AN INTELLECTUAL FRAMEWORK FOR ASSESSING AGRICULTURAL CLIMATE ADAPTATION COMBINING STAKEHOLDER ENGAGEMENT AND PROCESS BASED MODELING: LOWER BOISE RIVER BASIN, IDAHO

by

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The following individuals read and discussed the thesis submitted by student Andrea Leonard, and they evaluated her presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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DEDICATION

This thesis is dedicated to my niece and nephew, Ember and Maison, whose future I will continue to defend through science, environmental stewardship, and love. I hope you both develop passions that make the world a better place.

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ABSTRACT

The impacts of climate change have significant implications for agricultural yields and water use. Previous studies have focused on impacts of climatic factors on crop phenology and yields, with little consideration of local farm management strategies that might mitigate some of these negative effects. Further, the inclusion of stakeholders is commonly left out of many biophysical studies of agricultural landscapes. Therefore, there is considerable uncertainty in the future of regional agroecosystems. In this study, we adopt a social-ecological systems perspective to develop an intellectual framework for assessing agricultural climate adaptation. With research questions focused in both biophysical and social science, we utilize a process-based crop simulation model and stakeholder meetings to examine agricultural response to climate change and adaptations that mitigate for climate change effects. This study advances our understanding of future climate effects on local agriculture, and provides a framework to include local variables into process-based modelling methods.

A regional assessment of baseline (1980–2015) and future (2015–2099) yields and water use for four irrigated crops in the Lower Boise River Basin (LBRB) of southwestern Idaho was conducted using a stakeholder informed model. Six different future climate scenarios, ranging in precipitation and temperature, were applied to our model to understand the potential degree to which climate change might affect yields, hydrologic fluxes, and planting date. Analysis of crop yields in most climate scenarios show a slight to moderate decrease in wheat and corn yields by 2100, while alfalfa and sugarbeets stay the same or moderately increase in more mild scenarios. Next, we identify potential concerns with the current irrigation season, which starts on April 1. Under all climate scenarios, our model predicts the growing season to start earlier in the year based on ET estimates and planting dates. This has major implications for future water policy, as the current irrigation season may need to be redefined to allow for early season irrigation in the coming decades. Our results, along with continued communication and iterative stakeholder engagement in the LBRB, can lead to adaptive solutions and policy changes in the agricultural sector. This research highlights the usefulness of combining local information with biophysical models that aim to understand agricultural systems, and can therefore be adjusted to other regions.

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LIST OF ABBREVIATIONS

DOA:	Day of Allocation
EPIC:	Environmental Policy Integrated Climate
ET:	Evapotranspiration
GCM:	General Circulation Models
IPCC:	Intergovernmental Panel on Climate Change
LBRB:	Lower Boise River Basin
MACA:	Multivariate Adaptive Constructive Analogs
NASS:	National Agricultural Statistics Service
NRCS:	Natural Resources Conservation Service
PHU:	Potential Heat Units
PNW:	Pacific Northwest
RCP:	Representative Concentration Pathway
SES:	Social-ecological Systems
TV:	Treasure Valley
UBRB:	Upper Boise River Basin

1 INTRODUCTION

Earth’s population of 7.5 billion people is supported by agricultural systems that are a product of local climate conditions, soil properties, and the practices of growers. From industrial large-scale agriculture to small local farms, the global population depends on agriculture for food. Research suggests that unless consumption and distribution patterns improve, agricultural production must roughly double by 2050 to keep up with economic development and per capita demand (Tilman, et al, 2011; FAO, 2009; Pelletier and Tyedmers, 2010). An additional variable to consider when thinking about the future of agriculture is climate change. Climate change is expected to have both positive and negative effects on global agriculture, depending on region, crop type, and management (Tubiello and Fischer, 2007). The joint occurrence of climate change and population growth is forcing farmers to plan and execute adaption strategies when it comes to planting choices and schedules to changing climatic variables. At the same time, agriculture is under other pressures including local politics, economics, product demand, and water shortages (Smith et al., 2007).

In this thesis, we estimate the effects of climate change on agricultural production and water use in the semi-arid Lower Boise River Basin (LBRB), also known as the Treasure Valley, of southwest Idaho. We model yield and hydrologic fluxes within the LBRB using a regionally calibrated, process-based crop simulation model. Further, we use focus groups and informal interviews with farmers to explicitly construct the modeling scenarios. Stakeholder engagement provides us with local knowledge about the water and agricultural system in the LBRB that is critically important in developing plausible management scenarios to inform the modeling exercise and ultimately lead to further adaptation strategies. What is lacking, and the overarching goal of this thesis, is a methodology for modeling and analyzing complex social-agroecological systems.

In support of achieving this overarching goal are three specific research objectives: (1) to gain knowledge of the local agricultural and water systems that inform the simulations through stakeholder engagement, (2) to design and carry out a series of numerical experiments to understand the effects of climate on crop yields and hydrologic fluxes in the LBRB using a process-based crop simulation model, and (3) to use results from both the model and stakeholder meetings to hypothesize potential agricultural adaptations that could mitigate for climate change effects.

Background

The 20th century resulted in significant increases of agricultural production in the United States. Agricultural yields (per unit area) steadily increased at a 2% annual rate in the United States from 1948-1994. Increases in yield have been brought on by adaptation of farming practices, advancing technology, better understanding of crops' nutrient requirements, and irrigation advances (Onofri and Fulginiti, 2008; Tilman et al., 2011). This increase in crop outputs paralleled global population growth occurring during that time, as the population tripled during the 20th century. However, current yields have begun to stabilize while population is still increasing. Our previous reliance on agricultural advancements to increase yield, such as fertilizer, efficient irrigation, and modified seeds, is not being matched by advancements in the present day (Ramankutty, Foley, and Olejniczak, 2002). As agricultural technology expanded during the 20th century, crop yields increased exponentially. Our current agricultural system requires new innovative adaptation measures to sustain production with an increasing population. At the same time, modern agricultural practices critically depend on a wide variety of ecological processes to succeed and harvest abundant yields (e.g., pollination services, nutrient cycling in the soil, etc.).

Climate Effects on Agriculture

With the global population expected to reach 9 billion by mid-century, the agricultural sector faces significant challenges in the coming decades related to food security (Foley et al., 2011; Von Braun, 2007). Research suggests that unless consumption and distribution patterns improve, agricultural production must roughly double to keep up with economic development and per capita demand (Tubiello and Fischer, 2007; FAO, 2009; Pelletier and Tyedmers, 2010). These challenges are amplified by the repercussions of climate change, which will affect agricultural lands on a global scale. Not only will agriculture be burdened with increased production demand, but will also be forced to adjust to a changing climate (Risbey et al., 1999; Howden et al., 2007; McLaughlin and Kinzelbach, 2015).

Changes in carbon dioxide concentration, temperature, and precipitation have varied impacts on agriculture depending on region, crop type, and management, while climate-related stresses such as pests, weeds, and drought are known to cause reductions in crop production (Adams et al., 1999; Siikamäki, 2008). Each crop species has physiological limits that are often conceived of as a set of temperature thresholds that define growth and reproduction, along with optimum temperatures for each developmental phase.

Lobell et al. (2008) demonstrate how increasing temperatures and varying precipitation in semiarid environments are likely to reduce corn, wheat, and rice yields over the next two decades, as well as many other important crops. Semiarid regions (including regions like southwestern Idaho) are characterized by relatively low annual precipitation volumes arriving via episodic events in time, but contribute a major proportion of the world's supply of grains (Lobell et al, 2008). Furthermore, the United States is currently the world's largest agricultural producer and exporter of agricultural commodities, suggesting global food security and prices are likely to be affected by climate change (Schlenker and Roberts, 2009). However, there are numerous studies that predict an increase in yields of certain crops in certain regions; impacts on crop yields of corn, wheat, and soybean cropping systems in the central U.S predicted increases in yield in response to increased CO2 (Stockle, 1992). These contradicting studies exemplify the need for regional models that include local climate and management practices.

Although global crop models are valuable for estimating the sensitivity of global crop production to climate change, the spatiotemporal patterns of agricultural productivity depend on local conditions like the nature of irrigation practices, climate, pest management, fertilizer use, politics, and market. A large body of literature has demonstrated that local agricultural practices depend on a variety of social, economic, and political factors that are difficult or impossible to capture at the global scale. Regional studies that integrate local knowledge of agricultural management, water use, and politics, therefore, fill an important gap in global understanding of these effects. In addition, regionally focused studies can advance regional agricultural resilience in the coming decades through robust interaction with agricultural communities.

Irrigation

Irrigation is the primary user of freshwater in semi-arid and arid regions, exceeding 70-80% of total diverted freshwater (Ferreres and Soriano, 2007). Timing, magnitude, and phase of precipitation will be altered as the climate continues to change. (Mote et al., 2005, Knowles et al., 2006). Changes in hydrologic fluxes will vary spatial and temporal patterns of supply and demand of water for agriculture, the largest user of freshwater globally (Turral et al., 2011). For agricultural lands relying on surface water irrigation, the most important changes may be those associated with precipitation phase. In the mountainous western United States, snowpack has steadily declined in the last century due to increased temperatures (Folland et al 2001). As more precipitation falls as rain instead of snow, our ability to use snowpack as a reservoir for late season use diminishes. In mountainous regions that manage snowmelt for irrigation, this results in uncertainty for downstream users, including farmers that rely on irrigation water for agricultural success. For agricultural regions that rely on groundwater for irrigation, the impacts of climate change on the spatiotemporal patterns, rates, and timing of recharge are critically important.

The agricultural sector has immensely benefited from irrigation technologies for thousands of years. Irrigation serves as a buffer to inadequate rainfall during the growing season, reduces uncertainty in water supply, and significantly increases harvested yields (Fischer et al., 2007). When water is no longer a limiting factor for crop growth and production, agriculture is viable in dry regions. Irrigation systems range in efficiencies, which can have implications for runoff, percolation, and evaporation. Flood irrigation is the most common system globally, an ancient system of allowing gravity to water an inclined field via ditches or pipes. Although this method is cheap, low-tech, and common, plants only are able to consume roughly half the water used to irrigate, which results in less water use efficiency (USGS, 2008). On the other hand, sprinkler irrigation systems are overall more efficient, but result in more evaporation of water into the air, rather than flood irrigation's losses in runoff and percolation. Drip irrigation is the most efficient type of irrigation, but cannot be used on all types of crops; this type of irrigation delivers water straight to the root zone to keep plants optimally watered. Irrigation efficiencies can be found in Table 1.

APPLICATION EFFICIENCY	
Surface Irrigation (flood, furrow)	60-80%
Sprinkler/pivot Irrigation	75-90%
Drip Irrigation	90-95%

Table 1 Irrigation efficiencies for each irrigation system (Brouwer et al, 1989).

Defining Stakeholder Engagement

Coupled human-natural systems are inherently complex. Not only do our environments depend on biophysical processes, but also on economic, socio-cultural, and political networks as well. This is especially true in the agricultural sector, where global markets drive decision making and local socio-political institutions are involved in water policy that affects farms. However, what is lacking in many current biophysical studies is the inclusion of stakeholders in the research process. Including stakeholders in scientific studies is fundamental to socially relevant research, better decision making, and project support (Maak, 2007; Caves et al., 2013).

In a natural resource context, stakeholder engagement is defined by stakeholder participation in one or more steps of the research process, aiming to integrate their knowledge and values to answer more specific research questions (Talley et al., 2016). Successful stakeholder engagement requires a precise methodology, such as that proposed by Talley et al. (2016). In their study, they defined "stakeholders" as people who are affected by or can affect a decision (following Freeman 1983), and can vary from an "average" citizen to highly invested groups and decision-makers. The authors of that work propose a Five Feature Framework when working with these stakeholders, which aims to retain theoretically robust stakeholder engagement while providing a metric with which to measure the outcomes. The Five Feature Framework includes:

1. Set clear objectives
2. Systematically represent stakeholders
3. Use relevant methodologies
4. Create opportunities for co-ownership
5. Reflect on processes and outcomes

Using this Five Feature Framework, along with continued communication and iterative stakeholder engagement in a specific region, can lead to adaptive solutions and policy changes in the agricultural sector. This research highlights the usefulness of combining local information with biophysical models that aim to understand agricultural systems, and can therefore be adjusted to other regions.

