DISSERTATION

CULTURE, WATER, LIVELIHOODS, AND ADAPTATION IN THE COMPLEX SOCIO-ECOLOGICAL SYSTEMS OF COLORADO, U.S.A.

Submitted by

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ABSTRACT

CULTURE, WATER, LIVELIHOODS, AND ADAPTATION IN THE COMPLEX SOCIO-ECOLOGICAL SYSTEMS OF COLORADO, U.S.A.

This dissertation comprises the results of several years of mixed-methods qualitative research on the socio-ecological systems of the U.S. state of Colorado, with a particular focus on their ability to effectively manage natural resource and ecosystem-related challenges amid intensifying social, environmental, and climatic change. Located at the interface of the Great Plains and the Semi-Arid Western U.S., Colorado faces numerous significant challenges from current escalations of climate variability, future trends towards warming temperatures, intensified urban population growth trends, and growing demand for limited water resources. This work, comprised of the results of two distinct but interrelated projects, therefore asks, in the broadest terms, *How are key livelihood and cultural systems in the state engaging with critical natural resource and climate-related risks?* Taken to a more granular level, it investigates, 1) What are the most vulnerable components of the socio-ecological systems of Colorado in terms of local expressions of climate change and resource management; 2) How are these systems currently engaging with those vulnerabilities on a cultural level, and 3) How can the interdisciplinary scientific community and policy-makers better align themselves to serve their needs for adaptation?

In Part I, titled "Changing Weather and Livelihoods in Rural Colorado," I attempt to answer these questions at a state-wide level. Here, I rely upon interviews with ranchers, farmers, recreational sector experts, and extensive secondary data gathering on the varied ways in which sensitive land-based livelihoods in the state have been impacted by drought, wildfire, flooding, extreme

precipitation events, and related phenomena over the last two decades, doing so in order to chart out how leaders in these sectors are adapting to changing weather-related risk profiles. In this, I identify significant vulnerabilities within livelihoods central to rural economics and identity, as well as barriers to current and future adaptation efforts in the form of economic, policy, information access, and cross-cultural communication challenges. As part of this, water – both as a resource and as a site of cultural values – emerges as critical to nearly every future-oriented line of inquiry, as the state's physical and socially constructed patterns of water scarcity weave through nearly every aspect of both its vulnerabilities and its capacity to adapt to climate- and ecologically-driven challenges.

In Part II, then, I ask, "How can the state's human-altered hydrological systems – i.e., socio-hydrological systems – approach a level of self-understanding that takes into account the wide range of diverse perspectives and livelihoods associated with water systems at the basin scale?" Titled "Conceptualizations and Valuations of Water in the South Platte Basin," it takes a more zoomed-in approach, examining cultures of water commodification, use, interaction, cultural connection, and risk management across six key viewpoints within the Colorado South Platte Basin's complex and multi-layered water management systems. In this, it attempts to bridge existing gaps within the varied literatures related to water resources management and the social-science investigation of human-water system interactions, aiming to advance understanding of how cultural systems within hydrological basins heavily influenced by human intervention influence contemporary and future dynamics of water management and socially-constructed water scarcity. Based on in-depth interviews with water managers, users, advocates, and consultants from around the region as well as a variety of secondary data, it attempts to sketch out a typology of water valuation and understand across four distinct levels of value and across six distinct viewpoints with implications for the water system's current operation and future capacity to adapt to increasing variability and extreme event risk. It finds significant diversity among different types of actor groups involved in the water

decision-making systems of the region, as well as numerous innovative avenues toward bridging these gaps in the form of "hybridized" or "nexus" approaches to water infrastructure development, environmental protection, and flood risk mitigation that capitalize upon multiple value orientations as they enact manipulations of the region's water systems. Finally, I discuss several important gaps identified in the region's cultures of water, including the lack of a meaningful system-wide identity, and the lack of affirmative spaces for creatively imagining the future at the basin scale.

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Introduction and Structure of the Dissertation

How human communities and systems will respond to changes in natural resource availability occurring as a result of on-going climatic change remains a domain of extreme uncertainty, whether at the scale of local resource management, regional economic planning or international policy making (Refsgaard et al. 2012; Kunreuther et al. 2014; Poff et al. 2016). Nowhere is this more true than with regard to water resource availability, which, in addition to being driven by highly unpredictable aspects of the changing climate system, has been (and will continue to be) dramatically altered by human modification of land cover, ecosystem structure, and hydrological dynamics (Haddeland et al. 2014; Sterling et al. 2012). At the same time, human systems can be dramatically transformed by changing water fortunes, with livelihoods, business models, governments, and even entire civilizations all having shown significant sensitivity to fluctuations in water resource availability and water-driven extreme events throughout history (Gleick 2014; Hall et al. 2014; Tainter 1988; Hsiang et al. 2013). Because of this, understanding the dynamics of the multiple individual and collective human components of regional hydrological systems constitutes a critical step in broader efforts to confront the many great challenges of the 21st century. However, due to the nested, multi-scalar, and networked nature of socio-ecological and hydro-social systems (Boelens et al. 2016), there remains a pressing need for research frameworks that allow researchers, advocates, resource managers, and decision-makers operating from a variety of vantage points to assess the increasingly complex cultural landscapes that shape aggregate patterns of human-environment interactions. This is especially true for adaptation approaches that hope to enlist cultural approaches to changing how resources move through human and natural infrastructure. These approaches, simply put, rely upon influencing various resource actors changing behavior, attitudes, and goals through processes such as mutual learning, conflict avoidance, scenario development, and a number of other processes that rely heavily upon leveraging existing cultural values and modes of behavior (Pahl-Wostl et al. 2007; Adger et al. 2013; Ratner et al. 2013; Wutich et al. 2014). As a result, should efforts to improve unsustainable arrangements of socio-ecological or -hydrological systems be attempted without an understanding of existing local-scale dynamics and the cultural systems that inform them, it is unlikely they will succeed, or, frankly, correctly apprehend the nature of the problems in question in the first place. Because of this, how interdisciplinary researchers can better integrate social and cultural systems into analyses of socio-ecological and socio-hydrological system dynamics remains a critical gap in existing knowledge and practice. (Caldas et al. 2015)

Granted, significant efforts are underway in a variety of fields to advance our understanding on how humans and the hydrological basins upon which they depend interact, and how those relationships can be shaped over time, whether intentionally or through emergent processes (Pande and Sivapalan 2017). At the same time, efforts to understand climate change and resource vulnerability – and, as a result, water vulnerability – have increasingly drawn attention to the role of human cultural, political, and economic systems in shaping water interactions – e.g., access, water quality, river flow patterns, flood incidence, and so on – underlining repeatedly the importance of integrating knowledge of both these social/cultural and technical/biophysical system dimensions into analysis and assessment processes (e.g., Swyngedouw 2009; Boelens et al. 2016). However, the development of truly integrative frameworks for socio-ecological (or socio-hydrological) systems research remains elusive, with most work still scattered across the various specialized fields converging on the topic (e.g., anthropology, sociology, history, law, hydrology, ecology, engineering, etc.) and emphasizing either qualitative (ethnographic; survey) or quantitative (indicators-based, model-driven, statistical) approaches, respectively. Though significant advances have been made in both broad areas, there remains a need for applied and conceptual frameworks that explore how the diverse and complex social systems that populate our world interact with the ecosystems, geophysical components, and climates surrounding them. Moreover, these frameworks need to pay adequate attention to effects of scale, human cultural complexity, and the virtual dimensions of both human and water flow patterns. More importantly, at the levels of local and regional community development, infrastructure planning, land use policy, disaster management, and resource security (to list a few), the need for more lucid and comprehensive information on the management of water and its diverse consequences only grows as current greenhouse gas emissions trajectories continue, and social systems likewise undergo equally dramatic transformations.

This dissertation represents a broad attempt to begin the process of answering this challenge. It does so through an examination of the case of Colorado, a state in the central United States whose unique geophysical characteristics, land use history, and socio-economic characteristics place it at the crossroads of both tremendous risks and promising opportunity as it faces down the social and environmental challenges of the 21st century. It is comprised of two parts: In Part I, I examine statewide patterns of adaptation and innovation in land-based livelihoods, whose increased vulnerability to climate-driven hazards places them at the front lines of contending with the risks of both existing climate variability and on-going trends of climatic change across the state. It focuses specifically on the roughly 20% of the state's population living in rural areas where land-based livelihoods form a critical component of local cultural identities, land use legacies, and economic vitality. In this, it attempts to provide policy-makers, concerned citizens, and others with a stake in the continued viability of the state's non-urban areas with a firm grounding in both the risks faced by rural livelihood systems and the range of adaptation actions currently being undertaken to deal with increasingly volatile weather- and climate-related risks. Here, I attempt to answer the question, broadly speaking, of how those most exposed and sensitive to changing climate conditions are experiencing those changes, what actions are being taken in response, and what paths forward might lead to more successful outcomes both for rural livelihoods and the state as a whole.

In Part II, I shift scales, turning toward the water management and use systems of the Colorado portion of the South Platte hydrological basin, where diverse livelihoods, values, and economic patterns all play a role in shaping the state's most populous, rapidly growing, economically productive, and agriculturally intensive region. Typified by significant water-related challenges centered around the over-appropriation of existing surface water resources, heavy reliance upon trans-basin diversions and groundwater withdrawal, and an increasingly culturally divided populace whose views on water system management vary widely, the basin's future character and resilience remain an open question, both in the face of climate change, and in its ability to adapt to increasingly dramatic processes of demographic, cultural, and livelihood system change. In this section, then, I attempt to answer the question of **1) how the many key stakeholder groups operating in the basin perceive, value, and understand water resources**, and 2**) how these patterns of valuation are inflected by their positions within the water system**. I do so with a mind to provide actors within and peripheral to the water management system with a more thorough grounding in the cultural landscape – and numerous challenges and opportunities it represents – as they attempt to collaborate on the evolution of the region's character over the coming decades.

