments
Example:	"…Specifically, what would you say were the biggest changes you made to deal with the settlement agreement? F: Put ugly rock patches in my farm. The thing that I. My biggest concern with it is - is the extra money that we had to give out. I have not seen where it has benefited the aquifer."

Code:	Meters
Brief Definition:	Discussion of putting meters on or costs of meters
Full Definition:	The water meters seem to be the most tangible outcome of the agreement from the farmers' perspectives. Many of them discussed the financial burden of it, the logistics of putting them on, etc. A few actually like the meters as a management tool. All of that should get coded here.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"M: How many. My understanding is they run around $5,000 per meter? F: Ours were a little less. We done six of 'em. F2: Somewhere between $3,000 and $5,000, depending on your. F: On average about $4,000 apiece."

Section 6: Tradeoffs

Section notes:

This is where I'll start to piece together the picture of tradeoffs in this context. In particular, I'm looking to start outlining the multi-scalar tradeoffs that I'll need to work with Becca on. For now, it's a fairly bare-bones take on it, but it'll get fleshed out as we develop our collaborative framework.

Code:	Community scale
Brief Definition:	Tradeoffs at the scale of the local community or district
Full Definition:	This will most often appear in district policies. These could be tradeoffs in equity and public trust, tradeoffs in participation and efficiency, etc.
When to use:	Use when someone discusses either the water district or another community-level institution making some sort of tradeoff between values.
When not to use:	--
Sub-codes:	N/A
Example:	--

Code:	Explicit Tradeoff
Brief Definition:	Values tradeoff discussed and recognized by the speaker
Full Definition:	Explicit tradeoffs are how we're referring to tradeoffs that are recognized by the speaker. In other words, some sort of clear exchange of values is discussed and framed as a tradeoff.
When to use:	This one should be more obvious but will still probably be mostly a second-stage code. There will likely be some cases where things are really obvious. No matter what, it will be a matter of interpreting someone else's value sets, which will be challenging. This will often be double-coded with a scale code and maybe a type code.
When not to use:	--
Sub-codes:	N/A
Example:	"J: I buy it. Okay. So, the last couple questions. When you are making these decisions and you are choosing between different things like that, different benefits, whatever it might be, however you want to phrase it, how do you? Do you often feel like you are forced to sacrifice certain types of benefits, certain features of the farm in favor of others? Is that something that? F: Yeah. Everything is a give and take. Yeah. J: What is your year-to-year? What would you say your give-and-take, your tradeoffs are? F: I'm kind trading off because I went back to new-seeding alfalfa and I probably could have maybe grossed more dollars on corn and that. But

I need the feed for the cows so, you know, if there's extra hay, plus it's a better way of farming. See. Put a cover crop on for a couple years instead of erodible crop like corn. You know what I mean? You rotate back and forth. By textbook, that's a better way to farm. You know what I mean?"

Code:	Implicit Tradeoff
Brief Definition:	Values tradeoff discussed but unrecognized by the speaker
Full Definition:	Implicit tradeoffs are how we're referring to tradeoffs that go unrecognized by the speaker. In other words, some sort of clear exchange of values is discussed but not framed as a tradeoff. Theory suggests that this should create some level of cognitive dissonance, and it also suggests that it is likely that either 1) one of those values far outweighs the other or 2) they are both sacred values and the failure to recognize is self-protection. This will often be double-coded with a scale code and maybe a type code.
When to use:	This one is tricky. I think it will, for the most part, be a second-stage code. There may be some cases where things are really obvious, but for the most part, it will be a matter of interpreting someone else's value sets, which will be challenging.
When not to use:	--
Sub-codes:	N/A
Example:	--

Code:	Individual-scale
Brief Definition:	Tradeoffs at the level of one farmer or farm
Full Definition:	This is the scalar code for tradeoffs that happen at the level of an individual farmer or farm. This will be where the psychological core of tradeoffs sits. While my definition of tradeoffs is always seated in values, this one is particularly interesting in that context, because it depends on the values of the person being interviewed.
When to use:	For the most part, this will not be a first-pass code. We need to have a grip on the values at play and perhaps develop some sort of categorization for the interviews. However, anyone being really explicit about weighing different values against each other can be placed here.
When not to use:	--
Sub-codes:	N/A
Example:	--

Code:	One bucket
Brief Definition:	Each expense or action comes at the expense of something else

Full Definition:	This is a localized term or framing for tradeoffs that I came across a couple times. Farmers don't necessarily think about tradeoffs in those terms, but they do frame their farm as all one bucket and expenses of labor or capital in one area will always come at the expense of labor or capital somewhere else. This has also been used to describe the aquifer.
When to use:	Code this phrase ("It's all coming from the same bucket") or close relatives of it. The goal here is to see if there is broad use of this kind of colloquial version of tradeoffs, since that might have implications for the study of tradeoffs academically as well.
When not to use:	--
Sub-codes:	N/A
Example:	"F: I don't really know what more else. You know, I'm about as efficient on labor, you know. I manage a lot of my costs on the forage side. I'm not paying anybody any fees on raising my heifers. I'm doing that all in house. I just can't get too much more efficient."

Code:	Regional [Scale]
Brief Definition:	Capturing tradeoffs between values and services at the regional scale
Full Definition:	This code is intended to lay the groundwork for some of the collaborative efforts with another researcher – this will presumably be broken out further as we develop a codebook, but for now I'm just trying to get a basic understanding of how folks view the tradeoffs that have emerged regionally as a result of the agreement.
When to use:	This can be used pretty broadly for now, since it's not really an analytical code yet. It'll need to be refined and probably
When not to use:	--
Sub-codes:	N/A
Example:	"F: Yeah. Well, it all goes to the same place but it's like I say it's all about money. We're tired of paying the lawyers. We're gonna say, okay, we're gonna line the canal. Put the water here. Even though you're not getting any more than what you were anyway. But we're not paying lawyers."

Code:	Temporal
Brief Definition:	Acknowledgment or discussion of short-term and long-term tradeoffs
Full Definition:	This is really interested in farmers' discussion of the short- and long-term costs and benefits that can accrue from a decision. In this case, we're looking to understand the temporal aspects of decision making. This is discussed in psychology as the discounting effect, and in larger-scale tradeoffs it could appear as a sort of prioritizing of outcomes across time.
When to use:	--

When not to use:	--
Sub-codes:	N/A
Example:	"F: I'm gonna answer that question this way. I look at it. Money that I can spend more than once. I have had people actually get mad at me because I will not sell them. I do have a mortgage on them. These are my retirement. I do not have a 401-K. So, if you talk about decisions and the different benefits, I can sell them. I can get a big chunk of change. But then I spend it and it's gone. If I keep it and keep improving it, it will keep paying me from now on."