Study Area

Agricultural Land in the LBRB

The LBRB is an agriculturally intensive area located in the Snake River Plain of southwestern Idaho (Figure 1.1). The LBRB is the most populated metropolitan region in Idaho, containing the state’s three largest cities - Boise, Nampa, and Meridian. Ada and Canyon counties make up most of the LBRB, and it encompasses a total area of 3298 km2. In the 2012 Census of Agriculture, there were 1,233 farms in Ada County (a 7% decrease from 2007), farming 144,049 acres (a 25% decrease from 2007); in Canyon County, there are 2331 farms (a 2% decrease from 2007), farming 303,836 acres (a 17% increase from 2007) (NASS, 2012). The elevation in the agricultural area ranges from 680m near Parma, ID to around 820m in the more upstream agricultural lands near Kuna, ID.

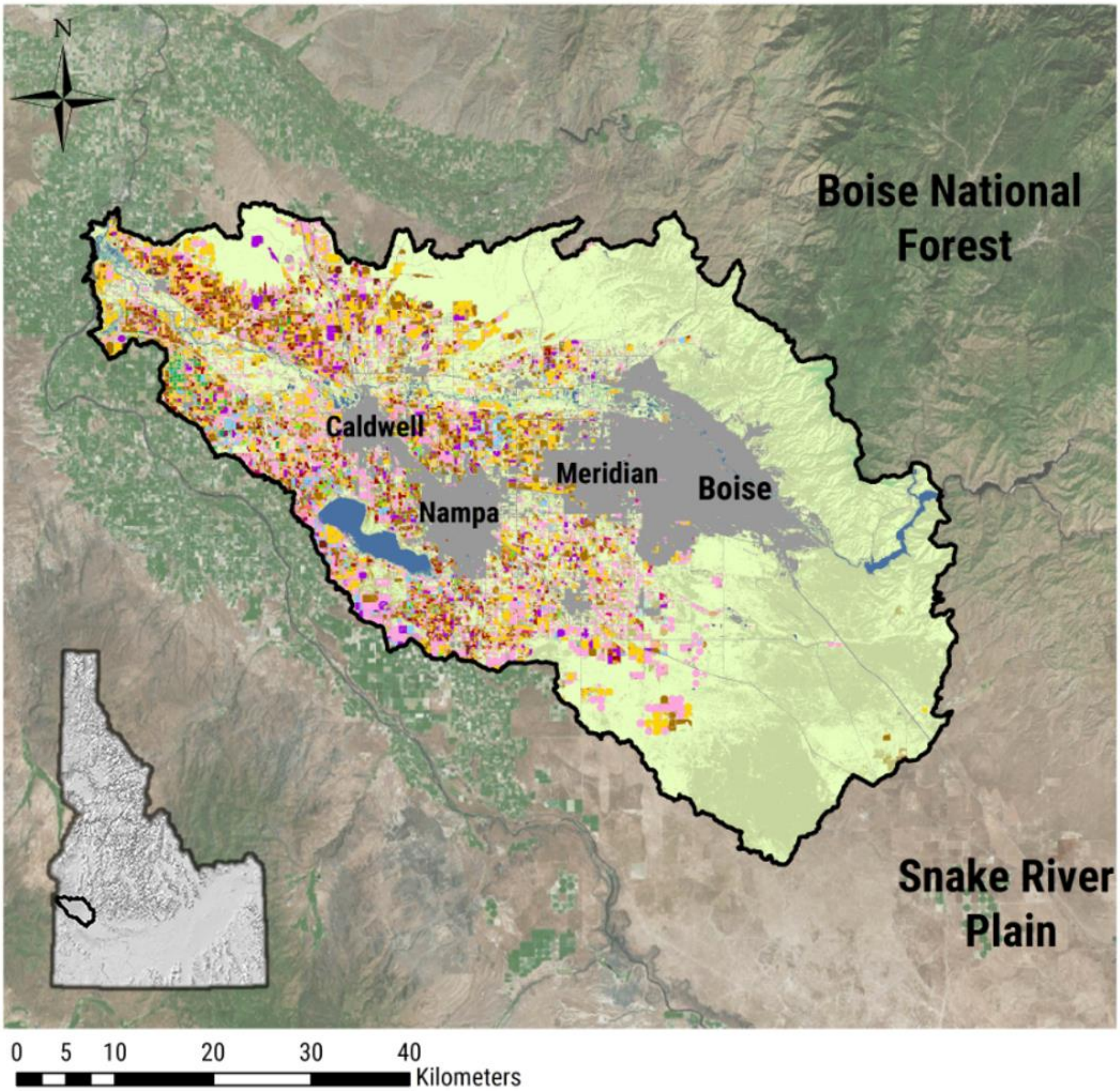


Figure 1.1 Map of the Treasure Valley (TV) in southwestern Idaho. The TV is delineated by the Lower Boise River Basin watershed. Colored polygons represent agricultural land, while gray represents urban areas.

The LBRB in Idaho has been agriculturally driven since the mid-1800s. Idaho's agricultural sector is vital to the economy, producing over 185 different commodities. In 2015, 21% of Idaho's total economic output in sales and 16% in GDP was attributed to agriculture and food processing (ISDA, 2015). In 2014, Idaho was the nation's largest producer of potatoes, barley, and peas, the second largest producer of sugarbeets and peppermint, and the third largest producer of hops, cheese, and alfalfa hay (NASS, 2014). Other crops produced in the state include onions, corn, and wheat. The LBRB's top crops can be seen in Figure 1.2. Fluctuations between years is caused by varying water availability, market trends, and acreage of total fallow land.

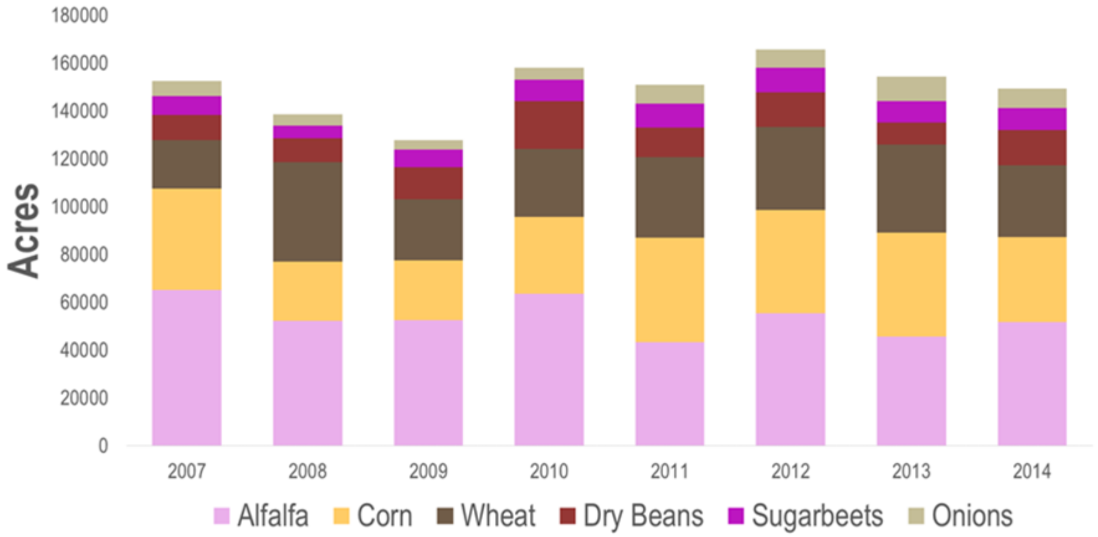


Figure 1.2 Top crops grown in the LBRB, by acreage. Fluctuations between years are due to water availability, market, and increased fallow lands.

According to the National Agricultural Statistics Service (NASS) Cropland Data Layer, irrigated agriculture accounted for 19-23% of acreage in the entire valley from 2008-2015. This suggests around 21% of land, on average, is being irrigated each growing season. Since the 1970s, however, this rural agricultural land has quickly been displaced by urban land (e.g. commercial, residential, and industrial; Alig et al., 2000). In 1990, the combined population of Ada and Canyon counties was 385,927, and has grown to an estimated 655,726 as of 2016 (US Census Bureau). The area is expected to exceed one million inhabitants by 2040 (COMPASS, 2014). Thus, the LBRB region is being subjected to significant land use conversion, resulting in changes to biophysical and social systems, and interactions between the two. Urbanization in the LBRB, and globally, creates economic and personal pressures for rural farmers and ranchers. As their land is being encroached upon, they are forced to choose between maintaining their land and keeping it in agricultural production, selling it to developers, renting the property, among other options. Urban areas are expected to account for 70 percent of world population in 2050, while rural populations continue to decline (FAO, 2009).

Climate Trends and Predictions

According to Koppen-Geiger climate zones, the LBRB exhibits a BSk climate, or a “cold semi-arid environment”, marked by hot dry summers and moderate winters. Total annual rainfall averages around 300mm with a summer precipitation average of about 100mm. This amount of natural precipitation is not sufficient to sustain high yielding crops, therefore irrigation is necessary to allow for agricultural production (Figure 1.3). Idaho ranks second only to California in acreage of irrigated agriculture. The EPA’s analysis of average rainfall depth in the Boise area, based on 48 years of 24-hour precipitation data obtained from NOAA and collected at the Boise Airport, demonstrates that approximately 95% of all storms in the Boise area result in a rainfall volume of 15mm or less; 90% of all storms result in a rainfall volume of 12mm or less.

The watershed upstream of the Boise River Basin is composed of the LBRB and the Upper Boise River Basin (UBRB). The UBRB encompasses an area of 6935 km2 with elevation ranging from 930 to 3000+ meters. It is bound by the Sawtooth range to the east, the Payette River Basin to the north, the Snake River Plain to the southwest, and the LBRB to the southeast. The majority of winter precipitation in the mountainous UBRB falls as snow. However, temperatures have increased in the western United States during the past century (Folland et al., 2001), which has resulted in a declining snowpack within the snow-dominated mountainous regions. From 1955-2016, April snowpack declined 23 percent in the western United States on average, which has major hydrologic, ecologic, and societal impacts (Mote et al., 2016). Climate change studies project warmer, wetter winters in the Pacific Northwest (PNW) region that will result in a greater proportion of precipitation falling as rain instead of snow in fringe winter months (October/November, March/April). This shift toward more rain, less snowpack, and warmer temperatures affects hydrologic regimes in mountainous terrain. In semi-arid regions such as the LBRB, small changes in climate variability and precipitation can have major impacts on water supply (Barnett et al., 2005).

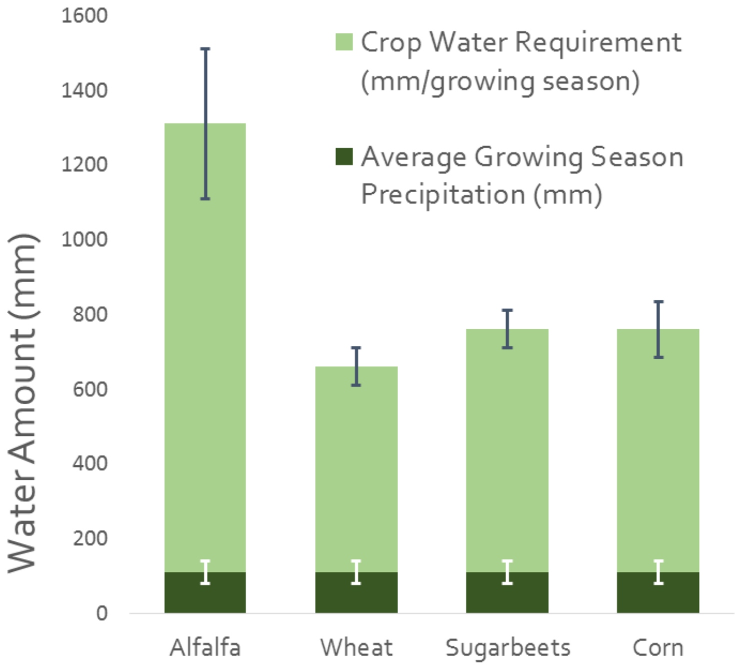


Figure 1.3 Irrigation requirements of four modelled crops. Error bars show the range of applied water needed for optimal growth, depending on local variables.