Throughout this project I rely upon what could be described as a compound lens, cobbled together from elements of socio-ecological systems analysis (Ostrom 2009), socio-hydrological systems theory (Sivapalan et al. 2012), anthropological inquiries into the functioning of water and land-based livelihoods (e.g. Brondizio et al. 2013; Boelens et al. 2016; Galvin et al. 2016), and other related frameworks relating to process of hazard vulnerability and adaptation. That is, it conceives of the human populations, living ecosystems, and non-living components of the environment as complex, adaptive systems whose configurations through time are bound by feedbacks operating at diverse temporal and spatial scales in a co-evolutionary fashion, and in which cultural systems – of norms, beliefs, laws, behaviors, and ideas – operate as the mechanism and substrate of these processes of co-evolution. Within this framework, the complicated and often counter-intuitive socio-hydrological systems of water infrastructure, management and law that exist within these systems are likewise but one of several subsystems within this larger coextensive network of environments, non-human species, physical processes, chemical flows, individuals, groups, and institutions, being both bound by the physical realities of water and shaped by the ambitions and desires of the human actors that value it and the environment's many, diverse uses. Similarly, land-based livelihoods, such as ranching, farming, fishing (and fishing guide work), river rafting businesses, outdoor recreational tourism-focused businesses, and so on are similarly viewed as distinct set of human-environmental-hydrological linkages, within which human traditions, behaviors, and desires interlock with specific environmental processes in patterned ways through time, with each living and non-living component of the livelihood system influencing the others along the way. Along these same lines, cities and communities can be thought of as quasi-living systems, whose human populations, operating under cultural and social drivers and through the cultural mechanisms of technology and institutions work to build the network of physical connections to resource systems surrounding those cities, often in patterns that link them to increasingly distant resource systems through both physical and virtual means.

Moreover, the social and cultural systems that operate within socio-ecological and socio-hydrological systems are conceived of as operating in variously hierarchical ways, with access to resources, technology, and certain domains of resource use and behavior being privileged and limited to specific portions of the population. In the United States, this expresses itself mainly in the form of economic inequalities, systems of racial and ethnic discrimination, and systems of legitimized authority and institutional power that ascribe certain domains of action, violence, and performative agency to specific members of society based on educational, class, economic, or familial attributes. As a result, they are inflected by patterns of diverse vulnerability to hazardous system states, with some individuals and portions of society likely to face disproportionate impacts either through their heightened sensitivity to those hazards, limits to their adaptive capacities, due to increased rates or types of exposure, or some combination of the three (see Smit and Wandel 2006; Blaikie et al. 2014; Adger 2006; Turner et al. 2003; Fussel 2010). Land-based livelihoods, for their increased exposure to natural weather phenomena, increased sensitivity due to dependence upon living environmental systems or livestock, and often limited adaptive capacity due to costs of land and water or attachments to specific places, are therefore seen as particularly vulnerable to both current natural hazard profiles and future hazards associated with climate change. Water management and use systems, likewise, are also seen as being particularly important sites of vulnerability, as they represent the interface between often highly variable systems defined by natural precipitation which bring with them both the essence of opportunity – reliable access to water – and many of its most dire hazards, such as floods, drought, and damage to critical ecosystem processes. Moreover, as will be discussed in more detail below, these types of systems are often tightly linked, with urban water demands and use patterns often interacting in dramatic ways with the viability of land-based livelihoods, be it for good or ill.

What these frameworks are brought into service for, however, is not so much the expansion of existing bodies of academic knowledge, or the development of novel synthetic frameworks. Rather, what I hope to lay the foundation for with this work is to put these at-times disparate bodies of knowledge to service for the betterment of the decision-making, advocacy, and civic participation processes that shape both the South Platte and the state as a whole. To this end, Part I is presented in a manner suitable for public consumption by interested readers, and includes significant background information on the state for those who may not be familiar with the complexities of its character. Part II, while written in a more traditional academic style, is also meant to point towards improving existing efforts within the state to collaboratively imagine, plan, and execute projects to secure its water supply future, doing so through the interrogation of the multi-dimensional value systems encountered in water-related discussions in the region. Going further, I attempt to highlight what the findings of this work might mean for novel approaches to public education, engagement, and participatory adaptation planning in the context of on-going developments in innovative approaches to agent-based simulations, scenario planning, and related work.

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PART I: CHANGING WEATHER AND LIVELIHODDS IN RURAL COLORADO: A REPORT ON 21ST CENTURY IMPACTS AND ADAPTATION IN THE FARMING, RANCHING, AND OUTDOOR RECREATION SECTORS.

Executive Summary

Introduction

This report attempts to provide members of the policy-making and land management community with an introductory understanding of the broad array of issues facing rural and mountain communities in Colorado due to extreme weather events and changes in historical weather patterns. In addition, it aims to introduce the wide array of conversations – and strategies for action – currently being undertaken with the aim of adapting to these challenges. It is based, in large part, upon on-the-ground observations made by people living and working in rural and mountain communities of the state. Sources for these observations include conversations held in 2018 with actors in the ranching, farming, and recreation sectors, as well as local news coverage, government and non-profit sector reports, and the academic literature.

Key Messages

Rural communities are a critical part of Colorado's economy and way of life

Depending on the definition used, rural communities a

re home to between 500,000 and a million people in Colorado as of 2018. Though these communities are diverse in character, style of life, environmental situation, and economics, they are all characterized by some degree (often great) of connectedness with and dependency upon the iconic natural environments for which Colorado is well known. Industries related to farming and ranching have long been a part of many rural areas – as well as the state as a whole – and continue to play a central role in all areas of the state. In rural communities found on the Western Slope, and in the state's high-elevation mountainous areas, outdoor recreation and tourism – be it in the form of skiing, rafting, hunting, fishing, hiking, climbing, or otherwise – are also a critical and growing part of both local and statewide economic activity.

Rural communities are vulnerable to weather-related disasters and long-term change

As weather patterns and the occurrence of extreme weather have shifted over the last few decades, connections to natural resources and environments – as well as the character of rural communities themselves – have meant that the impacts to rural lives and livelihoods have been particularly acute. Due to diminished response and recovery resources, many small rural communities face difficulties in dealing with wildfires, floods, and other extreme events. Due to heavy dependence upon agriculture and outdoor landscapes, drought effects both rural economic well-being and the viability of rural communities as a whole. In mountain towns, where tourism often plays a prominent role, resources to adapt may be more readily available. However, even well-resourced rural areas face significant risks and future challenges should long-term drought, temperature rises, and increased extreme event occurrence continue as they have since the turn of the century. In many cases, the intensity of these risks go well beyond those faced by large cities.

Adaptation to challenging environmental conditions is a part of rural life, but significant barriers exist for those hoping to address current and future challenges.

Livelihoods that depend upon the land have long required those who practice them to pay careful attention to weather and other environmental conditions, and to respond in prudent ways. In

Colorado, numerous efforts are already underway to help farmers, ranchers, and recreational businesses of all sorts find ways to deal with the "new normal" of 21st century weather patterns and variability. These include practices within businesses – such as changing farm practices – as well as community- and regional-scale coordination to support rural industries and more effectively manage shared resources during times of stress. However, many rural communities face significant challenges when it comes to addressing weather-related risks. These include a lack of economic resources for program implementation, a lack of coordination at the local level around critical risk management issues, and pressures related to demographic and socio-economic factors that make implementing new strategies and shouldering the risks of innovation untenable. At the same time, rising demand for water from growing cities, rising prices for farmland, and increased population pressure on previously "isolated" mountain communities may place limits on adaptation options.

Policies and programs aimed at improving the well-being of rural communities must be rooted in local values and ways of thinking

Colorado's rural communities are highly diverse in terms of how they engage with global and national issues, including climate change. As a result, those hoping to find ways to build resilience and improve adaptation in vulnerable sectors like agriculture and outdoor tourism must find ways to work within existing, trusted systems for understanding science, land management best practices, and long-term weather patterns – be they national weather programs, Agricultural Extension services, county commissioners' offices, or regional business alliances. At the same time, Colorado's academic and scientific communities must find ways to become more engaged, at the ground level, with the needs of rural communities, both in the form of more practical research and development programs and in terms of bringing up-to-date information and science to trusted institutions within rural communities. Similarly, while national-level risk management programs (e.g., crop insurance) play some role in supporting rural communities during times of weather-related stress, the rapidly changing character of the farming, ranching, and recreational sectors mean that programs must be able to evolve to meet on-the-ground needs and new business configurations. This is particularly true as the state aims to support growth in diversified farms and more localized food production systems.

For while the risks that Colorado's rural communities face are real, and are already having severe impacts in many areas, adaptation has always been a part of rural life, and will likely continue to be so as global scale changes are felt at the local scale. However, adaptation is neither easy nor cheap, and if changes occur too rapidly or with too great of an intensity, even the most resilient community may face no option but to abandon the ways of life that have defined this state for over a century. If policy-makers, planners, and resource managers aim to avoid this outcome, then a dynamic approach to learning about, engaging with, and supporting rural community well-being will be required.