Code:	Win-win
Brief Definition:	In the framing of tradeoffs, win-win is a gain in two values or services
Full Definition:	Win-wins are the subject of much of the tradeoff analysis to date. In particular, folks like to frame governance/management models as creating synergies and "win-wins" where multiple groups or multiple services or multiple values benefit.
When to use:	This one is tricky, but it might be an interesting framing at the psychological level – lots of farmers like to talk about sustainable management as "common sense," since you're saving water and money simultaneously.
When not to use:	--
Sub-codes:	N/A
Example:	--

Section 7: Values

Section notes:

This section is designed to capture what I would call guiding heuristics in farm management. It is closely tied to the values section, but it's more about people talking about what their

Code:	Certainty
Brief Definition:	Clarity in the policy landscape moving forward.
Full Definition:	A common theme around the settlement was that no one was fully thrilled with how it turned out, but they were generally happy that some sort of conclusion had been reached. They now had certainty in the political and economic landscape, at least in the near-term. This allows more comfortable investing and planning. This may play an important role in both regional and individual coding.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"F: It's been a long time coming. I mean and so yeah we've been fighting the thing for quite a few years. We've been concerned about it for probably. I mean. The only good thing about the agreement now is that it's kind of set in stone. You know what is there. Hopefully, we are not going to be paying more lawyers millions of dollars."

Code:	Do things differently [than other farmers]
Brief Definition:	Value standing out in practices
Full Definition:	This and the converse code are based on a question asked in each interview about doing things differently or similarly to other farmers. This version is tracking when farmers say they stand out a bit, kind of follow their own path. This is treated as a value, since there is a fairly significant body of literature discussing normative influences in farmers.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"F: I probably do things different. I've had the ability to rent this ground out to the onion growers…"

Code:	Do things similarly [to other farmers]
Brief Definition:	Value fitting in in practices
Full Definition:	This and the converse code are based on a question asked in each interview about doing things differently or similarly to other farmers. This version is tracking when farmers say they generally follow similar

	strategies to others or use that as some form of confirmation. This is treated as a value, since there is a fairly significant body of literature discussing normative influences in farmers.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	“F: Pretty close to normal. You know. Some of the big guys, you know, so there's a little bit difference than I do. You know, most guys with 10,000 to 20,000 acres, they make decisions a lot different than I do.”

Code:	Efficiency
Brief Definition:	Making the most of resources available
Full Definition:	This is a value that seems to pervade the farming community in Idaho. I think this forms the backbone of a lot of the tradeoffs we see, since farmers are trying to choose what they see to be the most productive path, and this involves a series of tradeoffs between different values. So far, efficiency is resembling a sacred value.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	“F: But we've scraped dirt out of all the corners and buried them to make the pivot more efficient. If you put wheel lines in there, then you are farming the whole thing. You can't scrape the. See, then you just leave the rock piles. So it became a lot more efficient use of the water I felt like.”

Code:	Family
Brief Definition:	Family history, legacy, or well-being as a value
Full Definition:	Many farmers are sitting on land that has been in their family for generations or they use management strategies they learned from their parents or any number of ideas tied into family history and legacy. This is just a code to capture discussion of this. For many others, farming is about the current family, supporting the nuclear family at home. This should also be considered, although they may eventually be coded separately if this appears a lot.
When to use:	Use this when folks are talking about things they learned from their parents or things they did because the family did it or needed it.
When not to use:	Don’t use when people are just describing their family or working with family.
Sub-codes:	N/A
Example:	“There's about 250 acres of it that has more or less been in my family for I would dare say I'm the third generation of it. My grandparents.

Actually, my grandma, my dad filed on what they called a desert entry, basically homesteaded it."

Code:	Farm appearance [aesthetic]
Brief Definition:	Valuing the beauty or appearance of farmland
Full Definition:	Folks see value in the pastoral landscape, the farm as "it should be." This is deeply embedded in the legacy of the land, the desire to keep the desert green. Things like rock blows and empty corners disrupt this landscape – these shape the decisions of farmers interested in preserving it.
When to use:	This will most often be used in discussing the consequences of using less water or as something they seek to preserve in determining their management strategies.
When not to use:	--
Sub-codes:	N/A
Example:	"M: Did you go with the 5% reduction? F: We went with the 5% reduction. Yet, it's still. I call 'em rock patches. Around here, we have little rock patches in the middle of our field that we are always trying to work with and everything else. When they done that, they put more rock patches and bald spots in my fields. F2: More weeds. F: More weeds and made the farm ugly."

Code:	Farm because it's a passion
Brief Definition:	Farmers continue to farm because it's more than a job
Full Definition:	Passion here is taken quite broadly. For some farmers, it means they do it out of respect for a legacy, for some it is truly what they love doing, and for some it is just what they've always done and who they are. So passion could be construed as identity, history, or truly passion. Basically, the goal here is to capture valuing farming as something more than just a job, or valuing farming for farming itself.
When to use:	As described above, this can be quite broad. Really focus on capturing it whenever a farmer describes their work as something more than just a job or way to earn money. Something with inherent value.
When not to use:	--
Sub-codes:	N/A
Example:	"F: It's turned out. It was the only choice I had because I looked hard and long and I'd read books for five or ten years knowing I needed to do something. And at this age, you know, maybe tomorrow is the day, maybe it's not. Nobody knows. I like what I do and I intend to keep doing what I'm doing as long as I can do it and enjoy it. Well, that doesn't suit other people very well. Cause they want a plan. Well, I agree you gotta have a plan, but my plan's gotta be for me."

Code:	First in time, first in right
Brief Definition:	Prior appropriations in value form
Full Definition:	This focuses on farmers expressing support for the principle of prior appropriations ("first in time, first in right"), which is how water has traditionally been managed in the American West (with many notable exceptions). Many farmers view the settlement agreement as a break with that tradition.
When to use:	Use whenever someone mentions prior appropriations as the way that it "should be."
When not to use:	--
Sub-codes:	N/A
Example:	"F: Let's put it this way. We talked a little bit about my priority dates on our wells. Like I say, I've got one anywhere from 1950 to 1981. The state of Idaho states that you know first in time/first in. I think. I feel like they've gotten away from that. Well, let's help these other poor little guys out. And I'm one of 'em. That have a junior water right. I believe that somewhere along the line everybody knew the risk that they was getting into when they got into this game. If you have a priority date that falls into this line. I'm sorry to say. They should shut your water off."

Code:	Global perspective
Brief Definition:	Viewing the settlement and farming from a broader perspective
Full Definition:	This emerged a couple times when farmers discussed one of the challenges in the region as folks not seeing the bigger picture. This could be related to water, related to flooding the market with oversupply, related to environmental degradation. There's a whole variety of moments in which people blame a siloed perspective for some of the issues in the area.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"F: Probably. The average guy doesn't - They are not involved enough. They run their dairies and they like to go fishing or in the winter they go skiing or whatever. They kind of live in their own little world. They have their own lifestyles. They don't sit on boards. They don't, you know. I mean, I've been on the Zion's Bank board. I've been on the Federal Land Bank board. I've been on the U.S. Bank board. I've been on the board of United Dairymen of Idaho. Right now, I sit on the Glanbia board. So, I've already. I get all of this information and I meet all of these people. I've been to Ireland two or three times, where Glanbia is. Then I'm originally from Holland. I was only seven years old when I came to the

states. But I've been back about five times. I know people there. I still got a couple of relatives that dairy, so I get, you know. I see that, the other side of this thing. So I'm. Probably have a much bigger view or broader grasp, if you will, not that I'm any smarter. But just a broader grasp than the average dairyman. Let's put it that way."