Furthermore, a warmer climate effects the timing of snowmelt, resulting in peak discharge of snow-dominated regions occurring earlier in the year. (Stewart et al. 2005, Yamanaka et al. 2012). Along with this shift in runoff toward early season, solar radiation, evapotranspiration (ET), and potential heat units (PHUs) are shifting as well, causing an earlier growing season for producers (Su-jong Jeong et al, 2011; Bindi and Olesen, 2011). PHU, or growing degree days, are a weather-based indicator that assesses crop development. Farmers use this calculation that is a measure of heat accumulation used to determine when to plant and predict plant development rates. Planting dates for all four modelled crops can be found in Table 2. Development will only occur if the temperature exceeds some minimum development threshold, or base temperature. The base temperatures are determined experimentally and are different for each crop. More information about PHUs can be found in Chapter 3.

Table 2 Planting dates for four modelled crops, specific to Idaho (FAO, 2009)

Crop	Usual Planting Dates			Usual Harvest Dates		
	Begin	Most Active	End	Begin	Most Active	End
Alfalfa	varies	varies	varies	May 22	varies	Oct 20
Spring Wheat	Mar 21	Apr 7 – May 3	May 26	Jul 23	Aug 4 – Aug 25	Sep 14
Corn	Apr 21	May 5 – May 26	Jun 9	Aug 4	Aug 13 – Sep 8	varies
Sugarbeets	Mar 24	Apr 3 – Apr 21	May 5	Sep 15	Oct 8 – Oct 30	Nov 10

Hydrology and Water Use in the Agricultural System

The UBRB's snowpack serves a vital role in water security, storing water and releasing it in the spring and summer months. A series of reservoirs (Anderson Ranch, Arrowrock, and Lucky Peak) capture melted runoff and are managed for flood control and downstream uses such as irrigated agriculture, recreation, municipal supplies, environmental flows, and hydropower. Of these, irrigation is the primary user of freshwater in the LBRB and other semi-arid and arid regions, accounting for 70-80% of total diverted freshwater (Ferreres and Soriano, 2007). Idaho is second only to California in volume of water use for irrigation (Maupin et al., 2014).

The irrigation delivery system in the LBRB is complex and integrated. A large system of social, political, economic, and physical infrastructure to capture and store runoff from the UBRB has been developed to support agricultural productivity in the study area. Dams, reservoirs, canals and distributaries route water from the Lucky Peak outlet to each irrigation point of use. Non-physical infrastructure includes a complex legal and administrative framework for supplying irrigation water to users. Federal agencies maintaining some responsibility for maintaining, monitoring, and allocating water include the US Forest Service, Bureau of Reclamation, Army Corps of Engineers, Geological Survey, Fish and Wildlife Service, and the Idaho Department of Water Resources. Local organizations involved in allocation and delivery include irrigation districts of varying size, age, composition, and operating models; canal companies responsible for conveyances; and end-users themselves (e.g., irrigators/farmers).

On or around April 1, stored water is released from Lucky Peak Dam to start the irrigation season. Surface and ground water ownership in the western United States, including the LBRB, is guided by the Prior Appropriation Doctrine; water is allocated based on fundamental principles of beneficial use and first in time is first in right (Harrington, 2012); priority is given based on the date the water was first put to beneficial use. Idaho uses this method as described in Idaho code section §42-602.

Idaho uses a day of allocation (DOA) to manage water shortages. The DOA is defined by the date when three requirements are met (IDWR memo, 2014):

1. the last day of reservoir accrual to reservoir rights has occurred in the water rights accounting
2. diversion demand is equal to or greater than the available natural flow
3. the maximum physical total reservoir system contents has occurred

Holders with more junior priority rights may have their rights curtailed, or reduced, in years of short water supply to ensure that senior right holders receive their full water allotment. Therefore, junior water right holders are the first to feel the pressures of water shortages. When the Boise River's flow decreases to the point that all right holders cannot be delivered their full allotments, diversions are reduced, in priority order, to 75% of the decreed allotment. When the flow becomes insufficient to deliver 75% to all, the process is repeated, this time reducing diversions to 60% of the each right-holder's allotment. After all diversions are reduced to the 60% level, any further shortages take diversions to zero, again in priority order (Fereday, Creamer, max use doctrine). Steimke et al. (2016, in review) conducted an analysis of future discharge from the UBRB, and found the future DOA to come earlier in the season, by as much as 36 days early in extreme climate projections.

Irrigators in the LBRB use mostly flood and sprinkler irrigation systems (Figure 1.4). Compared with sprinkler and drip irrigation systems, flood irrigation methods result in significantly more percolation from the root zone into shallow aquifers. In the LBRB, water levels in the shallow subsurface have increased as much as 30 m over the past century due to the expansion of flood irrigated agriculture in the area (Petrich, 2004). Over the past two decades, however, sprinkler irrigation is more prevalent in the LBRB (Figure 1.5).

Figure 1.4 Sprinkler irrigation (top) and Flood irrigation (bottom) systems used in the LBRB.

Figure 1.5 Landsat 5 TM 8-Day NDVI Composite of agricultural area in the LBRB. Flood irrigation (rectangle-dominated in 2000) decreases significantly over the ten years as more farmers switch to sprinkler irrigation in 2010 (pivot irrigated circles).

2. SOCIO-ECOLOGIC SYSTEMS

In this chapter, we investigate the social system involved in agriculture and present some key factors that contribute to decision making on a farm. By coupling the biophysical and social systems, we are able to understand the local variables that affect agriculture. A schematic of example drivers and feedbacks involved in the agricultural social-ecological system can be found in Figure 2.1.

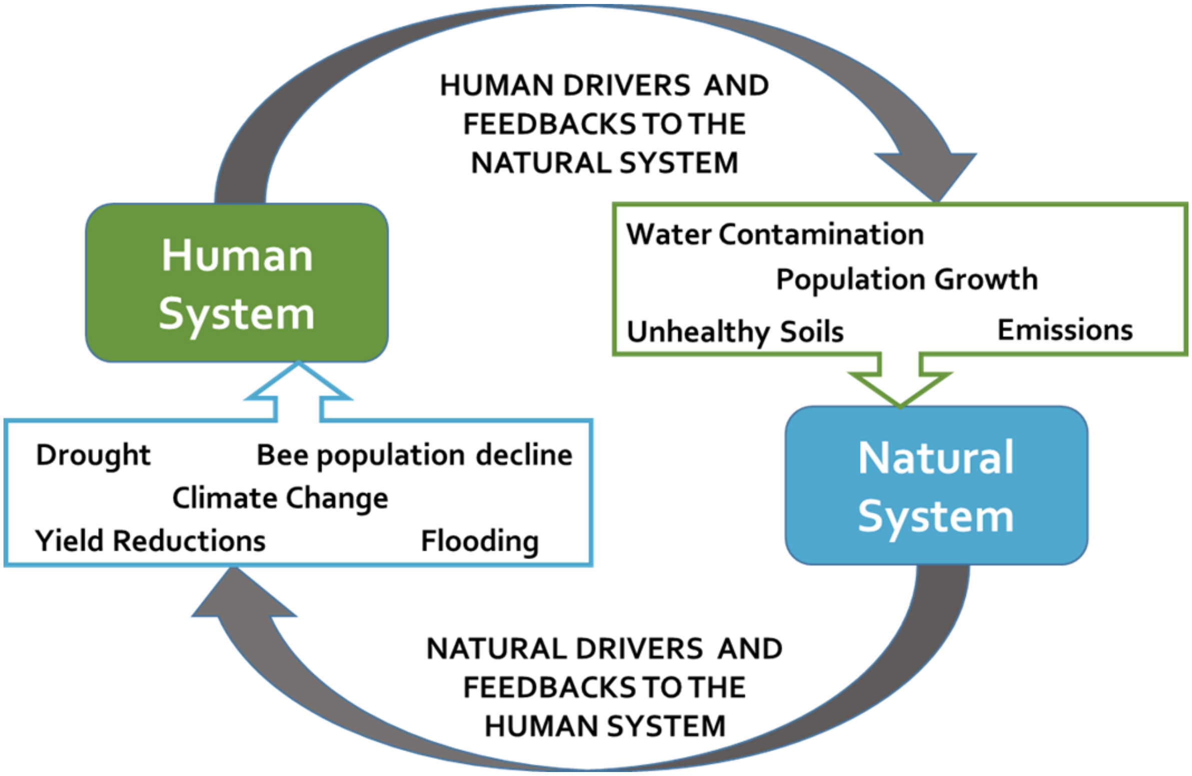


Figure 2.1 Diagram that shows the coupling of human and Natural systems; natural system dynamics are governed by biological and/or physical processes, while human systems are those whose dynamics are governed by human actions (Adapted from NSF, 2014).

Natural ecosystem changes have been taking place for the entire history of our planet, yet the magnitude and rate of such changes has significantly increased in the recent past. This rapid shift can be attributed to human activities, which influence the state of our planet enormously through land use change and have had dramatic impacts on the structure and processes of our ecosystems (Karali, et al., 2011; Murray-Rust et al., 2011). The transition from natural vegetation cover to an agriculturally intensive area is one type of land use change, tied to complex interactions between biophysical and social systems. Agriculture is the major land use across the globe, accounting for 1.2-1.5 billion hectares of croplands and another 3.5 billion hectares being grazed (Howden et al., 2007). While growing crops depends on many biophysical processes, agriculture is also a social and engineering practice, involving groups of farmers, agricultural organizations, and laborers, while also feeding local and global populations.

Complex feedbacks that connect humans to the environment, such as agriculture, are considered social-ecological systems (SES). SES research allows for the integration of data from natural and social science disciplines, which provides robust means of testing hypotheses involving both (Ostrom, 2007). Leslie et al (2015) concluded that by using an SES framework, we can move toward more effective environmental governance and sustainable resource management. It is not sufficient to consider biophysical or social systems in isolation, but necessary to treat socio-ecological systems as dynamic, complex interactions that co-evolve in response to linked processes within both human and biophysical systems (Murray-Rust et al., 2011). By coupling human-environment systems, we are able to understand how sociocultural systems affect their biophysical environment and how evolving ecological systems are in turn causing sociocultural changes; therefore, an opportunity to implement research into policy making arises (Gual and Norgaard, 2008).

Agriculture is a major economic, social, and cultural activity in the United States and globally (Nesheim et al., 2015). Population growth and climate change intensify competition for water resources, resulting in increasing pressure for efficiency in water use for food production (Hsiao et al., 2007). Limited water availability, rising temperatures, and increased droughts are all challenges that the agricultural sector already faces (Mancosu et al, 2015). As these trends continue and become more extreme, we can examine management alternatives that increase water use efficiency, decrease harmful emissions, and preserve the land.

As farmers recognize how they might be affected by a changing climate, they can plan and implement measures to mitigate the deleterious impacts of climate while potentially keeping their operations both profitable and sustainable. Understanding the values, norms, customs, perceptions, and beliefs that influence decision-making is necessary to understand how practices aimed at climate change mitigation will ultimately impact agricultural productivity and associated water use.

Factors that Influence Adoption of Mitigation Activities

Agricultural practices have numerous effects on redistribution of the water supply, nutrient cycling, sediment runoff, and land use, among others. To advance fundamental understanding of how coupled human-agrosystems respond to climate change and agricultural practices aimed at mitigating against its impacts, the appropriate modeling tools and frameworks need to be developed (Matthews, et al., 2007). This requires understanding of what influences farmers’ decisions, how they make their decisions, and the impact of those decisions on the aggregate level. It is therefore important to capture who exactly is making the switch from industrial agriculture to more sustainable alternatives. In this section, we aim to obtain a greater understanding of the various factors that shape a choice to participate in sustainable agricultural practices. Understanding these indicators can lead to the discussion of which potential farmers would be most likely to switch to sustainable practices if given the proper guidance and education, given likely economic and market trends.

Studies that have been conducted that aim to understand the determinants of environmental stewardship in the agricultural sector are comprised of literature reviews, agent-based modeling , framework construction, multivariate statistical models, surveys, interviews, etc. Some of the variables that have emerged as important in these studies include education level, capital, income, farm size, access to information, environmental attitudes, environmental awareness, and utilization of social networks such as farm cooperatives and organizations (Prokopy et al 2008). Burton (2014) conducted a literature review to observe how demographic characteristics such as age, farming experience, and gender affected environmental behavior, and the causal links between those traits, which we will explore in this chapter.