Introduction

Significant work is underway across the United States to better understand how changes in the global climate are shaping impacts at the national and regional scale.[1] However, whether one is planning national policy, regional land management, urban water infrastructure, or simply next year's crop, long-term climate information and regional weather trends are not enough to ensure adaptive and efficient decision-making. Much as with politics, all adaptation is *local*, as it is local communities that experience weather, perceive it, react to it, and try to make a living within its narrow range of mercy. To achieve goals of reduced vulnerability and improved resilience in rural communities, decision-makers at all scales need to understand how the systems they are tasked with supporting operate on the ground. A key part of this is understanding how local people living with day to day weather conditions are impacted by and respond to the challenges their environments present. Few places make this principle more obvious than Colorado, whose diverse terrain, climate, local communities, and ways of life make generalization a risky endeavor, at best. Here, where if you do not like the weather, you need merely wait – and if you don't like the people, you just have to drive to the next town – local perspectives are a critical source of information on how changes in global climate are impacting everyday life. and, more importantly, how we might take steps to adapt to the challenges caused by these impacts. This is especially true in the state's many rural communities, where livelihoods and ways of life are often tied closely to the surrounding lands, livestock, wildlife, pastures, and forests – all of which are already responding dramatically to increased temperatures and more variable precipitation.

This report aims to collect insights into just these local-scale interactions between people and weather, with a specific focus on rural communities. In contrast with other assessments that examine statewide climate trends or specific threats to resources using official, scientific resources,[2] this document aims to gather together stories from the people across Colorado whose daily work brings them into close contact with the local-level consequences of the state's changing weather. It hopes to shed light on how rural communities across the state – whose economies are linked to local weather dynamics in intense and complicated ways – are being affected by and responding to both changes in weather and the natural resource impacts those changes cause.

In this, our primary goal is to provide decision-makers at the state and national levels with better information on how to ensure that policies serve to enable effective adaptation to mounting weather variability and extremes. At the same time, however, we also hope to demonstrate how global climate change, experienced on the ground as storms, drought, hail, wildfire, and other tangible weather-driven events, is already shaping the ways in which Colorado communities live, work, play, and manage their businesses. Because of this, this report also hopes to demonstrate just some of the numerous ways in which people across the state are already working to adapt to increasingly unreliable weather. Ranging from farm- and ranch-level strategies for resource management to grass-roots regional water conservation and watershed restoration efforts, Coloradoans – urban and rural alike – are already demonstrating significant capacity for innovation and adaptive thinking as the state's weather changes, much as they long have in the face of the state's already tumultuous climate.

That said, significant hurdles – some, owing the nature of weather impacts themselves, and others, to policy and resources – stand in the way of even the most ingenious and innovative communities. Although many are already making strides through the modification of long-established adaptation strategies in attempts to deal with drought, wildfire, or other readily observable weather phenomena, it is increasingly clear that new strategies and solutions will be required as changes in weather increase. Because of this, we also examine some of the practical, scientific, and policy approaches currently being discussed in Colorado communities, bearing in mind while doing so that, in a state as diverse as Colorado, no one solution – or even set of solutions – will likely be the answer to all problems.

The report is structured as follows: first, a general overview of the ways in which Colorado weather has changed over the last few decades and how it is expected to continue to change in the future. Next, we detail examples of how these changes are impacting rural communities and livelihoods across the state, both in terms of economic impacts as well as less tangible – but no less important – damage to deeply-rooted ways of life. We then turn to on-going examples of adaptation from across the state, and, finally, some of the solutions currently being proposed, both to specific adaptation challenges and broader barriers to building resilience.

This report differs significantly from most work on weather-driven risks, both in the focus of its analysis and the resources used in the process. In it, we attempt to utilize the experiences of practitioners of various land-based livelihoods – that is, ranching, farming, and various outdoor recreation-related businesses – to shed light on how changes in weather patterns across the state are affecting the rural economies and communities in which they play an important role. To do this, we rely upon a variety of sources, including telephone conversations with rural residents and organization representatives, news stories related to weather related impacts, the scientific literature, reports from various trade organizations and conservation groups, and a number of drought impact reporting and general resource management tools that integrate local-scale information. As a result, it is not meant to be either comprehensive in scope nor definitive in its descriptions. Instead, it is meant as but an introduction to the variety of complex challenges – and opportunities for adaptation – presented by changing weather in the 21st century to rural Colorado communities, both for those in the decision-making community whose experience with rural Colorado life is limited, and for those living in rural Colorado who hope to learn from the experiences of others across the state.

Changing Weather in Colorado

If someone were to ask ten native Coloradoans what the weather was like in their state, they might find themselves confused to hear a wide range of answers, no two of which seemed to describe exactly the same place. This would be no accident: with its towering Rocky Mountain peaks cutting through much of the state's center, its wide, sloping canyons along the western slope, and its broad grassland plains in the east, describing the "climate" in Colorado is an exercise in frustration – or at least, exhaustion – as its often chaotic terrain and position at the center of the North American continental landmass mean that its local weather patterns are defined by both high levels of diversity from one area to the next and wild levels of variability from day-to-day and year-to-year. Dependent upon innately variable atmospheric rivers of ocean moisture flowing down from the arctic and north-western Pacific coast, and north from the Gulf of Mexico, the lion's share of the precipitation in the state comes as the result of high altitude condensation, as water vapor suspended in the atmosphere is pushed upwards by the rapidly sloping terrain. As a result of this phenomenon, while the state's lower elevation regions may only receive between 10-15 inches of total precipitation per year, along the sides of peaks and in the highland valleys of the Rocky Mountains snow and rain can add up to nearly four times as much, with some peaks along the Jackson/Routt county line in northwestern Colorado seeing upwards of 60 inches per year. In stark contrast, some areas, such as the San Luis and lower Grand Valleys see on average fewer than 10 inches, while others, such as the lower Arkansas Valley in southeast Colorado, see much of the (relatively abundant) moisture they receive lost to high winds and heat in the form of evaporation. As a result of this unequal distribution of water, the relationship between the people of the state, the weather they experience in the places they live, and the weather that ultimately determines the water resources they rely upon is not always direct, as it is heavily controlled by the state's vast network of creeks, streams, rivers, ponds, lakes, and, perhaps most importantly, man-made water diversions. Because of these networks, water that falls and freezes on the mountainside is able to eventually make its way to the much drier areas downstream, enabling settlement, industry, agriculture, and a wide range of outdoor recreational activities. What this also means is that, no matter where you live in Colorado, local weather conditions and those in the (often distant) mountains upstream both work to shape how you experience daily life, and how – in many rural areas – you go about seeking your livelihood.

And while this has meant, for most of the state's history, that people in all walks of life have had to learn to deal with unpredictable and dangerous weather, recent decades have brought increasingly challenging conditions to many areas. Indeed, as another summer of extreme high temperatures, destructive wildfires, and costly drought conditions draws to a close, it seems more and more evident that the historically challenging weather patterns normally seen across Colorado are becoming even more intense. In this, the most consistent and readily observable trend has come in the form of higher temperatures, with the state as a whole having shifted over 2.0 degrees Fahrenheit above the 1900s average, with spring temperatures rising over 3.0 degrees over the same period (See Figure 1).[3] As a result of these climbing temperatures (and the state's already fickle

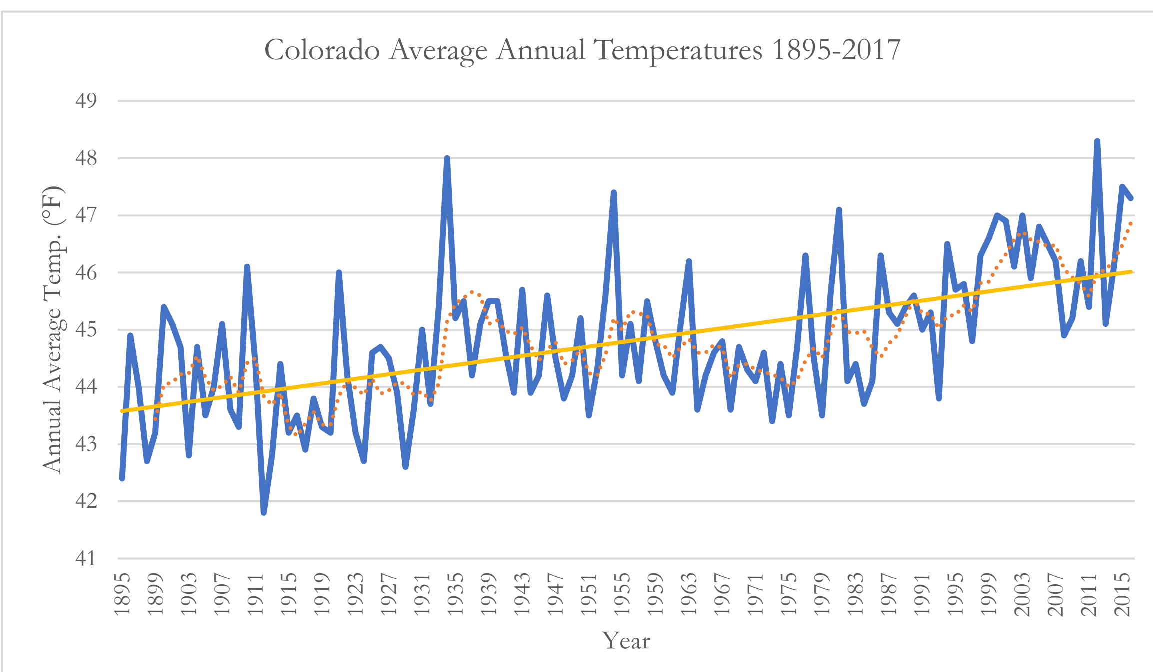

Figure 1 - Temperatures are rising across the state. Source: NOAA

precipitation), drought conditions – or abnormally dry conditions caused by either low rates of precipitation and/or extreme rates of evaporation due to heat – have been at the center of much of the shift in how Coloradoans experience weather. Although no stranger to drought during the 20th century, with the 1934, 1954, and 1977 droughts standing out for their extraordinarily low precipitation[4], in just the 18 years since 2000 alone, Coloradoans have dealt with numerous extreme drought periods, with the most hard-hitting impacts happening outside of cities. These include the multi-year 2002-2006 drought (whose economic costs surpassed $1.6 billion statewide), the 2007 and 2012 "flash" droughts, and now, in 2018, another year where almost one hundred percent of the state found itself facing some degree of abnormally dry conditions (See Figure 2). In the southern portions of the state (as is often the case), the result is people and environments dealing with plummeting reservoir levels, parched soils, elevated wildfire risk, and withered pastures. Much like other extreme drought years in the past, the 2018 drought was preceded by a general failure of the expected wintertime snowfalls in both the mountains and plains followed by an early snowmelt, resulting in rivers running dry far earlier than expected in many regions. When these conditions