Code:	Knowledge
Brief Definition:	Highlighting discussions of knowledge or understanding as cornerstones of success
Full Definition:	This is mostly interested in farmers discussing staying informed or up to date and how and why they do that. It is important in the context of the settlement agreement, because one of the primary points of conflict seems to be the different narratives coming from different seemingly reputable sources of information. More broadly, people like to highlight understanding or not understanding as a key component of making decisions on the farm.
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"Knowledge and research is key. You gotta have knowledge and research what you think is gonna be the best irrigation system for ya. You gotta have knowledge and research on what they are planting in your field and what they're putting on your field. Everything."

Code:	Labor, time required
Brief Definition:	Valuation of own time or the cost of labor
Full Definition:	This is really interested in how people discuss the tradeoff of investing time, effort, or labor into something versus the outcome without that investment. In many cases, this will be a "I used to do X, but that required too much investment of time/labor, so I no longer do that."
When to use:	--
When not to use:	--
Sub-codes:	N/A
Example:	"F: We did alright with the dairy heifers. I don't know. Me and my wife are getting close to retirement age and we would just like to be a little more free to, okay, I gotta go. I can look up my phone and see how the pivots are doing. You know. Turn them on and off."

Code:	Land as an investment

Brief Definition: Farmland is considered a long-term investment, sometimes for retirement

Full Definition: Just as in much of the US, farmland is rapidly appreciating, and this does not go unnoticed by farmers. While this raises upfront costs, many also see the farmland as a long-term investment, assuming that as long as they take care of it, they can make a pretty penny when it comes time to sell.

When to use: Use this when people talk about the increase in value of the land or when they discuss explicitly its use as an investment or as their retirement savings.

When not to use: --

Sub-codes: N/A

Example: “F: You could look at it. I would say our farm ground is an investment. A lot of farmers obviously they use it in an investment plus also a way to generate income.”

Code: Land quality, Soil Health [Small-scale environment]

Brief Definition: Environmental values within a farm

Full Definition: This code is intended to catch moments when farmers are discussing the value of preserving small-scale environmental variables, particularly those within their farm. The most common of these is soil quality. Farmers discuss frequently the challenge between overburdening and overinvesting in soil.

When to use: --

When not to use: --

Sub-codes: N/A

Example: “F: Well, I do believe in trying to help the soil. And alfalfa is one them that really is beneficial to the soil usually. So. That's another reason I went to hay. You're not putting all the salts down from the commercial fertilizers so much and I think it's a lot better for the soil.”

Code: New technology, science

Brief Definition: Capturing general reactions to new technology and science, both positive and negative

Full Definition: This is really intended to capture people’s thoughts about the variety of new technologies available to manage a farm. I’m not certain exactly how it fits into the values equation, but it’s kind of an agglomeration of efficiency, traditionalism, labor costs, and up-front costs.

When to use: --

When not to use: --

Sub-codes: N/A

Example: “I can look up my phone and see how the pivots are doing. You know. Turn them on and off.
I: When did you install that?
F: This year.
I: That's pretty slick. I've run into a few people. I was here last year. I honestly. I think the irrigation companies must have really done a good job installing those this year because when I was here last year I didn't run into nearly as many people with those things on their phones. It is pretty cool.
F: Yeah. It's pretty handy.”

Code: Quality of Farmer
Brief Definition: Ability or skill as a variable in success
Full Definition: This is intended to capture when people comment on the importance of a farmer’s quality or skill. They can be referring to themselves or others. Most of the time, this will be discussing skill or quality as a trait that is important, but it is also seen when they discuss things that change over time or learning to become better.
When to use: --
When not to use: --
Sub-codes: N/A
Example: “F: Well, yeah. It's not quite that. It's probably about five/six miles from here. Then I got. My friend that I, you know, consult with, him and his dad quite a bit. They farm more or less on the east side of Blackfoot and down toward the southern part of Blackfoot, where it's more sandy, more. It's really interesting to me to hear what the farmers I work with, what they say about the benefits is where they farm and what the benefits of where my friends farm down out in the sand and that and the things they don't like about the sand and so. It's just really. I had one guy tell me there's no such thing as bad farm ground, just inadequate farmers.”

Code: Risk
Brief Definition: Risk aversion (or lack thereof) as a component of decision making
Full Definition: Risk is a constant characteristic of farming, particularly in light of ongoing changes in weather patterns. This is often acknowledged and discussed by farmers – sometimes this will take the form of risk management, other times it will refer to decisions that put them in a position of more or less risk.
When to use: --
When not to use: --
Sub-codes: N/A

Example: "F: You know, and your question what do any time that the farmer will come to me and it's a risk versus gain deal. Potatoes, you notice I say we don't raise potatoes. Potatoes are a real big risk. I mean, there are so many variables in potatoes that yeah.
M: So many things to go wrong with potatoes.
F: So many things to go wrong and it's really a big gamble. That friend of mine I was telling you about. They raise potatoes and they do quite well at it. But they also do things in a very conservative way. But they also keep a very close tie on all the variables. The supply versus demand, you know. What their product is doing. They keep very close, pay very close attention to it."

Code: Simplicity
Brief Definition: Importance of a straightforward approach or avoiding complexity
Full Definition: Simplicity is intended to capture when folks are interested in preserving a simple decision making process or operation – it is closely related to tradition, but it is referring to more than legacy but rather the general value of simple systems. It will often be discussed in relation to risk, s.t. complexity = risk.
When to use: --
When not to use: --
Sub-codes: N/A
Example: "My farmers had, like I say, is just don't tear anything up. You make money. I make money. That's pretty much how our approach is. Keep it pretty simple. The farmers is the ones that's gonna make the big decisions."

Code: Taking action
Brief Definition: Doing something rather than waiting
Full Definition: One way to think about this is that there are two alternatives in most situations – waiting to see or doing something active about it. This strategy argues that it is preferable to try something to continue improving rather than waiting to see how everything turns out.
When to use: --
When not to use: --
Sub-codes: N/A
Example: "F: Well, doing nothing doesn't work, cause you either go forward or you go backwards. Sometimes you can manage to stall for a year or two over some issue, you know, and just kinda get by. But you either gotta go this way or you gotta go this way. Cause you don't stand still. If you stand still, a big truck sure is gonna run over ya."

Code:	Tradition
Brief Definition:	Value of preserving old or family strategies
Full Definition:	This is really interested in the idea of "this is how we've always done it, so that's the way we do it." It kind of flies in the face of a lot of adaptation framings, but since any form of adaptation is going to require significant behavior change, this is intensely relevant to the relative success of adaptation planning.
When to use:	It is possible that tradition and simplicity could be combined into some sort of variable like comfort. TBD.
When not to use:	--
Sub-codes:	N/A
Example:	"F: So, I guess not all decisions are economic. You know what I mean? You know what I'm saying? In the long term, I'm better off doing things like that. But so not. Yeah. Not all of it is purely business or rational. Not every decision is. If I was a pure business man, then you'd make. Sometimes you do it cause you just feel comfortable, you like it that way. You know. That's a tough question. I don't have an answer to that one."