Understanding the demographics and underlying characteristics of farm families, households, and owners that adopt sustainable practices is necessary to decipher who makes those voluntary choices. Also, it is crucial to design conservation policies and programs that maximize the environmental benefits of those decisions (Lambert et al., 2007). Conservation practice adoption is generally voluntary, which suggests the land owner has to go through a decision-making process (Prokopy et al., 2008). Typically, it is assumed that the farmers adopt conservation practices and environmental management options only if that explicit farming practice is of direct or indirect benefit to them. For example, a farmer is more likely to adopt a best management practice if it increases his/her profits (Lambert et al., 2007). However, many other studies suggest additional motives behind conservation management adoption. Baumgart-Getz et al. (2012) conducted an extensive literature meta-analysis that aimed to understand why farmers adopt sustainable practices in the United States. They used a statistical technique to summarize the adoption literature exclusive to the United States by categorizing the independent variables being accounted for in the studies they incorporated in their research. Categories included capacity, attitude, and environmental awareness:

1. **Capacity:** Farm size, Age, Capital, Education (extensional and formal), Farming experience, Income, Access to information, Institutional, Networking (agency, business, local, university), and Tenure
2. **Attitude:** Environmental attitude, Profitability of practice, Heritage, Quality of environment, Regulation, Risk, Scientific appreciation, and Adoption payments
3. **Environmental Awareness**: Awareness, Cause, Consequences, Knowledge, and Program

Factors mentioned above are included in agricultural policy decisions and agricultural models because they influence the decisions farmers make, and therefore give an indication of how a group of farmers in a particular region or demographic might act in a particular situation (Burton, 2014). Below, we highlight some of the factors that may help inform research questions in the LBRB.

Environmental Attitudes

Ajzen (1988) defined an attitude as a negative or positive belief or evaluation that a person has towards an object and can be a reasonable predictor of actions and behavior. His Theory of Planned Behavior is a theory explaining the relationship between attitudes and action, and is one of the main reasons farmer attitudes have been studied when looking at implementation of best management practices in the agricultural realm. After all, farmers are the individuals who are applying the techniques on their land and those techniques presumably are an observable manifestation of those attitudes. Individual attitudes toward the environment and environmental awareness are known to positively affect adoption of environmental schemes and more sustainable practices affect agricultural land (Baumgart-Getz et al., 2012). In other words, the more an individual land owner values the environment, soil health, water quality, etc., the more likely he/she is to adopt a sustainable management strategy on his/her farm.

Experience

Another common attribute of farmers that affects their decisions is past experience with agriculture and adoption of new environmental strategies. According to Burton (2014), a farmer is more likely to use a management plan that he/she has previously used and has experience with; also, a higher experience level with a specific behavior is related to an increase in knowledge and skill pertaining to that behavior. If a farmer becomes skilled at one type of farming, the likelihood of him/her switching to another type of farming or scheme dramatically decreases. Also, positive past experience with best management practices and environmental schemes lead to a positive attitude toward that type of farming, and make it more likely for a farmer to adopt a similar alternative management option. Lastly, past experiences have a tendency to provide cultural and structural concreteness into the inherently risky profession of farming, or reinforce decision making.

A long history of farming decisions does not mean, however, one cannot begin to implement new techniques on a farm. On-farm experimentation is a way farmers often take up new management strategies. Instead of risking an entire year's crop on a new management technique, farmers will develop a test plot where they implement a new scheme and determine if it would be beneficial to their entire farm. Salamon et al. (1997) found that most sustainable farmers in her study area had test plots on their land, and were more likely to adopt a new strategy if they had tested it and had experience with the outcome.

Education (Extention vs. Formal)

Burton (2014) explained education's ability to change a farmer's perspective on farming by understanding more complex topics and scientific evidence. However, he split education into two categories, formal and extension. Formal education would be considered to be a college degree, while extension education comes from farm organizations and farming experience. He found that formal education increases the likelihood of environmental behaviors, while agricultural/extension education increases the likelihood of conventional farming behaviors.

Age

Age refers to a farmer's social/temporal setting in which he/she was brought up in. Therefore, the preferences of that particular generation are more likely to be a characteristic of that farmer. Baumgart-Getz et al. (2012) conducted a literature meta-analysis and found that age has a significant and negative impact on the adoption of conservation management, or that younger farmers are more likely to adopt. Prokopy et al. (2008) also concluded a strong negative correlation between age and likelihood of adopting conservative practices. However, many studies claim that age is not a reliable indication of adoption, and that other factors have more weight of indicating adoption.

Land Ownership

Salamon et al. (1997) found that a farmer who had rented his/her land was less likely to adopt conservation management because of the way it looks to the landlords. Conservation management often comes with more weeds due to the decreased use of weed killer, and uneven rows of crops due to no till practices. This deters farmers from adopting these practices. There may also be social pressure experienced from close proximity to neighbors and friends, who would see that as a weakness in the farm style.

3. METHODS

Climate change and food security research has commonly aimed to measure the impacts of climate variables (i.e. temperature, precipitation, CO_2) on agriculture. However, other factors contribute to agricultural success such as political infrastructure, market trends, local food systems, and regional water management. As mentioned above, this research aims to assess impacts of both biophysical and social variables on agriculture using a mixed method modeling approach. Here, we use a process-based model to understand how climate variables might affect crop yields and water use on a field scale. Further, we conduct stakeholder interviews to inform social processes within our model and gather perspectives about the future of agriculture in the TV.

Process-based models, which are based on a theoretical understanding of ecological processes, provide a useful framework to incorporate specific responses to altered conditions in an environment, such as an agricultural system. Further, they offer more explicitly stated assumptions and easier interpretation than detailed statistical and rule-based models (Cuddington et al., 2013). These models simulate a system’s key processes using first principles (e.g., conservation of mass and energy), attempting to use only parameters that can be directly measured or observed to explicitly represent those key variables that drive change. In agricultural studies, process-based models are popular for field-scale simulations of farms, while global agricultural analyses tend to use economic trends, global food demand, and more complex land use models. Process-based crop simulation models can be used at global scales, but not without significant simplification of the behavior of farmers, globally. While these global projections capture the biophysical processes, they often completely miss complex and heterogeneous patterns of social processes that impact the global distribution of agricultural practices. Field scale modeling approaches allow for the integration of biophysical and social practices when studying regional agricultural systems, and can be utilized by farmers. Management decisions are found to be best guided by models which are grounded in ecological theory, and which exhibit a balance between too much or too little detail of relevant processes (DeAngelis 1988, Nelson et al. 2009).

EPIC Model

Model Description

The Environmental Policy Integrated Climate (EPIC) model was developed by the Agricultural Research Service of the United States Department of Agriculture at the Grassland, Soil and Water Research Laboratory in Temple, Texas (Easterling et al., 1992). EPIC is a process-based model developed to evaluate agricultural management and simulates the chemical, physical, and hydrologic processes that occur on a farm or field under agricultural management. The modelled landscape in EPIC is a field-size area, up to about 100 ha, where weather, soils, and management are assumed to be homogeneous. Since EPIC can only simulate a single farm plot through time, it is not spatially explicit. The modeled area is assumed to exhibit no spatial variability in climate forcings, soil, and management operations. Instead, these properties are inputs to a suite of physically based equations that calculate hydrologic fluxes and crop production, among other variables (Figure 3.1). The model is subdivided into nine modules that capture weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and economic budgets (Williams 1990). Daily climate data – precipitation, temperature, solar radiation, relative humidity, and wind speed – are required as inputs. EPIC has been tested extensively throughout the United States and in several foreign countries (Williams et al., 1989). Studies have used EPIC to model yields of a wide range of crops (Gassman et al., 2004), success of adaptation measures (Schonhart et al., 2014), and modeling carbon sequestration under zero tillage practices (Gaiser et al., 2016), among other important applications. It has also been validated in semi-arid irrigated regions throughout the United States and the world (Wang et al, 2011; Wang et al, 2012; Balkovicˇ et al, 2013).

Here, we use EPIC to model four high acreage crops in the LBRB. Specifically, we analyze the impact of climate variables on agricultural water use and crop yields. This information can lead to discussions about further adaptation practices that may be adopted by farmers.

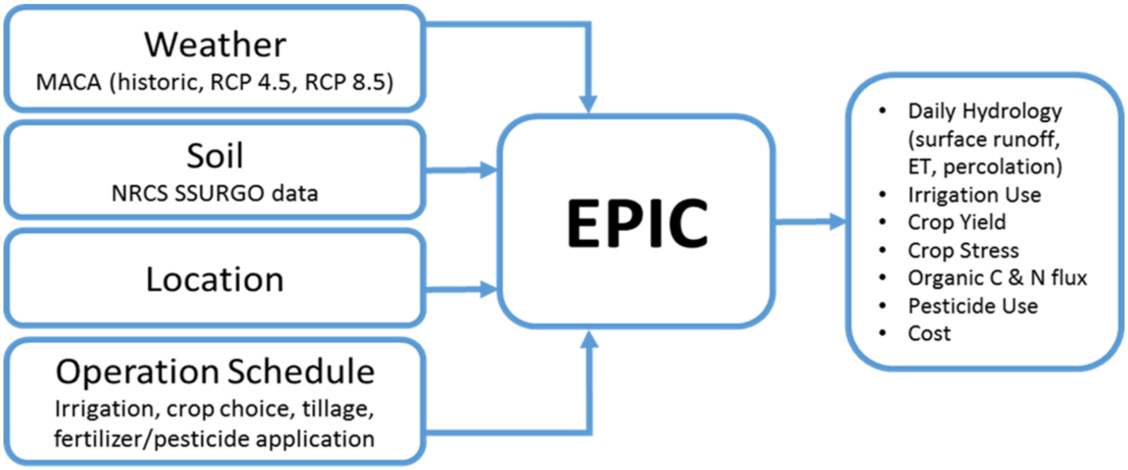


Figure 3.1 Flow diagram of process based crop simulation model, EPIC. Input data can be seen on the left, while outputs are on the right.

Input Data

Climate Variables

We obtained historic daily weather data (1980-2014) at the Boise Air Terminal weather station from the National Climate Data Center. Daily data files include minimum and maximum temperature (°C), precipitation (mm), relative humidity, solar radiation (MJ/m2), and wind speed (m/s). We used this climate data to run our model over the historic period and validate our model was producing comparable yields within reasonable error.

For future simulations, we used a statistically downscaled gridded (4km) climate dataset (MACAv2-METDATA) for a point location in the LBRB agricultural area (Abatzaglou and Brown, 2011). Downscaled data is available for all 20 general circulation models (GCMs) from CMIP5, and for both Representative Concentration Pathway (RCP) 4.5 and 8.5 scenarios.

We ran our model for six separate future climate change scenarios based on RCP 4.5 and RCP 8.5, each paired with three different GCMs. RCPs are distinct future trajectories based on plausible future greenhouse gas concentrations. RCP 4.5 emissions peak around 2040, then decline, while RCP 8.5 emissions rise throughout the 21st century (Figure 3.2) (Meinshausen et al., 2011). The three GCMs used are CanESM2 (hotter, wetter), CNRM-CM5 (warmer, little wetter), and GFDL-ESM2M (less warm, drier) , which best fit temperature and precipitation trends for the Pacific Northwest, (Rupp et al, 2013), and represent a range of plausible future climate scenarios, as seen in Table 3. Table 3 also describes the climate projection naming convention used hereafter.

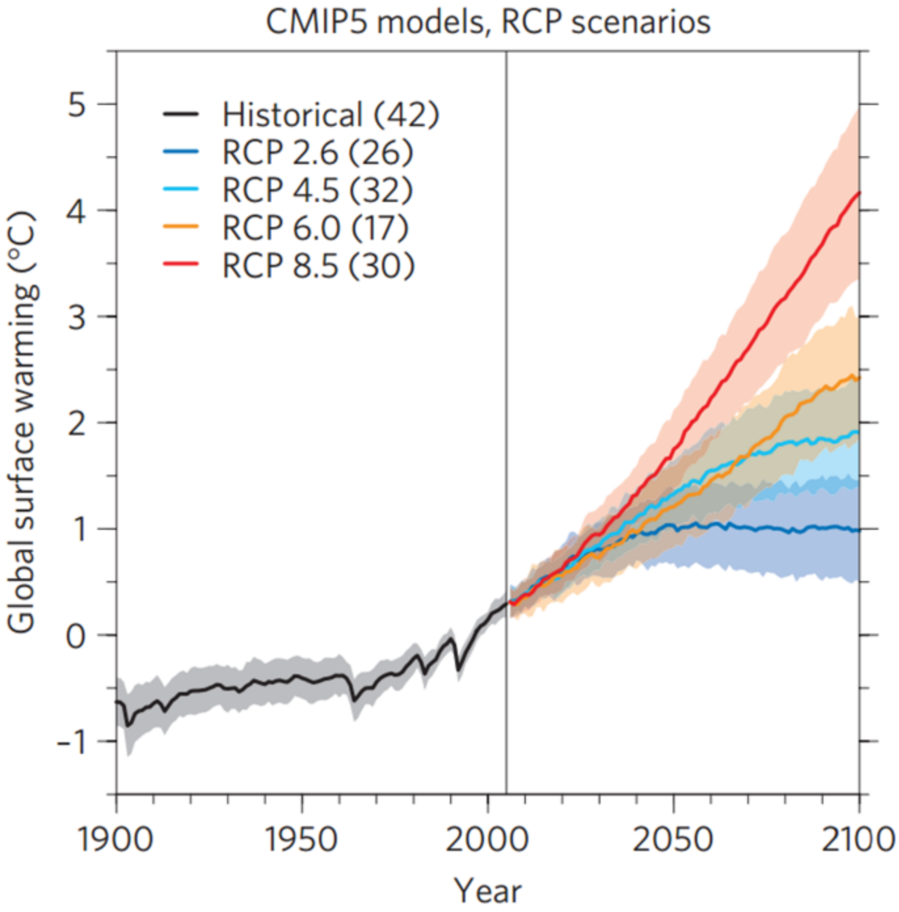


Figure 3.2 Representative Concentration Pathways for future emissions scenarios (Knutti and Sedlacek, 2013).