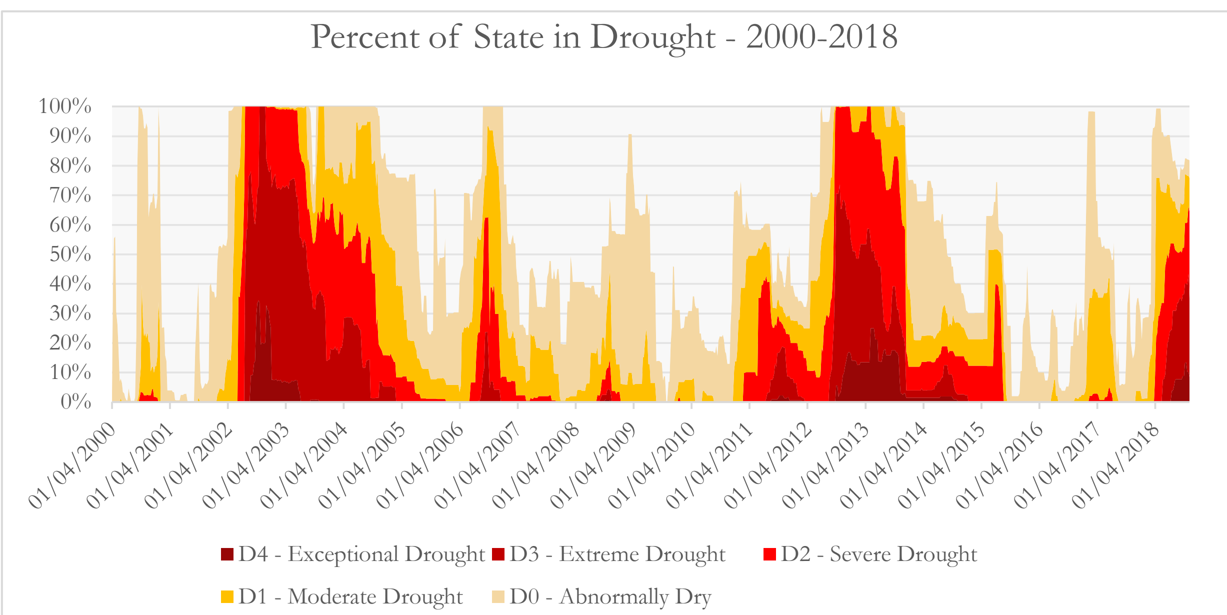

Figure 2 - Drought has been a mainstay of Colorado's statewide weather patterns over the last two decades. Source: U.S. Drought Monitor

combine with statewide trends over the last several decades toward higher temperatures that drive faster evaporation from soil and plants, the result is that extreme drought states are becoming more common. Indeed, many areas could be described as having experienced a full decade or more of long-term drought conditions, prompting questions about just how dry the new "normal" for some parts of Colorado is going to be. [5]

With these rising temperatures, while much of the change Colorado has seen over the last few decades has come in the form of water shortages - particularly during times when it is needed most – annual precipitation trends overall have remained more or less within historical ranges[6]. In Colorado, however, this means that the character, intensity, and magnitude of individual rain or snow storms has continued to present serious risks to Colorado communities, large and small. The 2013 floods that followed from intense rainstorms along the northern Front Range brought far-reaching impacts, with damage to property and infrastructure stretching from communities in the forested mountains to farming and oil and gas infrastructure on the northern Eastern Slope.[7] Alongside these sort of large, extreme events, numerous smaller-scale flooding episodes have come about from localized but intense rainstorms. Similarly, in small headwaters and ski towns, earlier and more rapid snowmelt has meant more intense peak flows over shorter periods of time, often pushing river management infrastructure to its limits. Hailstorms, similarly, have shown new characteristics, with several "plowable" hail events (which result in large accumulations of hail, requiring road plowing) having been observed since 2000[8]. At the same time, watersheds across the state, often parched due to drought, have shown evidence of becoming less able to absorb moisture when rain finally falls, ultimately resulting in more intense surges of water moving through rivers and streams. When high altitude storms occur in areas recently burned by wildfire, in particular, runoff

Quotes from the 2018 Drought

From the CoCoRaHS Drought Impact reporter, found at droughtreport.unl.edu

"While there have been some scattered rain showers around the San Luis Valley, there has not been enough to make a difference. The drought is persisting. Pastures are becoming short, cattlemen are in quiet desperation looking for pasture and hay that is affordable. The heat has crops well ahead of normal by anywhere from 2-3 weeks. Surface irrigation ended last month for all but the most senior water rights and without any subsurface moisture that is not going very far. Full fire restrictions are in place throughout the SLV on both public and private lands. Tourists are having to restrict their recreational activities. Warm water is affecting the fish, and wildlife is moving to water from the public lands." – Rio Grande County, 07/9/2018

"One fruit tree is dying, vegetable garden is mostly dead, because Grand Junction (nearest station to us) has had <14% of normal rain so far this summer. We irrigate from water collected off our roof (mostly as melted snow in winter) and since the winter had hardly any snow, we have now run out of water. Native plants are doing poorly as well." – Mesa County, 07/19/2018

"Native grasses haven't broken winter dormancy. Pasture has zero growth for 2018 grazing season. Ranchers feeding cattle. Herds being liquidated or put into feedlots." – Otero County, 07/6/2018

rates and the corruption of streams by debris and ash have created increasing concerns about water quality and treatment in many areas (e.g., Writer et al. 2014).

Wildfires, for their part, have also been showing signs of shifting to a new, more dangerous "normal," with fires burning with greater frequency, broader scope, and higher intensity than in the past across much of the state. Although a natural part of the long-term lifecycle of most of the state's varied landscapes, a century of fire suppression, growing development in areas with heavy vegetation, fire-prone invasive species, and more intense drought episodes have all combined to create fire impacts far beyond the historical norm. In fact, of the roughly 2.5 million acres burned in

"Very dry in Bent County and the western part of Kiowa County, already starting to cull cows, other people are talking about sending cows and calves to feedlot or early weaning calves and sending both to feedlots separately. The irrigation canals are saying 5 more runs of water in storage, water is not going across the fields and lots of fields are being fallowed or prevent planted. It looks like the dead of winter if it wasn't for the bar ditches being green. The rains have been very spotty and the high heat and winds have killed what moisture has come." – Ben County, 06/28/2018

"The wind has been horrible, very hot and dry, irrigation water is not going across the field like it should and people are taking cattle to the sale barn. Reports of people early weaning calves, and sending cows to the feedlot and out of state have also been reported" – Lamar, Prowers County, 07/10/2018

"Still very dry. We've been teased by rain in the distance, but no moisture here. Not even wildflowers are growing here this year. Disappointment Creek is noticeably lower than even a week ago. No green. The ground is very parched ... or as a visitor yesterday put it, "naked." The water truck is still watering the gravel while everybody else wonders how they're going to continue hauling water to cattle. BLM is watching the drought closely on behalf of the Spring Creek Basin Herd Management Area mustangs, ready to haul water when needed, which will be soon." – Redvale, San Miguel County, 05/22/2018

Colorado between 1980 and 2016, nearly 2 million did so after the year 2000, including a growing number of extremely large, multi-week fires, with many individual fires growing to tens of thousands of acres[9]. In addition to their effects on water and erosion, these fires have also changed the quality of our air, with low air quality an increasingly serious problem across much of the Front Range as smoke from fires mixes with pollution from local transportation and industrial activity.[10] In 2018, many areas across the Front Range and beyond experienced severely impaired air quality due to both nearby fires and those burning across much of the northwestern portion of the North American continent.[11]

In short, the historically fickle weather patterns found across the state are changing. In most cases, they are becoming more extreme, more unpredictable, and more punishing to those who fail to heed their risks. As global trends toward higher temperatures and more unpredictable precipitation patterns continue, Colorado will likely face even more challenges from changing weather in the future, particularly in places where water is already scarce, landscapes are vulnerable to fire, and demand for both is growing. In rural areas, in particular, the stakes are high, as these areas are often both short on the infrastructure needed to deal with issues like floods, fire, and drought and long on the number of ways in which tempestuous weather can damage livelihoods and ways of life. In the following chapters, ask: if the weather in Colorado is changing, how is it affecting the state's numerous, diverse rural communities? And more importantly: what are those communities doing to deal with the challenges they face?

Where (and *who)* is "Rural" Colorado?

Numerous definitions exist for what "rural" means, ranging from the simple to the complex. In the former case, rural areas are simply those with low population overall and low population density, i.e., the number of people per square mile. In the latter case, rural areas are defined by both low population density and limited access to modern services, such as hospitals, law enforcement, fire protection, water provision, and universities. In Colorado, however, access to cities alone does not a city dweller make, as numerous areas with deep connections to rural livelihoods find themselves increasingly close to rapidly growing urban centers. As a result, we expand our definition of rural to include those areas where land-based livelihoods – such as ranching, farming, and outdoor recreation – are seen as an important means of economic activity by local residents. In addition, we also include those who, while potentially living in cities, rely upon natural landscapes and ecosystems for their livelihood and culture, such as hunting guides, recreational outfitters, river rafting companies, and fishing guides.