Code:	Yield
Brief Definition:	Crop yield as a value outside of the economic value of the crop
Full Definition:	Sort of like farming as a value, this acknowledges that doing a good job and producing high yield fields has value to farmers outside of just the economic return.
When to use:	This can be used anytime a farmer discusses their yield, but it is particularly looking for moments when a farmer points to yield as either a value that they seek to promote or as a driver of their decision making. It is useful in both contexts here.
When not to use:	--
Sub-codes:	N/A
Example:	"F: I'm not into Field Net. I see where they are beneficial, but I don't believe. My son is all Field Net. Costs him a lot of money every year and I don't see it. My corn was about 29 bushel an acre more than his."

APPENDIX C - GROUNDWATER FARMER SURVEY

The following document is the groundwater farmer survey upon which much of the analysis in this thesis is based. It was a collaborative effort of Dr. Morey Burnham, Dr. Margaret du Bray, Dr. Katrina Running, Dr. Vicken Hillis, Dr. Zhao Ma, Dr. Chloe Wardropper, and Jason Hawes.

SECTION ONE - Farm Characteristics

1. What groundwater district is your farm located in (check all that apply)?

1 ☐ American Falls-Aberdeen
2 ☐ Bingham
3 ☐ Bonneville-Jefferson
4 ☐ Carey Valley
5 ☐ Jefferson Clark
6 ☐ Madison
7 ☐ Magic Valley
8 ☐ North Snake
9 ☐ Farm is not in a groundwater district
10 ☐ Other ___________

If your farm is in one or more of the groundwater districts listed above, please fill out the rest of the questionnaire and return it in the self-addressed, stamped envelope provided. If your farm is NOT located in one of the listed groundwater districts, it is not necessary for you to complete the questionnaire. Please return your incomplete questionnaire in the self-addressed, stamped envelope provided so that we can update our records.

2. How many total acres of land do you own? .... [ ] acres

3. How many total acres do you farm (include leased land)? .... [ ] acres

4. Use the table below to indicate how many acres of each of the following crops were planted on your farm in 2016, your yield, and what percent of the crop you have contracted or in a co-op.

	Acres	Total Yield	Percent Contracted or in Co-op
Alfalfa/hay			
Barley			
Corn for silage			
Seed corn			
Potatoes			
Sugar beets			
Irrigated wheat			
Other *(please list):*			
Other *(please list):*			

5. How many head of dairy cattle do you have on the land you own or manage? .... [ ] head

6. How many head of beef cattle do you have on the land you own or manage? .... [ ] head

7. How many head of other livestock do you have on the land you own or manage? .... [ ] head

8. In an average year, what percentage of your crops are insured? .... [ ] %

9. In an average year, what percentage of your livestock are insured? .... [ ] %

10. In the table below, please indicate which of the following irrigation methods you use on your farm and approximately how many acres that irrigation system is on.

Irrigation Type	Check the Box Next to Each Irrigation System You Use on Your Farm (Check All That Apply)	Acres	In What Year Did You Install This System?
Micro-sprinklers	☐		
Center pivot	☐		
Hand lines	☐		
Wheel lines	☐		
Drip	☐		
Furrow/flood	☐		
Other *(write in):*	☐		

11. In the following table, indicate what types of water rights you have (check all that apply) and what percentage of your total water portfolio that right makes up.

Water Right Type	Check If You Have Indicated Type Of Water Right	Percentage of Water Right Portfolio
Junior groundwater rights (1973-present)	☐	%
Senior groundwater rights (1972 or earlier)	☐	%
Surface water	☐	%
Dual rights	☐	%

SECTION TWO - Challenges to Your Farm Operation

12. Please rate how challenging each of the following is when it comes to making a living from your farm.

	Not a Challenge	Slight Challenge	Moderate Challenge	Major Challenge	Extreme Challenge
Low commodity prices	☐	☐	☐	☐	☐
High cost of farming inputs	☐	☐	☐	☐	☐
Obtaining financing	☐	☐	☐	☐	☐
Finding contracts for my crops	☐	☐	☐	☐	☐
Unpredictable crop markets	☐	☐	☐	☐	☐
Pests/weeds/disease	☐	☐	☐	☐	☐
Drought	☐	☐	☐	☐	☐
Unpredictable weather	☐	☐	☐	☐	☐
Not enough water to irrigate sufficiently	☐	☐	☐	☐	☐
Hiring and/or keeping labor	☐	☐	☐	☐	☐
Government regulations	☐	☐	☐	☐	☐
Lack of access to technical assistance	☐	☐	☐	☐	☐

SECTION THREE - Impact of Water Restriction on Your Farm Operation

13. In this section, we will ask you several questions about how your farm was impacted by the water reductions you were required to make as a result of the 2015 water settlement agreement.

	Percentage
What percentage of your total groundwater rights were you required to cut by your groundwater district?	%
In your estimation, what percentage of your typical yield have you lost because of the water cut requirements?	%
In your estimation, what percentage of your typical farm income have you lost because of the water cut requirements?	%

	Meters
How many well meters have you purchased to meet the terms of the settlement agreement?	
How many well meters do you still need to purchase to meet the terms of the settlement agreement?	

	2016	2017
How many acres have you taken out of production since the agreement took effect to meet your required water cut in the 2016 and 2017 irrigation seasons?	$	$
Overall, how much money did you spend to meet your required water reduction in the 2016 and 2017 irrigation seasons?	$	$

14. How concerned are you about the following issues related to the water cuts?

	Not At All Concerned	Slightly Concerned	Moderately Concerned	Very Concerned	Extremely Concerned
Meeting the water reduction requirements of the settlement agreement	☐	☐	☐	☐	☐
The impact of the settlement agreement on your farm operation	☐	☐	☐	☐	☐
Your ability to make a living from your farm with the required water cuts	☐	☐	☐	☐	☐

15. Indicate which of the following you or someone in your family have done since 2015 to deal with the financial impacts of the settlement agreement on your farm.

	Yes	No
Took an off-farm job	☐	☐
Started a new business	☐	☐
Reduced spending	☐	☐
Contracted more crops	☐	☐
Contracted fewer crops	☐	☐
Joined a co-op (e.g., Amalgamated Sugar)	☐	☐
Other *(write in):*	☐	☐

SECTION FOUR - Farm Operation Decision Making

16. Please indicate how important each of the following is in determining the decisions you make about managing your farm.