Table 3 Six climate scenarios used in future climate projections

	GFDL-ESM2M (mild)	**CNRM-CM5** (warmer)	**CanESM2** (hottest)
RCP 4.5	A-45	B-45	C-45
RCP 8.5	A-85	B-85	C-85

Table 4 Soil parameters needed for EPIC model

County	Soil Name	Texture	Hydrologic Group	Depth (m)		Moist bulk density (g/cm3)	pH	Saturated Conductivity
Ada & Canyon	Power	Sandy Loam	B	Layer 1	.5	1.4	7	18
				Layer 2	1	1.5	8	18

Soils Data

The drainage area considered by EPIC is generally small («1 ha) because soils and management are assumed to be spatially homogeneous. In the vertical direction, however, the model is capable of working with any variation in soil properties, the soil profile being divided into a maximum of 10 layers. The LBRB contains mostly silty loam and fine sandy loam soils. Crop growth and yield are a function of the soil's texture, sand content, moist bulk density, pH and saturated conductivity. Soil parameter values were obtained from the Natural Resources Conservation Service's SSURGO database (Soil Survey Staff, NRCS, 2015). Table 4 shows the soil parameters used in our model.

Social data used to develop scenarios

One of the most noteworthy capabilities of EPIC software is that it allows for the integration of farm management schedules. For example, yearly crop rotations and irrigation practices can be programmed into the model by date of occurrence. Since EPIC captures both biophysical and social (in the form of irrigation application timing and method, fertilizer application, and pest management) processes that occur on a farm, we are able to develop meaningful scenarios of management practices that are elicited through interactions with local stakeholders to increase the regional validity of our model. We assert that this information can: (1) facilitate regional assessments how crop yields in the LBRB will change in the future in response to both climate change and associated mitigation strategies, (2) reveal potential mitigation strategies most likely to sustain agricultural productivity in the region, and (3) be useful to farmers as they make decisions, policymakers as they manage water, and future researchers as they try to understand other water systems in the Western United States.

Focus Group and Participant Observation

As previously mentioned, stakeholder engagement aims to integrate local stakeholders’ knowledge into specific research questions and goals (Talley et al., 2016). Our specific research goal was to capture the perspectives of a variety of water users in the LBRB, including those involved in agricultural production, in a focus group. The meeting was approved by the Social and Behavioral Institutional Review Board; the attendees were given waivers to participate and granted anonymity during the stakeholder engagement process (see IRB approval letter in Appendix C). Participants were chosen using a “snowball” sampling technique. This non-probability sampling method operates via primary data sources (i.e., interviewees) nominating another potential data sources (i.e., interviewees) to be used in the research process. Here, we had previously held informal meetings with a local farmer and contacted him directly. Once an invitation was extended, we asked that participant to recommend other potential stakeholders. We also chose participants using purposive sampling.

Twelve stakeholders from the agricultural sector—including growers, irrigation suppliers, and soil conservation professionals—were invited to participate in a half-day workshop on farmer perspectives on water use and management in the LBRB. The focus group was held in April 2016 and was located in a conference room of the Environmental Research Building at Boise State University. By engaging with those that are directly affected by water management decisions, we build a better understanding of the system. This broad cross-section of interviewees helps ensure that these communities are represented in our research.

The first part of the meeting was devoted to understanding what the future of the LBRB may look like in 30 years in relation to shifting weather patterns over time, water availability, and soil quality. We asked questions about what participants thought will most likely happen (what is probable), what participants thought could happen (what is possible), and what participants thought should happen (normative recommendations). Next, we inquired about the irrigation systems used in the LBRB to understand the regional standard for irrigating land. We used this portion of the discussion to ask about the advantages and disadvantages of each irrigation system – flood, sprinkler, and drip – and to gauge perceptions of each. Last, the research forum provided an opportunity to learn about how farmers perceive the relationships between various organizations that seek to manage water resources by building ‘power maps’. During this exercise, the participants brainstormed a list of agencies, organizations, individuals, etc. that are involved in the water system of the LBRB. We then asked the stakeholders to draw a diagram of how each related to the water system and each other, while giving them characteristics including power, money, connection, and policy influence.

Mechanisms for Crop Growth in EPIC

A single model is used in EPIC for simulating all the crops considered, although each crop has unique values for the model parameters. EPIC is capable of simulating growth for both annual and perennial crops. Annual crops grow from planting date to harvest date or until the accumulated heat units equal the potential heat units for the crop. Perennial crops maintain their root systems throughout the year, although they may become dormant after frost. They start growing when the average daily air temperature exceeds their base temperature (Sharpley and Williams, 1990).

There are 59 parameters used to describe each crops’ growth characteristics. Crop growth depends on the availability of nutrients, water, and daily PHU accumulation, which uses the equation:

$$PHU_k = \frac{Max\,Temp_k - Min\,Temp_k}{2} - Base\,Temp_j$$

where *PHU, Max Temp,* and *Min Temp* are the values of potential heat units, maxiumum temperature, and minimum temperature on day *k*, respectively. *Base Temp* is the crop-specific base temperature, or lowest temperature growth can occur, for crop *j* (Sharpley and Williams, 1990). Annual crops start growing when the average daily air temperature exceeds their base temperature. They grow from planting date to harvest date or until the accumulated heat unit reaches a crop-specific requirement, it is considered mature and is harvested in the model (Williams et al., 1989).

A set of equations is used to simulate the growth of each individual part of the crop. Leaf area expansion is simulated as a function of PHUs, crop stress, and crop developmental stages. Crop height also uses PHUs as a growth function parameter as well as the harvest index of each crop, which determines crop yield at harvest time (Williams et al., 1989). Each crop has a known set of parameters for these growth functions.

Evapotranspiration is calculated in EPIC using the Penman-Monteith equation. Surface runoff is predicted for daily rainfall and irrigation by using the SCS curve number equation (USDA NRCS, 1986). The Percolation in EPIC is calculated using a storage routing technique to simulate flow through soil layers. Flow from a soil layer occurs when soil water content exceeds field capacity. Water drains from the soil layer until storage returns to field capacity.

Operations Modelled in EPIC

Irrigation is applied when the plant water stress factor becomes lower than 0.90, a value cited by Easterling et al. (1992) as recommended by researchers at the Texas Agricultural Experiment Station, where EPIC was developed. Irrigation is stopped once the soil water content reaches field capacity, and is not limited to an upper constraint in the growing season. Therefore, irrigation is applied to a crop when the crop is stressed, so that the crop never experiences water stress. With this irrigation scheduling technique, we can estimate the amount of water needed for optimal crop growth.

Fertilizer and pesticide application is set to occur when the crop is experiencing nutrient stress. The planting, plowing, and harvest operations occur based on the average amount of heat units needed for the operation to occur.

Agricultural Yields

We modelled four high acreage crops representative of the LBRB: alfalfa, wheat, sugarbeets, and corn grain. Historic yields for these four crops were gathered from NASS at a county level for Ada and Canyon counties, which make up a majority of the LBRB. Unfortunately, county level data does not capture the typical range of high and low yields that occur, as management, size of farm, and water rights greatly affect yields of individual farms. Also, historic yields exhibit a clear increasing trend due to advancements in technology, irrigation, and fertilizer. Despite not capturing historic yields exactly, our modelled historic yields are within reasonable error of current yields, and therefore have merit. This provides us confidence that future projections of crop yield simulated here are reliable in the absence of potentially disruptive technologies that would lead to very rapid increases crop yield without corresponding increases in water and fertilizer inputs.

4. RESULTS

In this chapter, we first present the results of our stakeholder engagement focus group. We deliver conclusions of farmers' viewpoints of climate change, the future of agriculture, and their thoughts on the water system as a whole. We also discuss some information we used in our model simulations. Next, we present the results of our process-based EPIC model. These results quantify future crop yields, planting dates, and irrigation use over the six climate scenarios.

Stakeholder Meeting Results

The results of the stakeholder focus group and informal meetings are a summary and synthesis created from notes taken by researchers during the discussion, they are not verbatim, unless quoted.

What does the future of the LBRB look like?

In regards to what the future of farming looks like in the LBRB, the participants communicated beliefs that as the urban centers grow, farmland will be broken up into smaller parcels and there will be more people on the roads and in surrounding farmland. Participants suggested that these changes will make it more difficult to farm, efficiencies will be lost, and water resources will become more contested and stressed. Thus, participants predicted that as the city expands into farmland, farmers will be more apt to sell their land and either stop farming or move their operations elsewhere. These reflections from the participants are parallel to the decreases in farmland presented in Chapter 1, which show a decline in acres in agriculture in counties with the greatest urban growth in population (Ada County). Previous research suggests that population growth and urban development are one of many factors that can influence the decision to sell farmland (Inwood and Sharp 2012).

When asked about future predictions regarding climate, water, and soil, participants suggested future obstacles but remained optimistic about agricultural adaptation. Considering weather and climate shifts, workshop participants felt there was a good chance that there would be more frequent weather extremes (e.g. colder winters, hotter summers, shifting seasons). This could prompt farmers to change their practices by either shifting to crops that are better able to survive extreme weather events, shifting their crop schedules, or both. Furthermore, many participants stated that as higher latitudes warm, the agricultural market will change--crops will essentially move northward as cooler climates warm. This could motivate a change in global markets, which would further drive a change in crop choice locally. Land use changes would also result. Participants stated that extreme weather events will not necessarily drive farmers to sell their land, but might force them to reevaluate what they farm and their farming practices.

Concerning soil, participants were very hopeful about the future. Soil health was unanimously considered the top mitigation strategy when preparing for future climate and changing crop yields. They cited healthy soil as able to retain double the water that unhealthy soils were able to retain. Practices that support healthy soils include no-till, cover cropping and diverse rotations, which increase soil organic matter and ability to retain nutrients and water. This has major implications for the future of water scarcity mitigation. If water right curtailment becomes more frequent, soil water retention will become an important factor contributing to successful crop yields.

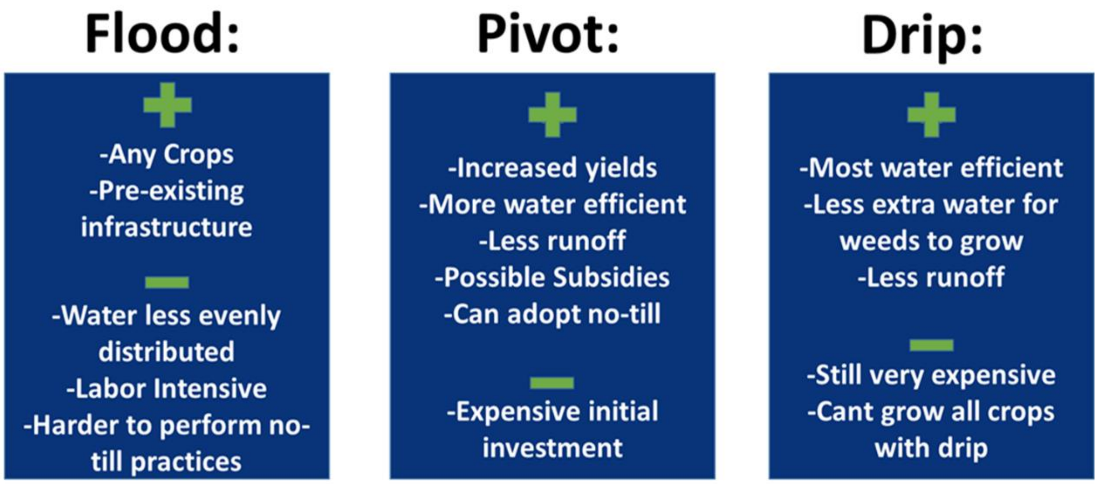
We then asked workshop participants questions about what they would like to see happen regarding future land and water use in the LBRB. Some participants felt that policymakers need to focus on protecting agricultural land from encroaching development and fragmentation; others noted that market signals (the price of food) would need to shift. Some participants also argued for the importance of educating urban residents about water use and conservation. The Natural Resources Conservation Service (NRCS) was mentioned to be the leading proponent of soil health in the LBRB, supporting local farmers to understand the advantages of healthy soils.