Because of Colorado's diverse environmental contexts, not all rural communities face the same set of challenges, nor do they experience common challenges – like drought – in exactly the same ways. For the purposes of this project, we divide the state into five areas that correspond roughly to major environmental, social, and long-term weather patterns, and that thereby help to distinguish between the specific circumstances of rural communities across the state. These are, in no particular order: 1) Northeastern Colorado, which includes the Front Range cities in and north of the Denver metro area, as well as Greeley, Sterling, and other medium and small towns in the South Platte and Republican River basins; 2) Southeast Colorado, which includes the Arkansas and Purgatoire River basins, the large cities of Colorado Springs and Pueblo, and the numerous rural communities located in the eastern plains; 3) South Central Colorado, including the San Luis Valley and the surrounding mountains; 4) Southwest Colorado, including the headwaters of the San Juan, Dolores, and Gunnison rivers; and 5) Northwest Colorado, which contains the Yampa, White, and Upper Colorado rivers, as well as the largest concentration of people in Colorado outside of the Front Range, in cities around and upstream from Grand Junction. In each of these areas, we also distinguish between the lowland areas (here, areas below 7000 ft. in elevation) and the highland, mountainous areas (areas 7000 ft. and above), as weather and ecosystem hazards are highly influenced by elevation and local topographic complexity.

In the following pages, we provide several maps that attempt to illustrate how people and their communities are distributed across each region, and how they fit into different classifications of "rural." We also provide several maps that illustrate what it means to live in these different areas, both in terms of local weather patterns and the overall nature of the local environment.

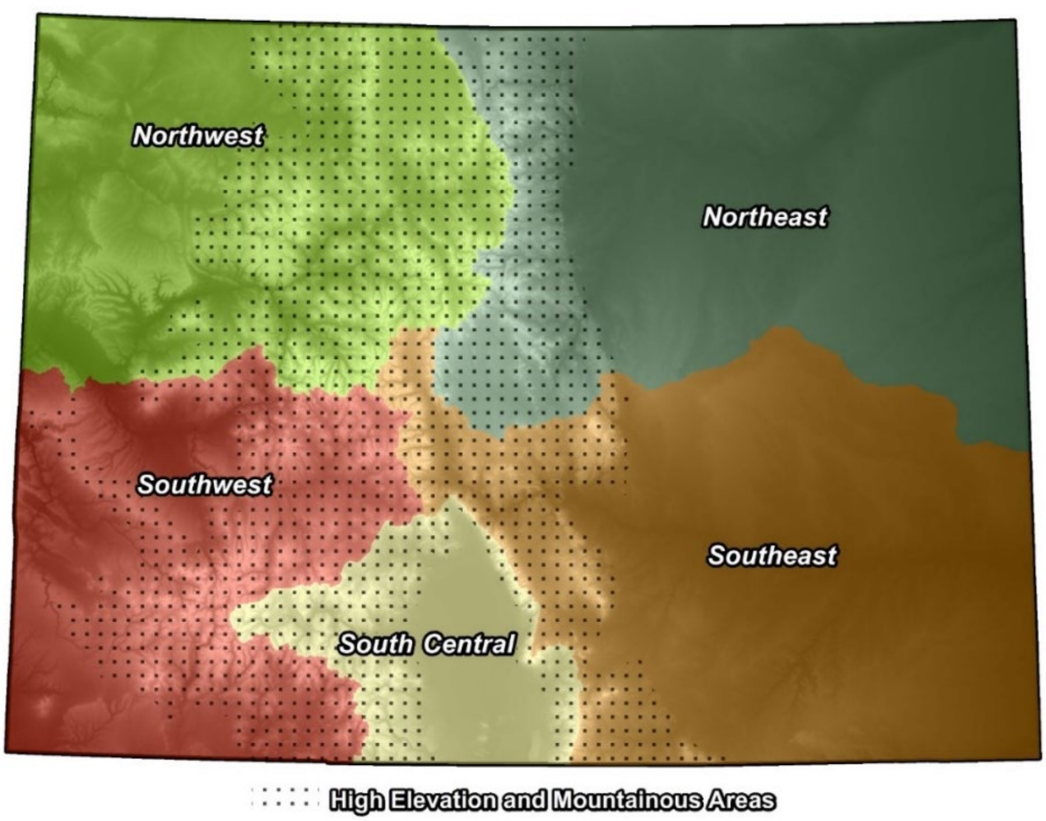

Figure 3 - Regions referred to in this report.

Population

The state's population is far from evenly distributed, and owes much to where settlers in the late 1800s found ready access to water and natural resources. Today, roughly 80% of the state's population is concentrated along the northern-central Front Range, which runs roughly from Fort Collins in the north to Pueblo in the South, including the large and rapidly growing cities of Denver, Boulder, Aurora, Longmont, Greeley, Colorado Springs, and Castle Rock. The rest of the state, however, shows a highly dispersed pattern of settlements. In the western half of the state, communities are largely confined to the small valleys and parks found between the many peaks and canyon walls of the southern Rocky Mountains. In the east, vast grasslands – now given over to irrigated and dryland agriculture, are home to numerous small towns and isolated homesteads, some of which have been within the same family for over a century.

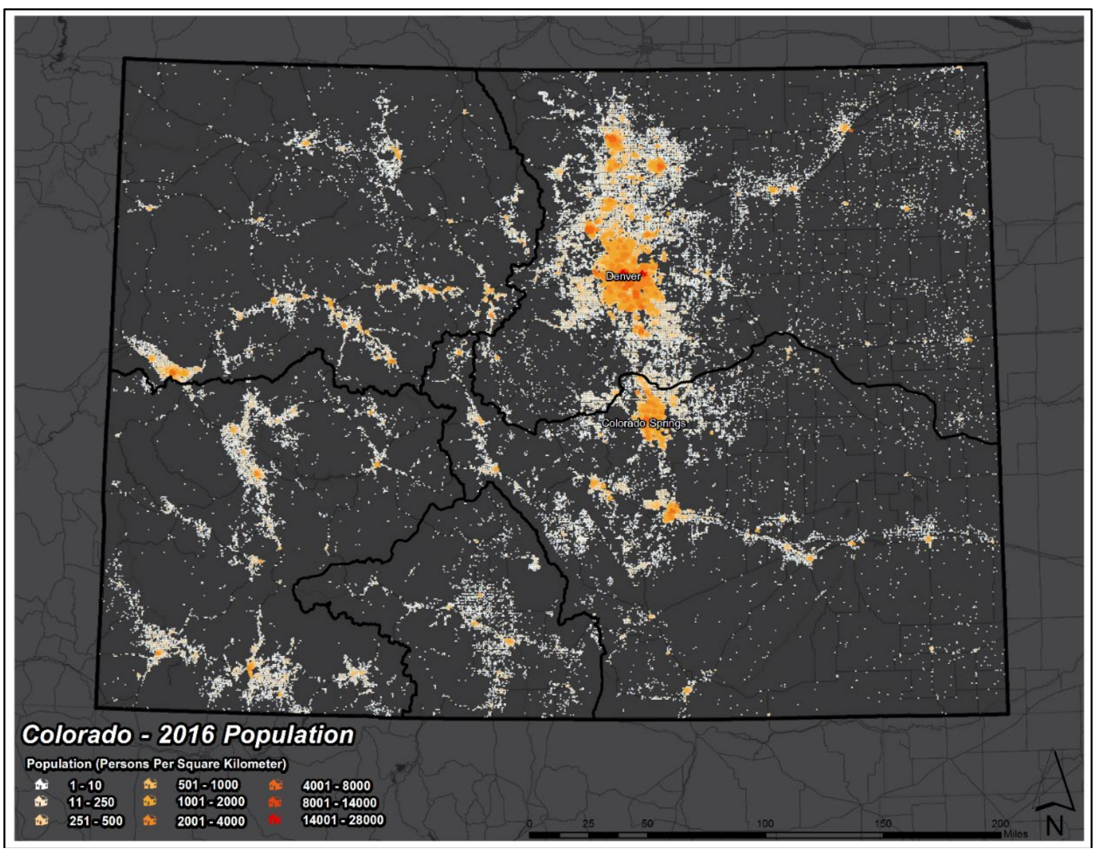

Figure 4 - Population data from LANDSCAN, a high resolution dataset that models human habitation at the square kilometer scale. Lighter colors represent areas of habitation with low population density, i.e., areas likely to be seen as "rural."

Services

Rural communities in Colorado are often faced with a lack of local services, such as general hospitals capable of conducting complex procedures. Similarly, fire-fighting, law enforcement, and emergency management capacities may be minimal or, in the case of major disaster events, insufficient. In many areas, access to the internet – and in some cases, cell phone service – is highly limited. Infrastructure in these areas, unlike in cities, is also often a highly individualized affair, with ranches, farms, and isolated resort communities managing their own water supplies on-site, and often connected to regional power grids by single transmission lines. In mountainous areas, transportation can also present serious challenges, as floods, fires, and extreme snow storms can quickly block or destroy roads entirely.