	Not Important	Slightly Important	Moderately Important	Very Important	Extremely Important
Labor availability	☐	☐	☐	☐	☐
Crop market availability	☐	☐	☐	☐	☐
Availability of crop contracts	☐	☐	☐	☐	☐
Commodity prices	☐	☐	☐	☐	☐
Price of inputs	☐	☐	☐	☐	☐
Access to credit	☐	☐	☐	☐	☐
Availability of financial assistance from government programs (e.g., Conservation Reserve Program)	☐	☐	☐	☐	☐
Cooperative or contract requirements	☐	☐	☐	☐	☐
Conserving water	☐	☐	☐	☐	☐
Last year's crop performance	☐	☐	☐	☐	☐
Last year's water use	☐	☐	☐	☐	☐
Dealing with unpredictable weather	☐	☐	☐	☐	☐
Availability of technical assistance	☐	☐	☐	☐	☐

17. Please indicate your level of agreement with the following statements.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disgree Nor Agree	Somewhat Agree	Agree	Completely Agree
I am willing to make short-term cut backs if they will lead my farm to long-term success	☐	☐	☐	☐	☐	☐	☐
I am willing to make up-front investments if they will lead my farm to long-term success	☐	☐	☐	☐	☐	☐	☐

SECTION FIVE - Farm Practices

18. In the following table, indicate which of the following practices you used to meet your required water cuts or deal with the associated impacts. Please also indicate if you plan to use these practices in the future. Check all that apply.

	Have Used This Practice		I Plan to Use This Practice in the Future	
	Yes	No	Unlikely	Likely
Changed crop rotation	☐	☐	☐	☐
Switched to or added dryland acres	☐	☐	☐	☐
Planted higher value crops	☐	☐	☐	☐
Planted less water-intensive crops	☐	☐	☐	☐
Changed tillage practices	☐	☐	☐	☐
Dried up corners	☐	☐	☐	☐
Turned off end guns	☐	☐	☐	☐
Irrigated less frequently	☐	☐	☐	☐
Improved irrigation system efficiency	☐	☐	☐	☐
Switched to a more efficient irrigation system	☐	☐	☐	☐
Used canal water to meet requirements (mitigate)	☐	☐	☐	☐
Purchased recharge credits (e.g., Snake River Storage or Recharge Development Corporation)	☐	☐	☐	☐
Purchased or rented canal shares	☐	☐	☐	☐
Put land into Conservation Reserve Program or other government sponsored program	☐	☐	☐	☐
Reduced livestock herd size	☐	☐	☐	☐
Hired consultant for technical help	☐	☐	☐	☐
Sold land	☐	☐	☐	☐
Adopted precision agriculture techniques (e.g. drones)	☐	☐	☐	☐
Stopped farming	☐	☐	☐	☐
Did not do anything	☐	☐	☐	☐
Other *(write in)*:	☐	☐	☐	☐
Other *(write in)*:	☐	☐	☐	☐

SECTION SIX - Farmer Perspectives on the Water Settlement Agreement

19. How would you characterize your attendance at groundwater district meetings?

- ☐ I attend every meeting
- ☐ I attend more than half of the meetings
- ☐ I attend less than half of the meetings
- ☐ I never attend meetings

20. How would you characterize your role in groundwater district decision making? (Check all that apply)

- ☐ I currently serve in a formal leadership position in my groundwater district
- ☐ I have previously served in a formal leadership position in my groundwater district
- ☐ I have served in an informal leadership position or on an advisory committee in my groundwater district at any time, either present or past
- ☐ I have no role other than attending meetings
- ☐ Other, please specify: ____

21. Did you attend any groundwater district meetings related to the 2015 settlement agreement process?

☐ Yes ☐ No

22. Please indicate your level of agreement with the following statements related to the *process* of reaching the 2015 settlement agreement.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
The decision-making process was transparent	☐	☐	☐	☐	☐	☐	☐
The decision-making process was fair	☐	☐	☐	☐	☐	☐	☐
I was able to influence the decision-making process to the extent I wanted	☐	☐	☐	☐	☐	☐	☐
My interests were represented during the negotiations	☐	☐	☐	☐	☐	☐	☐
Outside interests (not related to farming) had too much influence in the process	☐	☐	☐	☐	☐	☐	☐
I trust that the data used to make decisions in the agreement was accurate	☐	☐	☐	☐	☐	☐	☐

23. Please indicate your level of agreement with the following statements related to the ***terms*** of the 2015 settlement agreement.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
The settlement agreement was necessary to ensure water availability for all users in the future	☐	☐	☐	☐	☐	☐	☐
Overall, the terms of the agreement are fair for groundwater users	☐	☐	☐	☐	☐	☐	☐
Overall, the terms of the agreement are fair for surface water users	☐	☐	☐	☐	☐	☐	☐

24. Please indicate your level of agreement with the following statements related to the ***implementation*** of the 2015 settlement agreement.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
My groundwater district fairly assigned water reduction requirements to each farmer in my district	☐	☐	☐	☐	☐	☐	☐
Overall, I have been treated with respect by water managers	☐	☐	☐	☐	☐	☐	☐
I clearly understand what I am required to do under the settlement agreement	☐	☐	☐	☐	☐	☐	☐
I would be troubled if I knew other farmers were not complying with the settlement agreement	☐	☐	☐	☐	☐	☐	☐
If I do not comply with the agreement, I will face official consequences	☐	☐	☐	☐	☐	☐	☐
If I do not comply with the agreement, I will face criticism from other farmers	☐	☐	☐	☐	☐	☐	☐
In the end, I believe the goals of the water settlement agreement will be achieved	☐	☐	☐	☐	☐	☐	☐

SECTION SEVEN - Resources for Farm Management

25. Please rate your level of agreement with the following statements.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
My ability to make management changes on my farm is constrained by crop markets	☐	☐	☐	☐	☐	☐	☐
My ability to efficiently manage water is constrained by inadequate irrigation infrastructure	☐	☐	☐	☐	☐	☐	☐
My current approach for dealing with water challenges will be sufficient for future water challenges	☐	☐	☐	☐	☐	☐	☐
I experiment with new ways to irrigate	☐	☐	☐	☐	☐	☐	☐
I have the knowledge I need to solve water related challenges on my farm	☐	☐	☐	☐	☐	☐	☐
I have the financial resources needed to make management changes on my farm	☐	☐	☐	☐	☐	☐	☐
More efficient irrigation systems are too expensive for me to purchase and use	☐	☐	☐	☐	☐	☐	☐
To comply with the settlement agreement, I am willing to change the way I manage my farm	☐	☐	☐	☐	☐	☐	☐
To comply with the settlement agreement, I am willing to take cut backs on my farm income	☐	☐	☐	☐	☐	☐	☐
I anticipate some years I just won't be able to comply with the settlement agreement if I want to pay my bills	☐	☐	☐	☐	☐	☐	☐
The settlement agreement changes my relationship with other farmers	☐	☐	☐	☐	☐	☐	☐

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
My relationship with other farmers will help me find ways to deal with the settlement agreement	☐	☐	☐	☐	☐	☐	☐
Situations like the settlement agreement bring farmers together	☐	☐	☐	☐	☐	☐	☐
Under the settlement agreement, it will be more difficult for me and other farmers to help one another with water and farm management	☐	☐	☐	☐	☐	☐	☐

26. Please rate your level of agreement with the following statements.

	Completely Disagree	Disagree	Somewhat Disagree	Neither Disagree Nor Agree	Somewhat Agree	Agree	Completely Agree
There are job options available to me other than being a farmer	☐	☐	☐	☐	☐	☐	☐
Helping other farmers in my community is important, even when it means making small sacrifices	☐	☐	☐	☐	☐	☐	☐
I regularly change my farm management practices to deal with new challenges	☐	☐	☐	☐	☐	☐	☐
I seek the advice of other farmers in the region	☐	☐	☐	☐	☐	☐	☐
I seek the advice of extension agents and other agricultural professionals in the region	☐	☐	☐	☐	☐	☐	☐
My ability to make changes on my farm is constrained by government regulations	☐	☐	☐	☐	☐	☐	☐
When I need information about solving the challenges I face on my farm, it is easy for me to obtain it	☐	☐	☐	☐	☐	☐	☐

SECTION EIGHT - Landowner Information

27. Are you?

☐ Male ☐ Female

28. What year were you born? .... ☐

29. What is the highest level of formal education you have completed?

☐ Some high school or less
☐ High school
☐ Technical school/some college
☐ College
☐ Graduate degree (e.g. MS, MBA, PHD, MD)

30. Over the last five years, what is your average net annual ***household*** income (income after taxes and farm production expenses are paid)? Include farm and non-farm income sources.