In summary, most focus group participants seemed to agree that unchecked urban growth would lead to diminished farmland in the LBRB. More research needs to be done on what that means for food supply and production, water use, labor patterns, and ecosystem services (such as dual-use agricultural lands that also function as “open space” aesthetically or as habitat for wildlife). Furthermore, participants noted that climate shifts would impact their farming practices by forcing them to manage in different ways and to shift crop choices. Several noted that water-scarce years are more frequent than in previous decades, which affects water and land management. However, most seemed more concerned about overall economics and impacts of development than about climate change affecting crop yields. This tells us that farmers are accustomed to adapting their strategies based on the season’s weather and water availability. Soil health was said to have the most benefit for future farming systems.

How do irrigation practices affect management and how will that change in the future?

Focus group participants estimated that nearly 70% of the LBRB is currently flood irrigated, with 25% being irrigated by sprinkler and less than 5% being drip irrigated. This is due to the existing agricultural infrastructure and traditional farming methods, as well as economics of irrigation and crops grown in the LBRB. Figure 4.1 illustrates the advantages and disadvantages of each irrigation system, as noted from participants. Flood irrigation is associated with some inefficiencies. For example, it is labor intensive and does not evenly distribute water over the fields. Regardless of the inefficiencies, a farmer will not likely switch to sprinkler until it is economical to do so because of the expensive initial investments required. Future potential subsidies from Idaho Power for sprinkler nozzles may decrease the price of installation. Participants largely agreed that pivot irrigation can increase crop yield while decreasing labor inputs, control pollution due to less runoff, and lead to more water efficiency. It was agreed that although pivot irrigation would help to mitigate for stressed water and extreme weather events, the largest obstacle to switching from flood-irrigation was in the high initial start-up costs associated with installing pivot systems.

Of the three irrigation systems discussed, participants asserted that drip irrigation is the most water efficient, prevents runoff pollution, and controls for weeds due to virtually no extra water for weed growth. However, it is the most expensive system and can also be labor intensive. Due to the costs, it will likely not replace flood and sprinkler irrigation systems any time soon, although sprinkler and flood irrigation could potentially switch in terms of frequency (sprinkler will be used in 70% while flood in 25% of fields) in the medium-term. This change is relative to the type of crop being irrigated. Some crops are better suited for different irrigation methods and the size of the farm limits irrigation possibilities. Different irrigation systems favor certain crops and, thus, shifting crop choice due to changing climate could correspondingly influence irrigation practices. Similarly, switching from flood to sprinkler will dictate crop choice. This may help to mitigate against stressed water supplies and extreme weather events, but could have some unintended consequences that deserve further study. For example, flood irrigated fields may work to recharge the groundwater system, and may serve as wildlife habitat for some species. Moving to pivot systems could change how the hydrologic system works in the LBRB and could involve tradeoffs between energy use, water efficiency, and wildlife habitat.



Flood:

+

-Any Crops
-Pre-existing infrastructure

−

-Water less evenly distributed
-Labor Intensive
-Harder to perform no-till practices

Pivot:

+

-Increased yields
-More water efficient
-Less runoff
-Possible Subsidies
-Can adopt no-till

−

-Expensive initial investment

Drip:

+

-Most water efficient
-Less extra water for weeds to grow
-Less runoff

−

-Still very expensive
-Cant grow all crops with drip

Figure 4.1 Advantages and disadvantages of each irrigation system, as found by our stakeholder engagement focus group.

How is the management of water supplies organized in the LBRB?

Aside from eliciting the expert knowledge of the participants to understand current irrigation practices and what agriculture in the LBRB may look like in the future, the focus group provided an opportunity to learn about how farmers perceive the relationships between various organizations that seek to manage water resources. As mentioned earlier, the farmers were asked to build ‘power maps’. Participants brainstormed a list of agencies, organizations, individuals, etc. that are involved in the water system of the LBRB, and assigned each characteristics including power, money, connection, and policy influence. Figure 4.2 demonstrates some of the power maps that were created by participants.

The results from this exercise are complex, as many power maps varied greatly in content. Notable outcomes, though, are that water users—particularly agricultural users—feel they have little power or influence in the current water management system and are instead affected by policies created “at the top” and then implemented on those below. This finding was interesting, given the widely perceived wisdom that agricultural interests control policymaking in Idaho. It is possible that mid-scale LBRB farmers are not as well represented politically as other agricultural interests in the state. It is also possible that they do not see their influence reflected in the larger system but rather perceive their influence as primarily happening at the irrigation-district scale. More work needs to be done to understand these dynamics.

Additionally, farmers viewed the electric utility Idaho Power as having considerable influence regarding water policy. Since Idaho Power has the motivation to keep water running through dams for hydroelectric power, the money to influence policy, and stands to benefit from varying power rates throughout the urban and rural systems, they rank high in the management structure. Again, this is an important finding that integrally affects how water management is studied, and one that arises out of appealing to water-users to help in understanding the system.

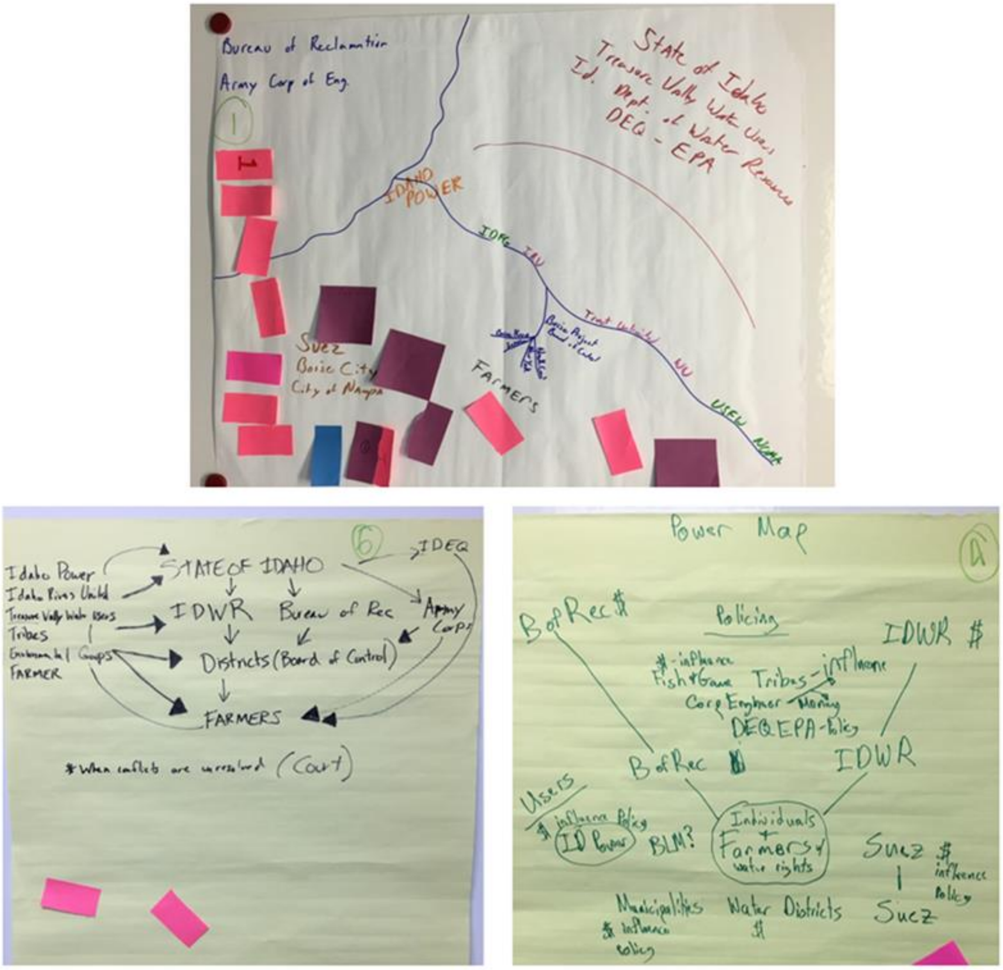


Figure 4.2 Examples of power maps created by participants in our stakeholder meeting.

Process Based Modelling Results

Crop Yields

Analysis of crop yields in most climate scenarios show a slight to moderate decrease in wheat and corn yields by 2100, while alfalfa and sugarbeets stay the same or slightly increase in more mild scenarios. All historic yields reported are for irrigated crops in the LBRB (Ada and Canyon counties). Results for crop yields are reported in units that are consistent with NASS reporting units, which differ between crop. For example, while wheat is reported in tons/acre, sugarbeet yields are reported in bushels/acre. For the purposes of this study, we did not convert to a single unit since both stakeholders and other agricultural studies use these standard units as reported by NASS. EPIC produces yields in tons/hectare, so appropriate conversions were conducted.

Wheat yields ranged from 71.6 – 113.1 bushels/acre over the historic period (1980-2014). In the C-85 scenario, wheat is reduced to an average of 63.3 bushels/acre by the end of the century (2090-2099). A-45 predicts wheat to remain the same until a slight decrease toward the end of the century, with an average of 92.3 bushels/acre. (Figure 4.3)

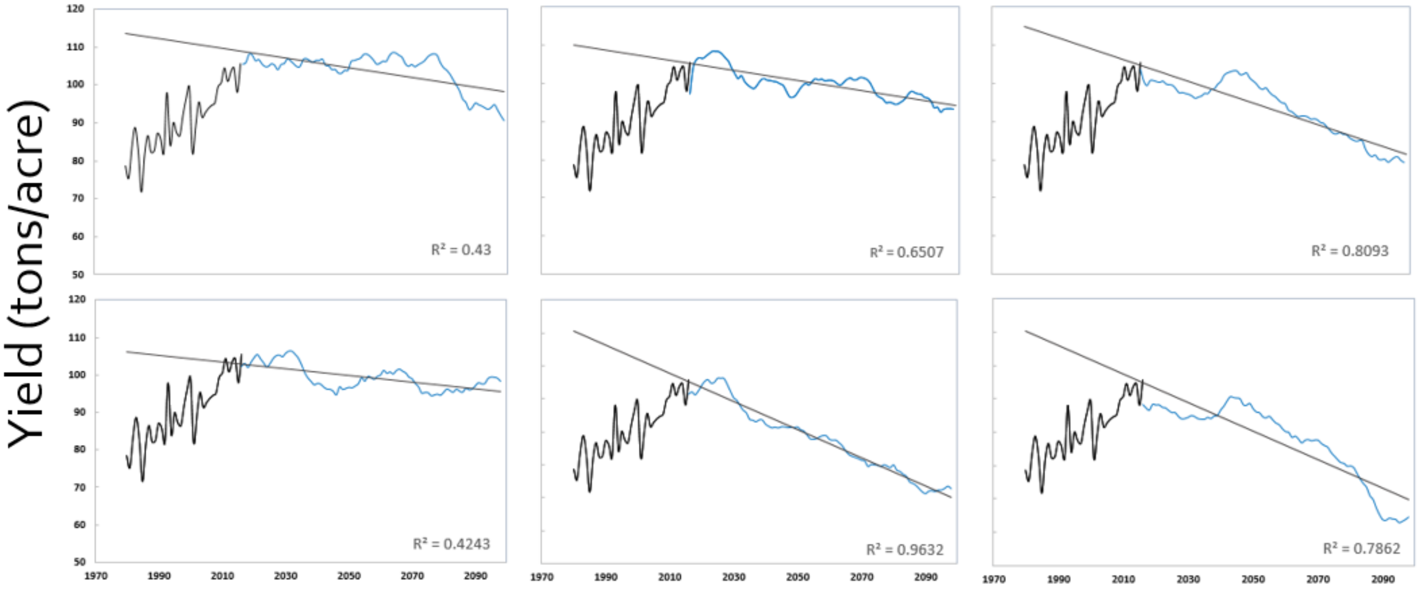


Figure 4.3 Spring wheat yields for six different climate scenarios. Black lines indicate historic observed yields.