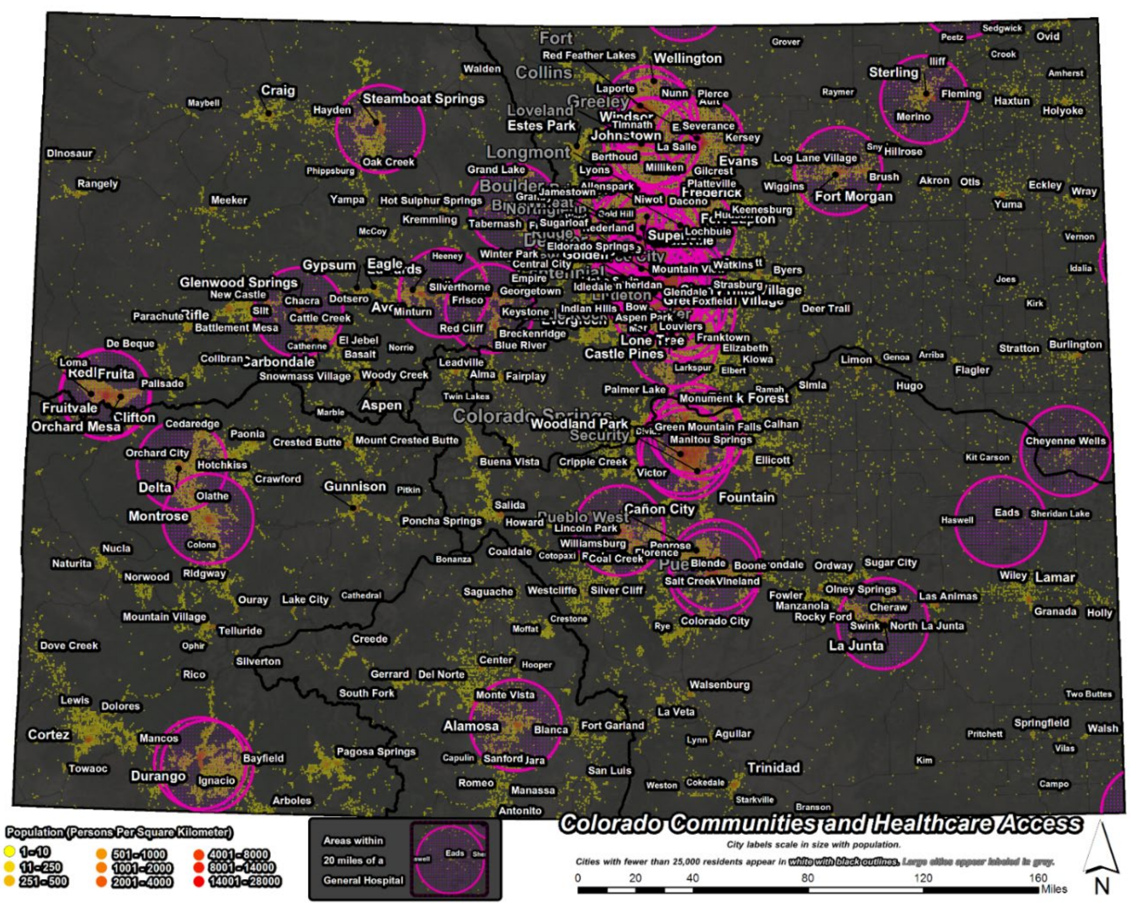

Figure 5 - Access to healthcare is often a serious challenge in many of Colorado's rural communities. When serious accidents occur, help may be hours away, and special medical procedures may require evacuation by air to Denver or other large cities.

In addition to limited access to these essential services, many rural areas are also isolated from universities and other institutions that can provide specialized training. In Colorado, the Colorado State Extension Service and various USDA programs have long attempted to bridge this gap. Nevertheless, many areas remain disconnected from the scientific innovation and inquiry that is concentrated within Front Range cities.

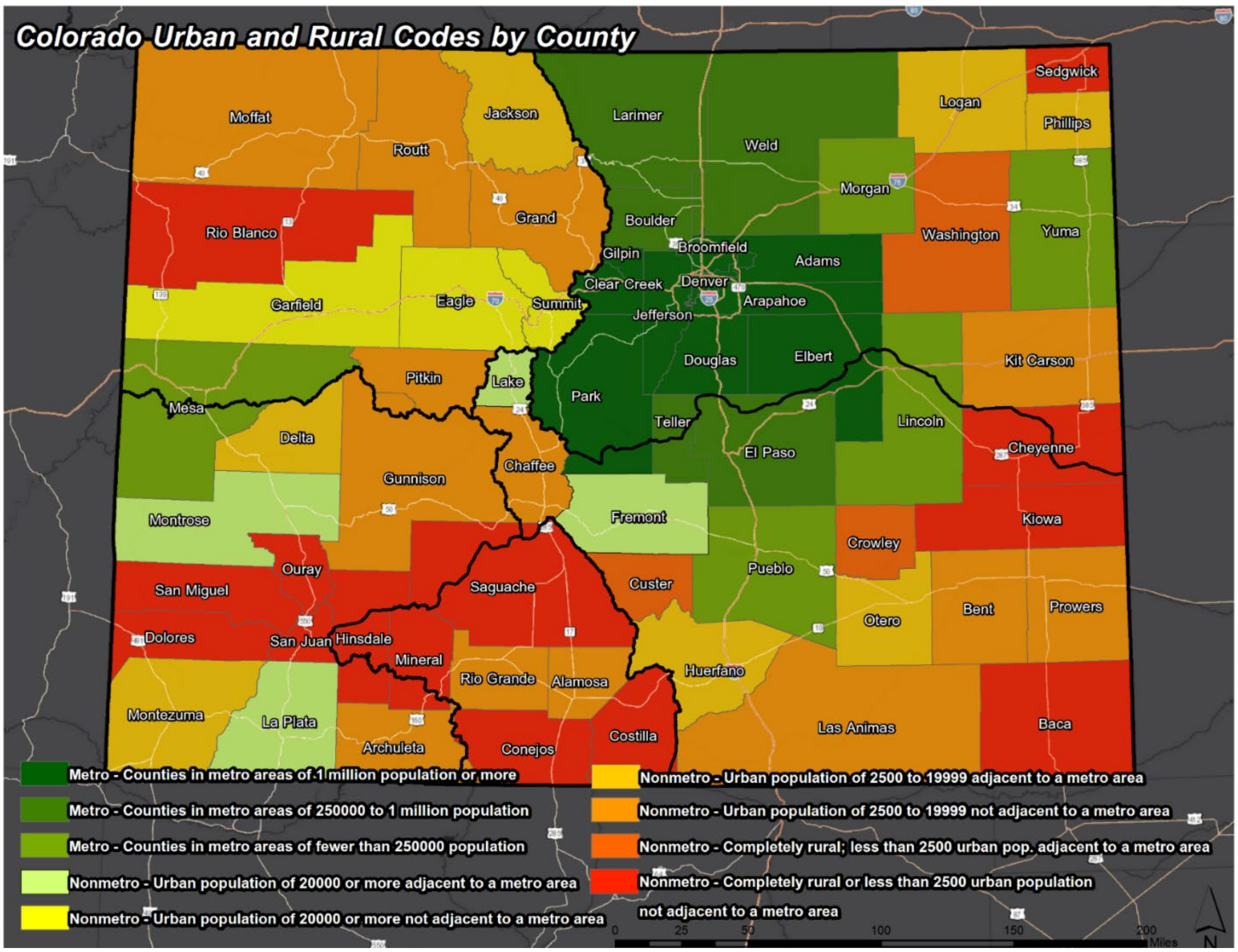

Figure 6 - "Rural" is a matter of degrees. The USDA utilizes the above coding scheme. Areas in orange and red are generally the most isolated, sparsely populated, and furthest from cities.

Socio-economic Vulnerability

Rural communities may also face greater than normal challenges due to issues such as poverty, low educational attainment, or aging populations. While some rural areas show high levels of wealth – for example, Aspen, Vail, and to a lesser extent, Steamboat Springs – many communities must deal with higher than normal levels of poverty, limited economic development opportunities, and minimal options during times of weather-related stress. In some areas, particularly in the southern and central Eastern Plains, population levels have fallen as younger generations move to nearby cities and elderly residents die off. Many rural areas in Colorado are also undergoing rapid demographic change due to immigration, which may hinder efforts to communicate and coordinate around natural resource and weather-related issues.