☐ Less than $25,000
☐ Between $25,001-$50,000
☐ Between $50,001-$100,000
☐ Between $100,001-$250,000
☐ Between than $250,001-$500,000
☐ Between than $500,001-$1,000,000
☐ More than $1,000,000

31. Over the last five years, what is your average net annual ***farm*** income (income after taxes and farm production expenses are paid)? Include only farm sources.

☐ Less than $25,000
☐ Between $25,001-$50,000
☐ Between $50,001-$100,000
☐ Between $100,001-$250,000
☐ Between than $250,001-$500,000
☐ Between than $500,001-$1,000,000
☐ More than $1,000,000

32. Over the last five years, what are your average yearly farm production expenses?

☐ Less than $25,000
☐ Between $25,001-$50,000
☐ Between $50,001-$100,000
☐ Between $100,001-$250,000
☐ Between than $250,001-$500,000
☐ Between than $500,001-$1,000,000
☐ More than $1,000,000

33. On average, what percentage of your household's annual income comes from the following sources?

Agricultural production (not including livestock) .... ☐ %

Livestock production .... ☐ %

Off-farm sources (e.g., other jobs, investments, retirement plans).......... ☐ %

34. With which religious faith do you most closely affiliate?

☐ Mormon/LDS
☐ Catholic
☐ Mennonite
☐ Other Christian
☐ No affiliation
☐ Other *(write in)*____________

35. What is your political ideology?

☐ Liberal ☐ Moderate ☐ Conservative

36. Would you like to tell us anything else about your experience with the 2015 settlement agreement or your ability to comply with its required irrigation restrictions?

Thank you for taking this survey!
Please return your booklet using the postage paid envelope provided.

Idaho State University

University of Idaho

BOISE STATE UNIVERSITY

APPENDIX D - EASTERN SNAKE PLAIN FARMER ADAPTATION MODEL – V.1 ODD +D

Overview

Purpose

What is the purpose of the study?

The study has two primary goals which will be addressed in consecutive phases. First, the study is intended to examine patterns of adaptation among groundwater farmers in the Eastern Snake Plain Aquifer. Due to the introduction of a new groundwater management agreement, farmers throughout the plain are required to cut an average of 13% of their groundwater use. This has led to the adoption of a variety of new practices and strategies for reducing water use. This model is intended to simulate this adoption and evaluate the success of various strategies, the overall impact on the region, and the long-term sustainability of an Eastern Snake Plain agricultural economy operating with 13% less groundwater. Adaptation and decision-making practices are simulated through the operationalization of three social decision-making theories; the model can be run using any of these three theories, thus allowing for parallel investigation of the first research question with three different theoretical drivers. This, then, lays the groundwork for the second objective and phase. The team seeks to better understand the implications of the adopted decision-making model for the results and conclusions of a modeling effort. To do this, the team will seek to investigate the first research question using all three decision-making models and, in the second phase of the study, compare these results and outcomes to each other. The implementation of three separate, theory-based decision-making mechanisms to govern farmer agent behavior within a fully functional model of an agricultural system allows the study team to investigate the original, applied research question, while also improving the collective understanding of the type of variability introduced when decision-making rules are varied.

For whom is the model designed?

The model is designed for use by researchers and practitioners interested in agriculture in the Eastern Snake Plain and decision-making theory. To this end, the interface is designed to allow for easy investigation of the agricultural and economic inputs and outcome variables, as well as to support a thorough understanding of the operationalization of social science theory.

Entities, state variables, and scales

What kinds of entities are in the model? By what attributes are these entities characterized?

Table A.1 – Table of model entities and key descriptors

Entity	Attributes by which entities are characterized
Farmers	1. Farm size 2. Farming history 3. Social connections 4. Geographic location 5. Starting equipment 6. Starting irrigation infrastructure 7. Starting bank balance
Agronomists	1. Attitudes
Crop consultants	1. Attitudes
Irrigation vendors	1. Attitudes

What are the exogenous factors/drivers of the model?

- Presence/Absence of ESPA Comprehensive Aquifer Management Plan

If applicable, how is space included in the model?

The NetLogo GIS add-in is employed to create realistic, spatially-explicit worlds for the simulation. Shapefiles of each groundwater district are used as inputs to provide the background information necessary.

What are the temporal and spatial resolutions and extents of the model?

Each simulation runs at the scale of one groundwater district, with the number of agents approximating the number of farmers in the district. Simulations runs on the order of years, with the number of years selected by the user at the onset of each simulation.

Process overview and scheduling

What entity does what, and in what order?

Farmers are the only actors with true agency. They proceed through a four-season year, which approximates their real-world schedule.

1. Planning season – traditional: Farmers determine preferred crop, plan for planting that best meets their requirements – may still be revised in adaptation planning. With each crop, farmers calculate their expected water use and analyze various water-saving measures, including more efficient irrigation, less water-intensive crops, and fallowing acres or corners. This is all considered in an overall utility function that uses the selected decision-making theory to approximate a farmer's decision-making process in light of available information.
2. Planting season: Farmers execute plan developed in planning season. Simulation determines total water use by farmers, yields (AquaCrop), and net revenue.
3. Harvest Season (Reconciliation): Farmers calculate their yield and income and adapt their attitudes based on this year's outcomes.
4. Offseason: Farmers communicate results with other farmers and with consultants in their social network. Afterwards, consultants speak with their farmer clients about the new attitudes they've developed after seeing that year's performance for a variety of farmers.

Other agents only participate in the offseason section of the model, communicating with farmers and sharing their opinions about each possible crop and irrigation method.

Design concepts

Theoretical and empirical background

Which general concepts, theories, or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?

The biophysical system in the model is driven by theory and empirical knowledge of irrigated agricultural systems. This includes the use of advanced crop modeling (AquaCrop), observed climate data, and GIS-based geographic referencing. The economic system is also developed using empirical knowledge of the agricultural system in the Eastern Snake Plain. This is primarily underlain by data such as crop budgets from the University of Idaho, extensive data sets available through USDA, and farmer interviews conducted by the modeling team.

On what assumptions is/are the agents' decision model(s) based?