Corn yields range from 19.8 – 30 tons/acre in the historic period. In the most extreme C-85 climate scenario, yields are reduced to an average of 15.4 tons/acre by the end of the century (2090-2099). Corn yields remain about the same in the mild A-45 scenario. (Figure 4.4)

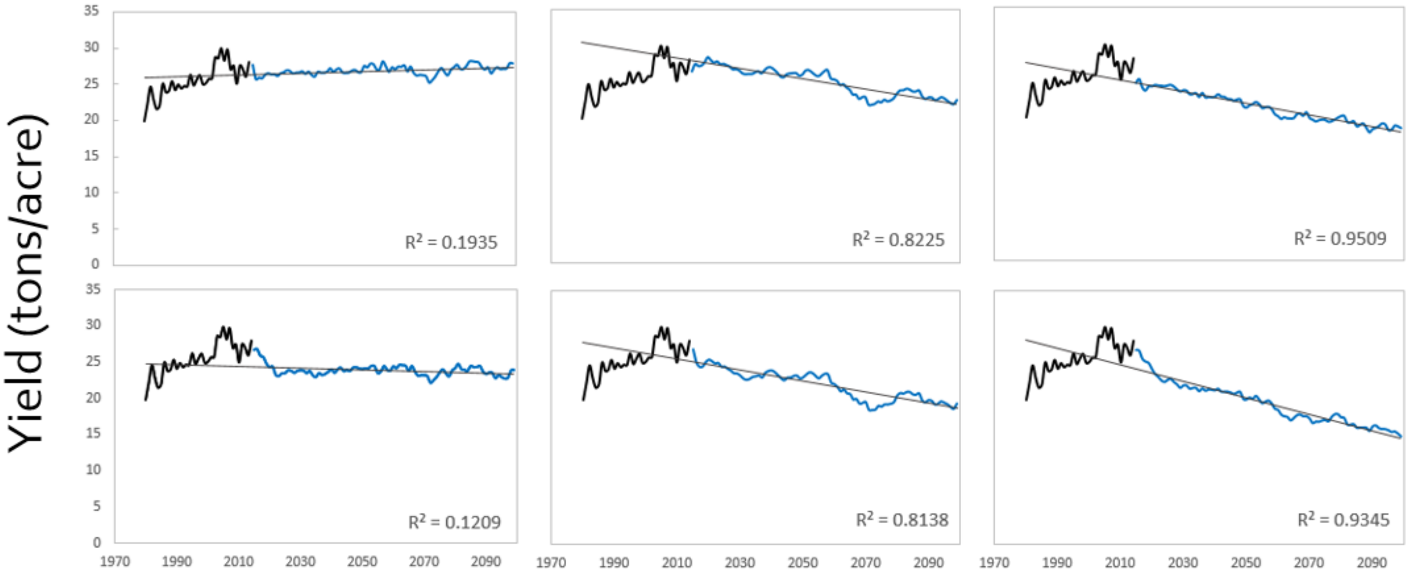


Figure 4.4 Corn yields for six different climate scenarios. Black lines indicate historic observed yields.

Historic sugarbeet yields range from 26 – 41.6 tons/acre. Sugarbeets see an increase in yield in most climate scenarios, and stay about the same in the extreme C-85 scenario. Increases seen in yield are up to 50.3 tons/acre at the end of the century. (Figure 4.5)

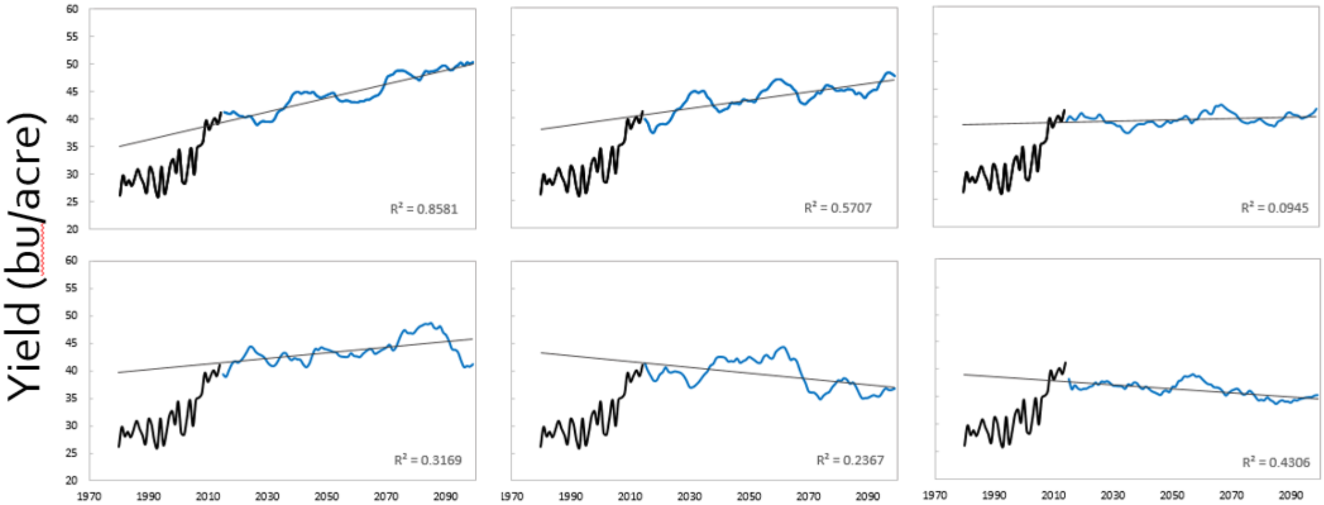


Figure 4.5 **Sugarbeet yields for six different climate scenarios. Black lines indicate historic observed yields.**

Historic alfalfa yields range from 4.6 – 5.9 tons/acre per cutting. The LBRB usually reports 3-4 cuttings of alfalfa each season, depending on water allotments. Our model predicts alfalfa to experience a yield increase to 6.5 tons/acre in A-45 scenario at the end of the century. Other climate scenarios produce a slight increase or remain the same regarding yields. (Figure 4.6)

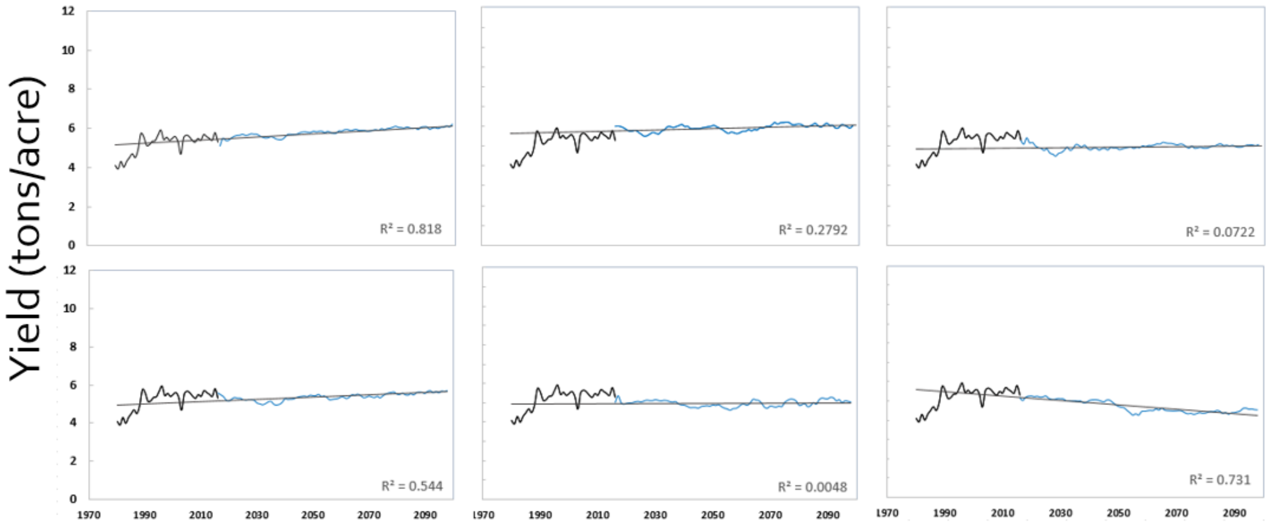


Figure 4.6 Alfalfa yields for six different climate scenarios. Black lines indicate historic observed yields.

Planting Date

In all six future climate scenarios, we see a shift in planting date toward earlier in the growing season. We averaged all climate scenario planting dates for each crop to quantify the number of days the planting date might shorten (Figure 4.7).

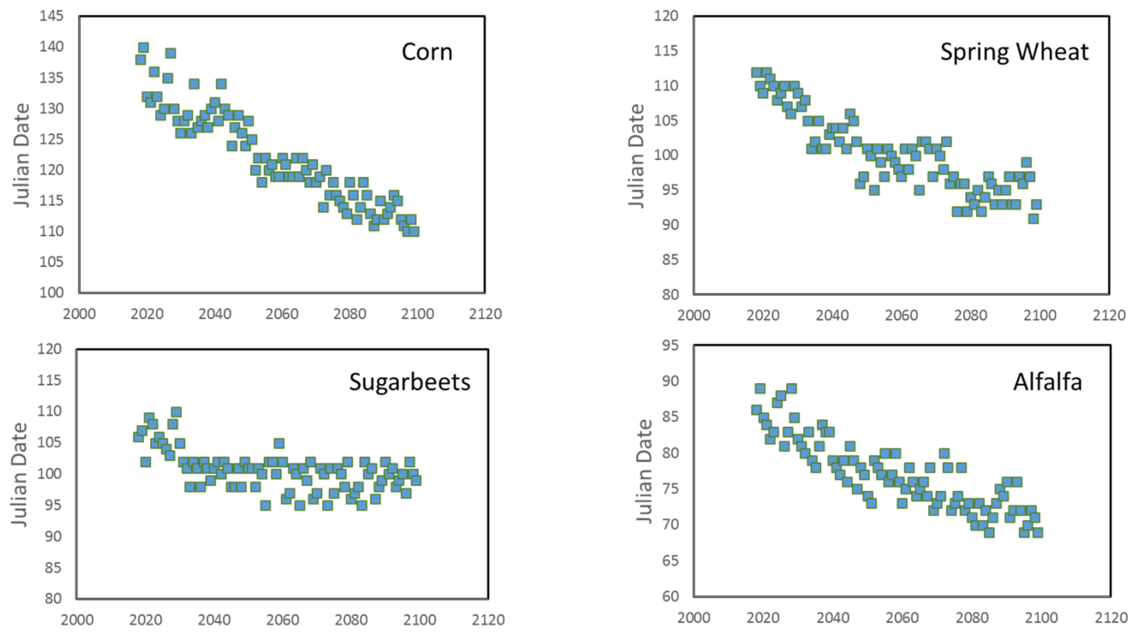


Figure 4.7 Planting dates averaged across all six climate scenarios for each crop.

5. DISCUSSION AND CONCLUSIONS

In this work, we adopt a social-ecological systems perspective to develop an intellectual framework for assessing agricultural climate adaptation using stakeholder engagement and process based modeling. With research questions focused in both biophysical and social science, we used a process-based crop simulation model and stakeholder meetings to examine agricultural response to climate change and adaptations that mitigate for climate change effects. This study advances our understanding of future climate effects on agriculture, and provides a framework to include local variables into process-based modeling methods.

First, we used local climate, soils, and crop variables to develop a process-based model representative of agriculture in the LBRB. We conclude that future high emission climate regimes are likely to cause decreases in corn and wheat yields. This is supported by Lobell et al. (2008), who demonstrate how increasing temperatures and varying precipitation in semiarid environments are likely to reduce corn, wheat, and rice yields. However, more mild climate scenarios predict corn and wheat yields to stay within current range or only slightly decrease. Sugarbeet and alfalfa yields are predicted to stay the same or slightly increase in more mild climate projections.