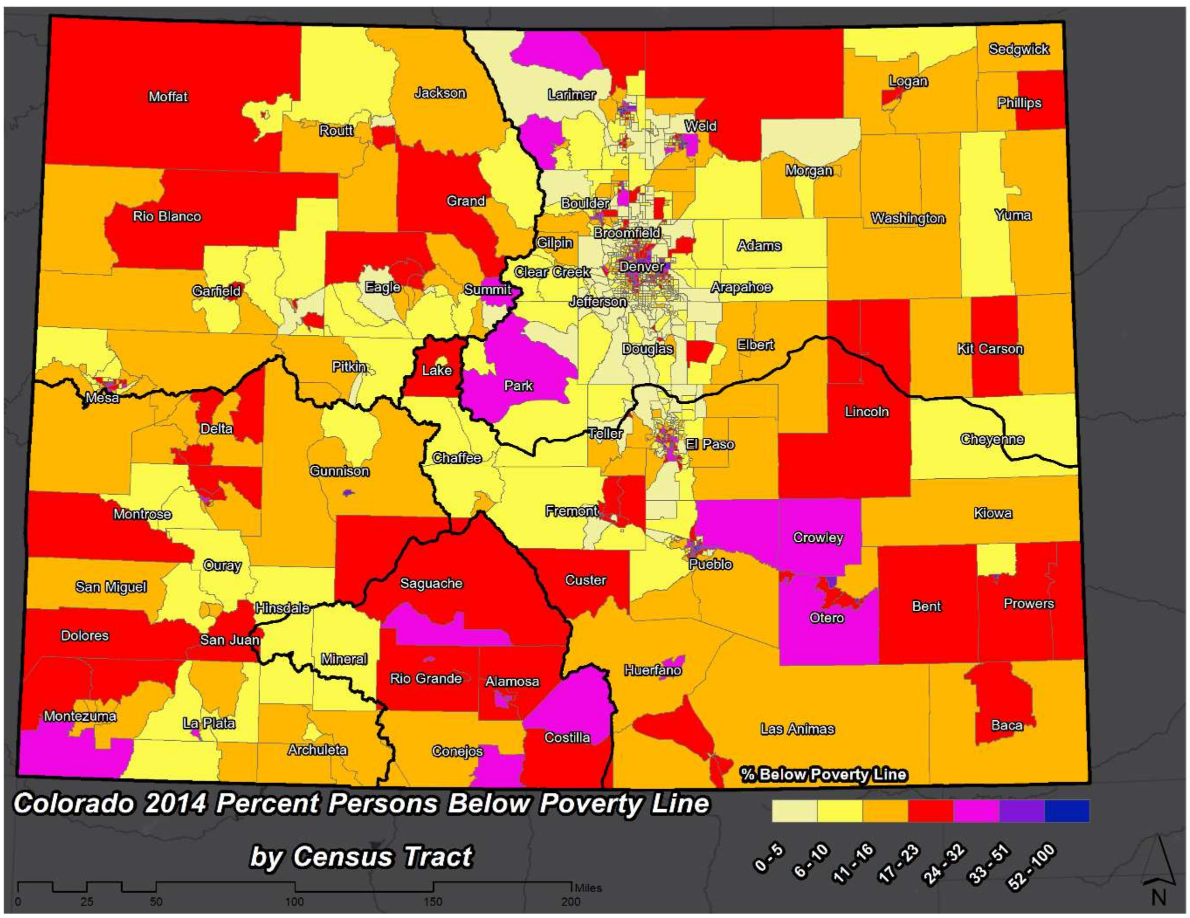

Figure 7 - Poverty and other socio-economic problems are no strangers to rural Colorado. At the same time, many rural areas have high levels of financial and other forms of capital. However, even in wealthier areas, small pockets of low income citizens are common, creating an increased likelihood for negative impacts following extreme weather events.

Resource Access and Weather

Many rural communities in Colorado must deal with the seemingly paradoxical distribution of ecological resources that characterizes the state. With most of the state's water supply located in high elevation areas, and most of the viable lands for farming, ranching, and living located in lowland areas, tremendous effort must be undertaken to move water to where it is needed and valued most, and to manage that water as it moves across and out of the state. Because of this, droughts can have effects that span well beyond the localized areas in which they occur. Likewise, water needs downstream can affect water users elsewhere, due to the state's complicated system of prior appropriation water law. While groundwater resources are available in many areas, these resources are often non-renewable, and are prone to collective overuse, particularly during drought periods. Many rural areas – particularly those in the eastern half of the state – face significant pressure to sell

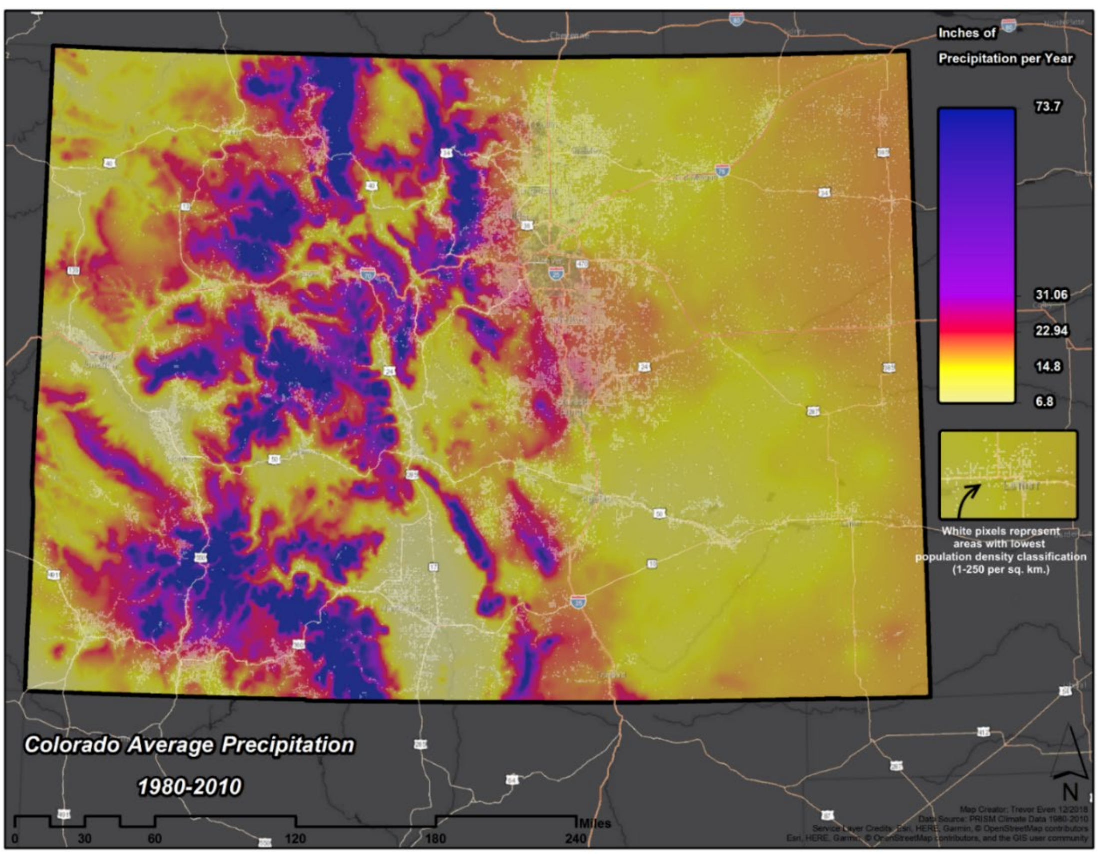

Figure 8 - Precipitation from the PRISM global dataset. Many rural areas in Colorado receive very little native precipitation and must rely upon groundwater and surface streams to meet their water needs.

agricultural water rights (which may be "senior" due to having been passed down for decades through families and specific farming operations) to growing cities along the Front Range.

At the same time, rural areas may also face heightened exposure to certain weather-related hazards, such as wildfires, hailstorms, tornadoes, and extreme precipitation events. Mountain communities, for example, may have access to majestic natural beauty and valuable recreational resources. During drought periods, however, these prized landscapes present serious risks in the form of wildfire and subsequent flash-flooding due to those same resources entering a volatile state. In the plains, broad, flat lands suitable for farming and ranching face high winds and extreme storms, and are highly vulnerable to both local droughts and failures of snowpack. Without snow in

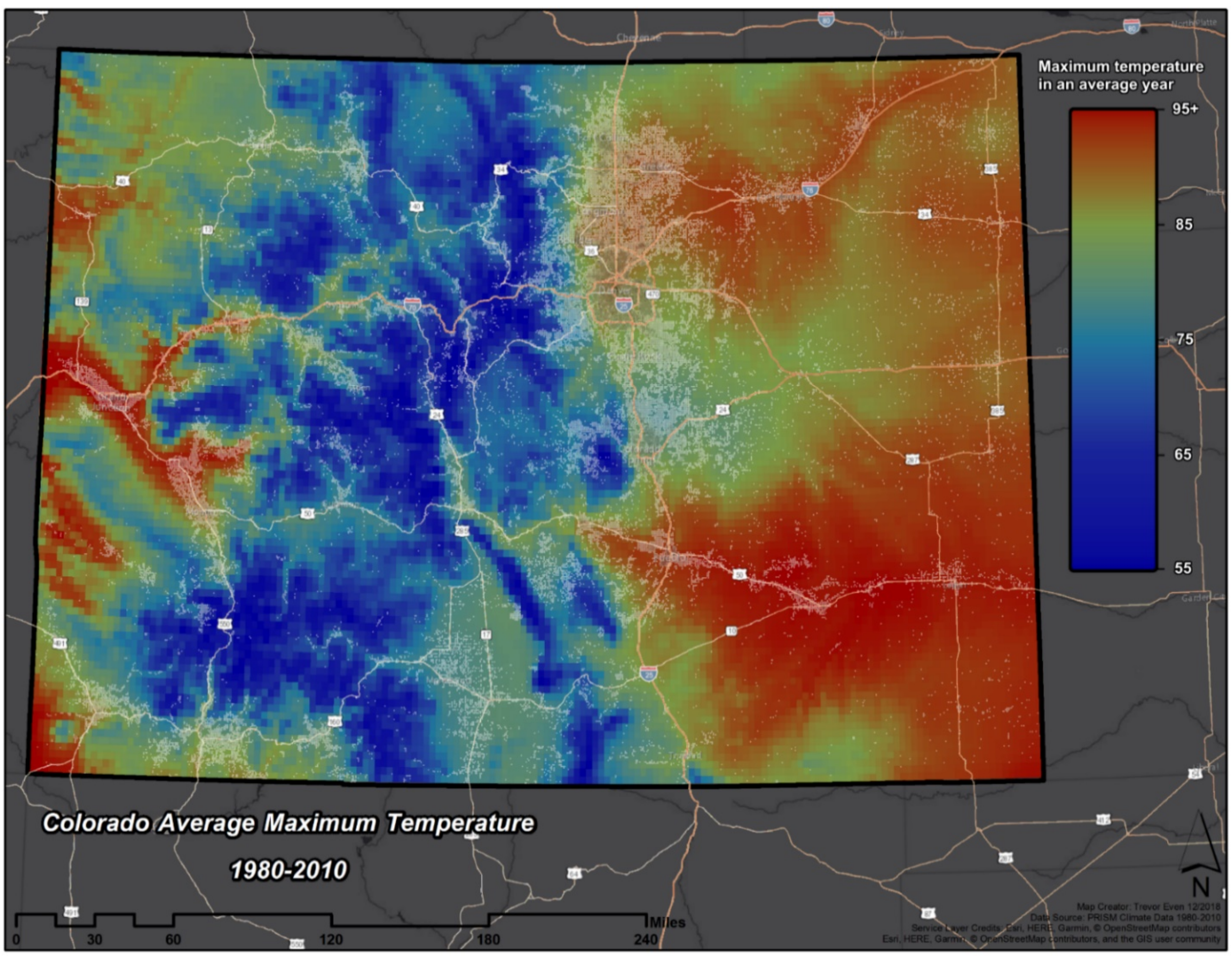

Figure 9 - Temperature from the PRISM Global Dataset, averaged over the period of 1980-2010. Because rural communities often rely directly upon the land for their economic well-being, high temperatures can result in losses well beyond the cost of additional air conditioning.

the mountains, plains and valley communities may be forced to go without the water they rely upon for human consumption, irrigation, and livestock. Many rural areas also see high temperatures during the summer, which may result in negative impacts to human health as well stress to crops, livestock, and the native vegetation that livestock rely upon. In the 21st century, many of these areas have also seen an in increase in days with temperatures above 90 degrees as part of the overall trend of rising temperatures across the state.