Agents' decision models are based on three different social science decision-making theories. These are: Bounded Rationality, Theory of Planned Behavior, and Integrated Agent-Centered Framework. These models are explained in greater detail in Table 2. The user selects which decision model is to be used by the farmers at the beginning of each simulation run.

Why is/are certain decision model(s) chosen?

Table A.2 – Decision-making theories employed in model

Decision-making theory	Basic description	Explanation for selection
Bounded Rationality (BR)	A derivative of early Homo economicus models of human behavior, bounded rationality owes its roots to the work of Herbert Simon and his interest in the impacts of limited information on human decision-making (Simon, 1955, 1972). Simon was the first to argue that rationality was context-dependent and that even utility-maximizing decisions in a world of limited knowledge and limited cognitive capacity could be ultimately irrational and/or lead to undesirable outcomes (Klaes & Sent, 2005). Since then, bounded rationality has become a cornerstone of most models of human behavior; in even the most complex theories of decision-making, bounded rationality is often considered an underlying principle, describing both the limited decision-making space of the actor and the satisficing nature of utility calculations (Simon, 1991).	In agent-based modeling, bounded rationality has served as the default decision-making theory, presenting an easy-to-operationalize step between basic rational choice and advanced social theory (An, 2012). Bounded Rational Actor Theory serves as the "control" framework in this work.
Theory of Planned Behavior (TPB)	Theory of Planned Behavior (TPB) is a social psychological decision-making theory extensively operationalized across the social sciences. This is due in part to its simplicity, a feature that makes TPB a good candidate for operationalization in ABM, as well (Schlüter et al., 2017). First proposed by Icek Ajzen, TPB integrates internal and external factors in decision-making, identifying norms, attitudes, and perceived behavioral control as the central factors in selection of an alternative (Ajzen, 1991). Newer iterations of the theory integrate feedback loops into the system, introducing the opportunity for actors to learn from the results and consequences of their decisions; this learning is characteristic of the shifting decision-making space in adaptive capacity.	The theory was selected for this work because of its preeminent status among scholars of the human dimensions of natural resources (Floress, Akamani, Halvorsen, Kozich, & Davenport, 2015).

Table A.2 continued

Integrated Agent-Centered Framework (IAC)	The Integrative Agent-Centered (IAC) framework was proposed in 2010 as a new way of describing decision-making among farmers in the United States (Giuseppe Feola & Binder, 2010). The work integrates two widely applied theories of decision-making and social systems, Triandis' Theory of Interpersonal Behavior (1980) and Giddens' Structuration Theory (1984). IAC framework was developed to draw together the large-scale socially-constructive forces described by Giddens and the small-scale perception-constructive forces of Triandis.	The framework was selected for this work because it was created with both farmer adaptation and modeling operationalization specifically in mind, allowing for minimal reorienting in translation to model rules (Giuseppe Feola & Binder, 2010).

If the model/a submodel (e.g. the decision model) is based on empirical data, where does the data come from?

This model is supported by a variety of primary and secondary data sources. A complete listing of variables can be found in the codebook, located in the GitHub repository identified earlier in this document. Variable sources, descriptions, and notes on use can also be found in that document.

At which level of aggregation were the data available?

Most demographic data were available at the county level. Using ArcGIS, the original authors determined the approximate composition of each groundwater district in terms of the counties with each district. Using this, the demographics of the groundwater districts were approximated. For future simulations, unless there is a compelling reason to use spatial extent, county (or a collection of counties) is the most straightforward choice for agricultural modeling.

Individual Decision Making

What are the subjects and objects of decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision-making included?

Decision-making is modeled at the level of the individual farm and decision-making agents are called "farmers." Given the demographics of the region and the strong history of family farming, this means that each "farmer" agent could represent any collection of decision-makers operating a farm (e.g. one individual; siblings; father and daughter; etc.). The objects and subjects of decision-making are the assets of each farmer. These include irrigation rights, land for cropping, money in the bank, equipment and equipment characteristics, farmer experience, farmer attitudes, farmer habits, and several other key characteristics. See a more detailed explanation of each algorithm in Chapter 4 of the thesis document which this accompanies[12]. Multiple levels of decision-making are represented in the form of varied policy across the groundwater districts – in future iterations, one expected improvement is a simulation capturing all 8 active groundwater districts, which could then include iterative policy decision-making on the part of district policy-makers.

What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?

Agents pursue the maximization of a utility function which varies between the decision-making models. This utility function includes economic, social, and environmental components, and each functions is an operationalization of a well-studies decision-making theory with high anticipated relevance in this context.

How do agents make their decisions?

Farmers make a two-part decision once a year for each field they control. They compile a list of all possible land uses and a list of all possible irrigation methods, and they determine which combination of these two maximizes their utility function.

[12] Hawes, J.K., 2019. Agricultural Adaptation to Water Scarcity. Purdue University.

Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how?

Yes. Agents react to changes in their state variables and to changes in climate and other exogenous variables due to the impacts of these various variables on their utility functions. In all cases, they are boundedly rational, estimating from year-to-year the performance of their farming decisions. These estimates are based on their knowledge of the state of the world around them.

Do social norms or cultural values play a role in the decision-making process?

In TPB and IAC simulations, subjective norms are explicitly included in the decision-making algorithms (TPB: "Subjective Norms"; IAC: "Subjective Culture").

Do spatial aspects play a role in the decision process?

Spatial aspects indirectly affect the decision process by influencing agents' social networks. Geography is not explicitly included in decision-making. A future version of the model is expected to include surface water availability as part of the simulation, a feature which would require the model to account for agents' proximity to surface water when allocating water rights.

Do temporal aspects play a role in the decision process?

Agents are aware that they have a three-year period to pull their average groundwater use below the cap. They are also aware of their cropping history and intended rotation. These are indirect methods by which temporality is incorporated into decision-making rules. More directly, the agents have an internalized acceptable return on investment period, which influences their calculation of the cost of new infrastructure. They also consider profit over the course of several years, meaning that they may be willing to take an up-front loss for a longer-term gain.

To what extent and how is uncertainty included in the agents' decision rules?

Uncertainty is captured in a variety of ways, intending to replicate the balance between art and science that most farmers attempt to walk in managing their farms.

- Uncertainty in precipitation projections and irrigation effectiveness is introduced through semi-random variation of irrigation schedules. Irrigation schedules are initially generated based on near perfect knowledge of crop needs and rainfall data, but these schedules are made "fuzzy" through the semi-random variation.
- Uncertainty in crop markets is reflected in a "fuzzying" of the farmer's estimates of crop prices. They use their knowledge of trends and market state to estimate prices at harvest, but these estimates are flawed by a semi-random percentage during calculation.

Learning

Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?

Individual learning is represented through the "experience" and "farming history" records kept for each farmer. Farmer learning does NOT impact utility algorithms directly; instead, variables included in that algorithm are updated to reflect expanded expertise for each farmer. Farmers can have experience with two components of the simulation world, crops and irrigation methods. A record of each is kept, which influences their attitudes.

Is collective learning implemented in the model?

Not in its current state. Future iterations may include measures of success of the CAMP, which would then allow for collective learning about and reevaluation of the agreement.