There is uncertainty in which climate scenario will be most closely reflect future reality. Depending on future radiative forcing we see a range of future plausible scenarios. Adaptation plans and on-farm mitigation have the ability to defend the agricultural practices against these climatic changes, which is why coupled human-natural systems is important moving forward in agricultural research. Participants in our focus group acknowledged that climate change is happening on a scale that already has or will affect their practices. They referenced climate shifts will inevitably force them to change management practices and to shift crop choices. The modeled crops are dominant in the agricultural areas of the LBRB, so changes in yield, as seen in our model, have implications for farmers' future crop choices. Our model suggests that instead of corn or wheat, farmers may be more likely to grow alfalfa or sugarbeets in the future. However, alfalfa is a more water intensive crop, so the adoption of alfalfa might be contingent to the water right possessed by the farmer. Further, macroeconomics play a significant role in farmers' decision making in a particular growing season.

Next, we identify potential concerns with the scheduled irrigation season, which starts on April 1. Under all climate scenarios, our model predicts the growing season to start earlier in the year based on ET estimates and planting dates. This shift influences when farmers plant and harvest their crops. C-85 predicts planting dates to be up to 24 days early, while the mildest A-45 scenario predicts planting date to be 19 days early by the end of the century. This has major implications for future water policy, as the current irrigation season may need to be redefined to allow for early season irrigation in the future.

Additionally, we determine the amount of irrigation water that optimizes each crop's growth and yield is actually less than the water currently being used on farms in the LBRB, according to water rights data. This information demonstrates that irrigation water in the LBRB is being lost due to conveyance losses or over application of water.

Over application may be caused by farmers' perceptions about the Prior Appropriation Doctrine's "use it or lose it" clause. Education regarding efficient water use and reassurance that water rights will be maintained if not used could improve water use efficiency and reduce future water curtailments for junior rights holders.

One limitation of the EPIC model was the irrigation system mechanics. Therefore, this study did not quantify the water application differences between sprinkler and pivot irrigation systems. However, studies have concluded the switch from flood irrigation to sprinkler irrigation would result in an overall reduction in water use on a farm. We found that this could have implications for shallow aquifer recharge and wildlife habitat in our system. There is also an additional need to change management schedules to include non-traditional farming techniques. The addition of organic, no till, small operational farm management would advance the understanding of management effects on yields.

Future studies that aim to couple human and natural systems to study regional agricultural systems would benefit from having historic field scale yield data, along with the irrigation and management schedules used on that individual farm. This finding highlights the importance of stakeholder engagement in scientific studies. Stakeholders can share important information about the system in question, and can benefit from the shared knowledge of the science. When made an iterative process, stakeholder engagement allows researchers to complete the feedback loop of coupled human-natural systems. This framework is transferable to other regions with local parameterization of both biophysical and management variables. Future work lies in the scaling up of this type of regional agricultural study. Larger studies would benefit from the incorporation of macroeconomics, localized downscaled climate data, and finer scaled management operations.

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APPENDIX A

Stakeholder Survey

Farmer Survey

Please answer the following questions to the best of your availability. If you do not want to answer a question, please feel free to skip it. In order to ensure anonymity, please do not put your name on the survey.

1. Farm Operation

A. How much land do you farm (acres)? __________________________ acres

B. What percentage of your land do you own? ______________%

C. What percentage of your land do you lease? _____________%

D. Do you live on the land that you farm?

1. yes
2. no

E. Do you have access to additional acreage you could farm if demand for your product were greater?

1. yes
2. no

E. If so, how much more land could you be farming (acres)? __________________________ acres

F. What do you grow?

____

____

____

G. How much do you grow (lbs./yr, units/yr, head/yr, etc)?

____

____

____

____

____

H. How would you define your growing practices?

1. Organic-certified
2. Organic practices – not certified
3. Conventional

I. If you employ a growing practice not listed above, please specify it here:

____

____

____

____

____

J. What agricultural inputs do you use on your farm (such as fertilizers, pesticides, etc)?

____

____

____

____

K. Where do you sell your product (Whole sale, retail, farmers' markets, CSA, etc)?

L. How do you currently irrigate your farm?

M. How frequently do you currently irrigate your farm?

N. Have you considered changing your irrigation practices?

1. yes
2. no

O. Why or why not?

2. Demographics

P. What is your age (as of your last birthday)? ___________ years

Q. What is your gender? _______Male _______ Female

R. What was your approximate gross household income from all sources, before taxes, for 2015?

1. Less than $9,999
2. $10,000 to 19,999
3. $20,000 to 34,999
4. $35,000 to 49,999
5. $50,000 to 74,999
6. $75,000 to 99,999
7. $100,000 or more

S. What is your current marital status?

1. Now married
2. Living together
3. Never married
4. Divorced/Separated
5. Widowed/Widower

S. How many persons in your household are the following ages (including yourself)?

1. Under 5 years of age ______
2. 5 to 18 years of age ______
3. 19 years of age or older ______

U. Which best describes you?

a. African American

b. Asian

c. Hispanic/Latino

d. Native American/American Indian

e. White

f. Other (please specify): ________________________________

V. How would you generally describe your political views on a scale of 1 to 7 (1=extremely liberal, 7=extremely conservative)? ***(Circle your answer)***

1	2	3	4	5	6	7

Extremely Liberal — Middle of the Road — Extremely Conservative

<u>Thank you for your cooperation!</u>

APPENDIX B

Stakeholder Discussion Questions

1. Are there certain types of crops that are most suited to different irrigation techniques? In other words, which crops go best with flood, pivot, drip?

2. What kinds of crop rotation do you do? What factors influence how you manage crop rotation—markets? Soil health?

3. Can you talk to us about the connections you see between water use and energy use? How do these factors impact the kinds of irrigation choices you make?

4. As you are no doubt aware, there is evidence to suggest that there is a transition away from agriculture in the Treasure Valley. From your perspective, what is motivating that transition?

5. When farmers sell their farms, what are they doing with their water rights? Are they leasing their water?

6. From your point of view, are most farmers in the Treasure Valley using surface water, or groundwater? Is this changing? How come?

7. Are you contemplating, or have you recently contemplated, a change or transition in your irrigation practices? What kinds of factors lead to such a change? What obstacles do you face to making an irrigation transition?

8. How do you perceive the access farmers have to water in the Treasure Valley? In other words, is water supply abundant and easily accessible? Or is it scarce and/or difficult to access?

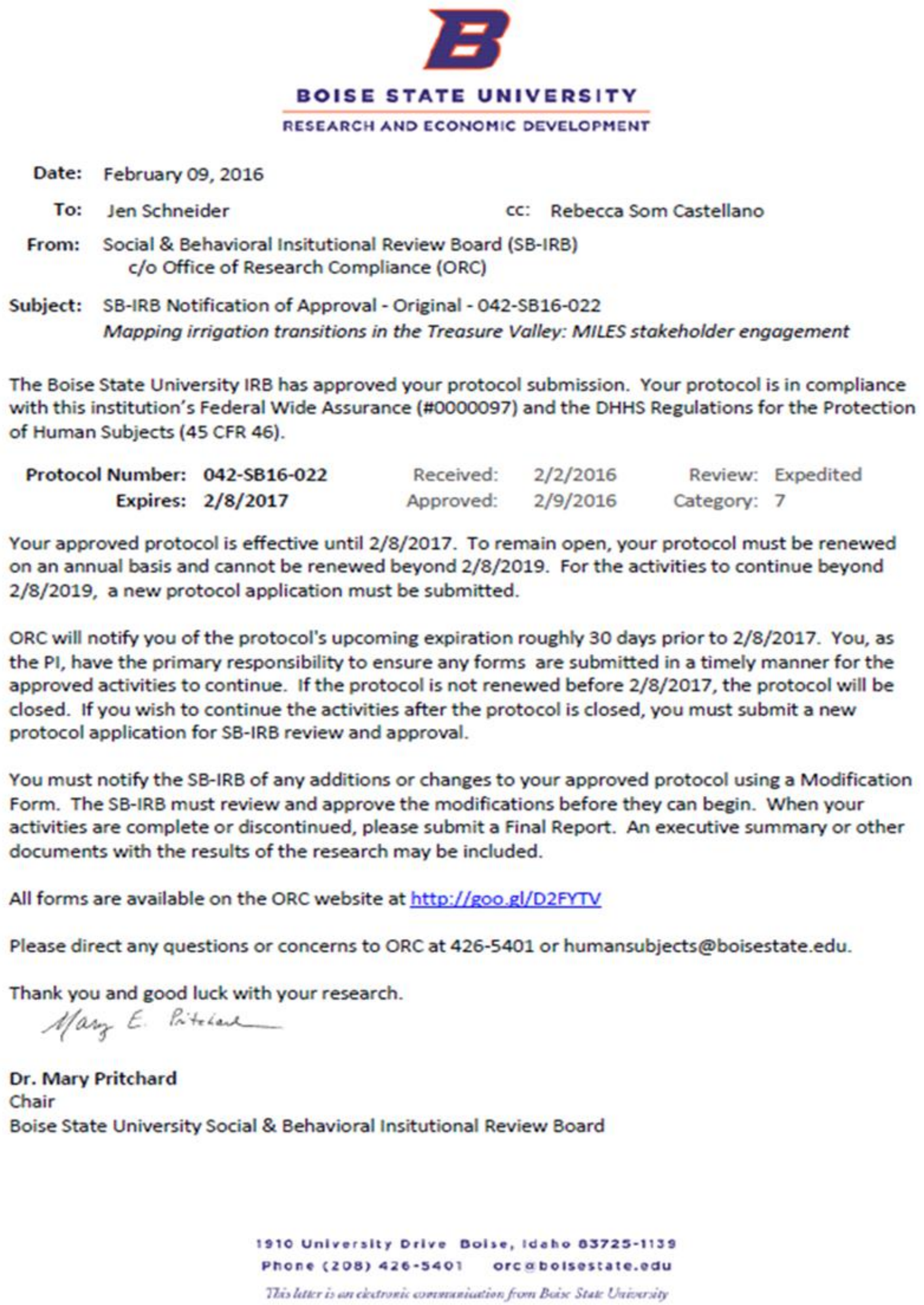
9. Do you see access to water for farmers changing over time? Why?

10. Do we have a water shortage in the Treasure Valley?

11. As you are probably aware, many scientists and policyakers predict that the climate will be come hotter and drier in the West in the decades to come. Do you see evidence of this now? Does it impact your irrigation practices? Does preparing for hotter or drier conditions impact the type of planning you are doing.

APPENDIX C

IRB Approval Letter



BOISE STATE UNIVERSITY
RESEARCH AND ECONOMIC DEVELOPMENT

Date: February 09, 2016

To: Jen Schneider cc: Rebecca Som Castellano

From: Social & Behavioral Insitutional Review Board (SB-IRB)
c/o Office of Research Compliance (ORC)

Subject: SB-IRB Notification of Approval - Original - 042-SB16-022
Mapping irrigation transitions in the Treasure Valley: MILES stakeholder engagement

The Boise State University IRB has approved your protocol submission. Your protocol is in compliance with this institution's Federal Wide Assurance (#0000097) and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46).

Protocol Number:	**042-SB16-022**	Received:	2/2/2016	Review:	Expedited
Expires:	**2/8/2017**	Approved:	2/9/2016	Category:	7

Your approved protocol is effective until 2/8/2017. To remain open, your protocol must be renewed on an annual basis and cannot be renewed beyond 2/8/2019. For the activities to continue beyond 2/8/2019, a new protocol application must be submitted.

ORC will notify you of the protocol's upcoming expiration roughly 30 days prior to 2/8/2017. You, as the PI, have the primary responsibility to ensure any forms are submitted in a timely manner for the approved activities to continue. If the protocol is not renewed before 2/8/2017, the protocol will be closed. If you wish to continue the activities after the protocol is closed, you must submit a new protocol application for SB-IRB review and approval.

You must notify the SB-IRB of any additions or changes to your approved protocol using a Modification Form. The SB-IRB must review and approve the modifications before they can begin. When your activities are complete or discontinued, please submit a Final Report. An executive summary or other documents with the results of the research may be included.

All forms are available on the ORC website at http://goo.gl/D2FYTV

Please direct any questions or concerns to ORC at 426-5401 or humansubjects@boisestate.edu.

Thank you and good luck with your research.

Mary E. Pritchard

Dr. Mary Pritchard
Chair
Boise State University Social & Behavioral Insitutional Review Board

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This letter is an electronic communication from Boise State University