Individual sensing

What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

Reference the codebook available on the GitHub for a complete list of variables, their sources, and the interacting agents.

What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?

Individuals can project crop market and weather trends up to one year ahead. Both of these perceptions are flawed. Agents perceive nothing of other agents directly. Instead, all sharing of information occurs through simulated communication along social networks. Individuals can also perceive any and all information about themselves and about their farm. This is not flawed.

What is the spatial scale of sensing?

Agents project crop markets and weather at the regional level.

Are the mechanisms by which agents obtain information modeled explicitly or are individuals simply assumed to know these variables?

Communication is modeled directly, as the social network is determined within the model.

Are costs for cognition and costs for information gathering included in the model?

No.

Individual prediction

Which data are used by the agent to predict future conditions?

Agents use their knowledge of their past outcomes to project future crop performance. They also use a 5-year memory of crop markets to project the prices available for goods. They rely on external projections of the weather and do not require any historical data.

What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

N/A

Might agents be erroneous in the prediction process, and how is it implemented?

Agents are wrong most of the time when projecting crop performance, crop markets, and weather. They estimate for the sake of a preliminary utility calculation, but just as in real farming, it is known that this is an estimate.

Interaction

Are interactions among agents assumed as direct or indirect?

Interactions are direct. Direct interactions take place through the built-in social network, with farmer and non-farmer agents communicating about their expertise and experiences with others close in their network. Indirect interactions have been proposed as a near-term improvement to the model. These would occur in the form of "looking over the fence" information acquisition wherein farmers learn information (somewhat flawed information) by watching those nearest them.

On what do the interactions depend?

Direct interactions depend on the social network. Indirect would depend on geographic location.

If the interactions involve communication, how are such communications represented?

Communications are represented as a simple positive or negative signal regarding a specific crop or irrigation practice. It is received and immediately applied to the recipient's attitude about that crop or practice.

If a coordination network exists, how does it affect agent behavior? Is the structure of the network imposed or emergent?

No such network exists. Agents are assumed to act independently.

Collectives

Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeler or do they emerge during the simulation?

No such aggregation exists in the district-scale simulation. In future, larger-scale simulations or in simulations that integrate multi-level decision making, agents would be aggregated into groundwater districts.

How are collectives represented?

N/A

Heterogeneity

Are the agents heterogenous? If yes, which state variables and/or processes differ between the agents?

Agents are dramatically heterogenous between breeds and more subtly heterogenous within breeds. Heterogeneity within breeds is primarily a factor of their possessions (farmers), experiences (farmers), and expertise (all).

Are the agents heterogenous in their decision-making? If yes, which decision models or decision objects differ between agents?

Breeds are heterogenous in their decision-making. Farmers are the only agents with deep and reactive decision-making. All other use simple scheduling mechanisms to share ideas.

Stochasticity

What processes (including initialization) are modeled by assuming they are random or partly random?

- Initial population of the world is semi-random around known means or otherwise informed by real-world distributions. This can be turned off and a saved world can be used to save time. When the world is populated randomly, agents are placed in a random location with a random amount of acreage pulled from a distribution of the users' choice. The mean and spread of these distributions are based on real-world data.

- Regional precipitation is random, based on real-world averages and patterns.
- Maximum yield for each crop (before farmer action) is generated randomly each year, varying normally around a known mean.
- Initial characteristics of farmers are semi-random:

    - Equipment is randomly assigned to each farmer, based on known percentages of farmers who own each equipment type.
    - Starting money can be generated randomly for each farmer. By default, it is constant, because it is hypothesized that this initial value will have important impacts on farmer success rates.
    - Water right seniority and size are randomly generated. Water right seniority is normally distributed around the year 1930, accounting for the earliest right in approximately 1880 and representing the gradual end to ground water rights issuing in the 1980s. Other possible distributions for water right seniority are gamma and uniform, both of which have been programmed but are not in use. Water right size is assigned through either gamma or normal distribution.
    - Irrigation planning strategies are distributed randomly based on a known percentage of farmers who use each strategy.
    - The presence or absence of "other jobs" as a primary means of making money is distributed somewhat randomly among farmers. Farmers with small farms are more likely to have another job, but it is possible for any farmer to have one.
- Some land characteristics are generated randomly.
    - The history of a piece of land is generated semi-randomly based on the rotation of a farmer.
    - The type of irrigation installed on a piece of land is generated randomly based on known percentages of farmers who use each type.
    - Soil quality (referenced inversely as a construct called "input intensity") at each patch is distributed randomly, although a setting can be changed on the interface to make this constant.
- A farmer's annual irrigation plan is modified randomly to reflect their imperfect knowledge. The standard deviation of this modification is based on the accuracy of their monitoring strategy.
- The social network is randomly generated based on the classic Erdős-Rényi random network.

Observation

What data are collected from the ABM for testing, understanding, and analyzing it, and how and when are they collected?

Data are catalogued at the end of every season. At the end of the simulation, two main outputs are produced, a record of what crops were planted and a record of how many individuals adopted new irrigation practices (adaptation).

What key results, outputs, or characteristics of the model are emerging from the individuals? (Emergence)

The model does not seek to accurately predict individual behavior. Rather, it is targeted at accurately reproducing large-scale trends in cropscape and adaptation. Therefore, the primary products of interest are emergent phenomena.

<u>Details</u>

Implementation details

How has the model been implemented?

The model is primarily implemented in the open-source agent-based modeling platform NetLogo. It can be accessed through NetLogo directly or through the open-source statistical package R. R must be used to run extensive experimentation when the user wants to import previously generated worlds. Not enough precise control of variables exists in the NetLogo BehaviorSpace environment to work with imported worlds.

Is the model accessible, and if so, where?

The model, its components, and the associated data are all accessible in the public GitHub repository for the project.

Initialization

What is the initial state of the model world, i.e. at time t = 0 of a simulation run?

At time t = 0, all agents have been initialized, the groundwater district has been drawn and defined, and the social network has been established. Farmers have been generated with property, experiences, equipment, initial budget, and psychological characteristics. Other agents have been initialized with their attitudes about different crops and irrigation practices. All agents are mapped into the social network in the district.

Is initialization always the same, or is it allowed to vary among simulations?

Initialization can vary or can be held constant. Many of the parameters are semi-random, based on known distributions or population means in the district of interest. However, the random seed can be fixed to produce the same district twice, and the districts can be saved and imported for future use. This importing feature is the primary mechanism for experimentation, since random world generation is time-consuming.

Are the initial values chosen arbitrarily or based on data?

Nearly every value is based on data. A few exceptions exist, which are detailed in the codebook available in the GitHub.

Input data

Does the model use input data from external sources such as data files or other models to represent process that change over time?

No. The model uses input data from the AquaCrop crop modelling software, but this is not changed over time. Two such model couplings have been proposed, however. The first would couple the model with a hydrologic model of the Eastern Snake Plain Aquifer. The second would use a climate model to more accurately generate weather patterns over the course of the simulation.

Submodels?

What, in detail, are the submodels that represent the processes listed in “Process overview and scheduling”?

What are the model parameters, their dimensions, and reference values?
How were submodels designed or chosen, and how were they parameterized and then tested?

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