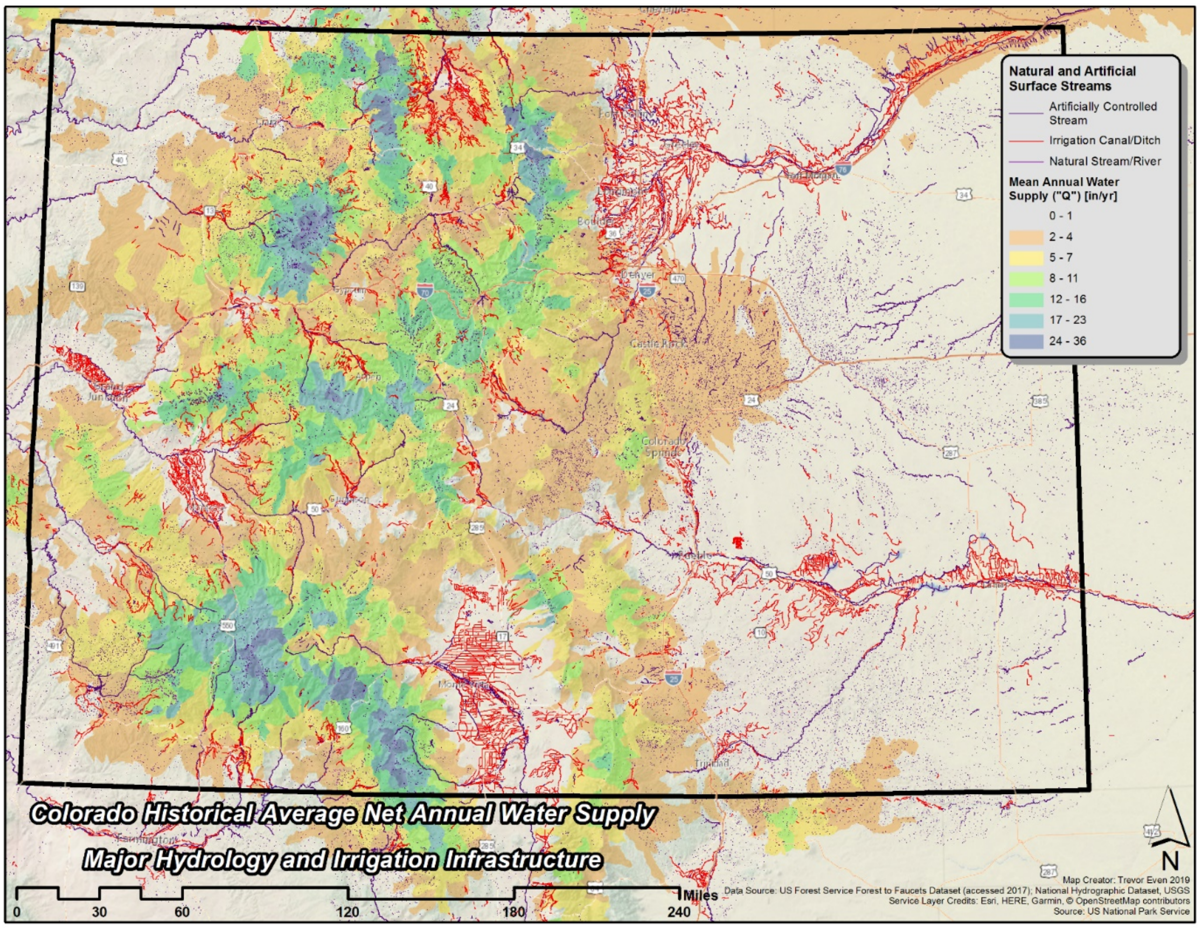

Figure 10 - "Q", a water supply metric that subtracts water lost to evaporation from average annual rainfall. (Provided by the USFS Forests to Faucets Program). Irrigation is critical to rural livelihoods, but many areas face serious issues in maintaining this infrastructure (shown in red here).

While cities along the Front Range may be able to invest in complex infrastructure to reduce water usage and improve water transmission efficiency, many rural areas face degraded or aged infrastructure issues at both municipal and industrial levels, and may rely upon irrigation systems that have been in place for almost a century. Though these systems are critical to agricultural livelihoods, especially, complex issues surround their improvement and maintenance further heightening risks from weather shocks to rural communities.

Effects of Extreme Weather and Disasters on Rural Livelihoods

In the previous chapter, we looked at some of the broad, statewide changes in weather that are shaping Colorado in the 21st century, drawing on a variety of scientific sources and weather monitoring information providers across the state. However, to truly understand how these changes in weather are impacting everyday Coloradoans, it is important to look beyond broad trends, and to understand how people living day-to-day with weather impacts are perceiving and responding to these changes. This is particularly true when considering Colorado's hundreds of small rural and mountain communities, where livelihoods and ways of life are often tied closely to surrounding lands and their response to various weather conditions. In this chapter, we attempt to capture some of the stories being told about the weather in rural Colorado today, bringing together information from personal conversations, news stories, and other on-the-ground research projects examining these issues. Our question here is straightforward: How is changing weather affecting rural Colorado communities?

Even beginning to answer this question, as we will see, is rather complex. To simplify matters, then, we focus on three distinct – but often overlapping – livelihood sectors: agriculture, ranching, and outdoor recreation, including hunting, fishing, river rafting, skiing, and various other outdoor activities. We do this, primarily, because these are livelihoods known to characterize the economic backbone of many rural communities across the state, and moreover, are often central to the values and ideals of many who choose to live in rural communities. From a scientific perspective, however, these livelihoods are especially interesting when considering weather impacts, as they are all united in their close relationship with the vicissitudes of the surrounding environment and the weather that shapes it. Whether a business owner is guiding tourists down a raging river, moving cattle to new pasture, or planning next year's crops, they must do so while always carefully considering what weather is going to give them – and what it might take. As a result, the perspectives of those engaged in these "land-based livelihoods" represent news from the "front lines," so to speak, in the state's attempts to come to terms with the risks, challenges, and opportunities that changing weather patterns present.

In the following sections, we present findings from our research into each of these three broad sectors and attempt to highlight some of the unique features of each that have allowed recent shifts in weather to present distinct challenges to them. That said, while the concerns of particular businesses and business types may vary – especially when taking into account the varied landscapes across Colorado on which they occur – it would be a mistake to assume that these sectors live and breathe independently. On the contrary, in many rural communities across Colorado, farming, ranching, and various recreational livelihood strategies often go hand in hand, both within a given town and, at times, within specific families. This is doubly true for the landscapes that these livelihoods rely upon, as much of Colorado's land-based livelihood community utilizes lands that serve multiple purposes, at times with multiple parties being involved. This complexity is most distinctly felt in the central mountains and western slope, where public lands administered by the U.S. Forest Service and Bureau of Land Management form a critical component of the region's natural resource base. Here, recreation, agriculture, and ranching often closely overlap as tourists, locals, livestock, nearby farms, and wildlife all vie for their part of resources scattered across a patchwork of private and federally-managed lands. As a result, while some of the impacts we will discuss may be specific to a given industry, for those who depend upon the economic vitality of rural communities, they never occur in isolation.

Ranching

Ranching has been a long-standing livelihood in Colorado, and the grazing lands, people, and livestock that make it possible have played an at times out-sized role in shaping the state's history, law, and general settlement patterns. Currently, over 20 million acres statewide (roughly 1/3 of the state) are used as pasture for cattle, sheep, goats, and other livestock, generating around $5-6 billion in cash receipts each year, and playing a powerful role in the state's $40 billion+ agriculture and food production sector.[12,13] As weather patterns change across the state, ranching operations – some of which have been in operation for 100 years or more – are finding themselves facing new challenges, from adversaries both old and new. Generally occurring on lands that are too dry for production agriculture, too rugged for easy navigation, or too remote for large settlements, ranchers in the state have always dealt with difficult circumstances and have had to deploy all manner of strategies to maintain healthy herds when rains fail, grasses wilt, and water sources dry up. In recent decades, however, cattle ranchers and other livestock herders across the state have found themselves dedicating more and more resources each year to addressing weather related risks, both from disaster events relating to extreme storms, flooding, and wildfire, as well as due to long-term drought trends. When these costs become too great, they can upset even the most resilient operation, and can have serious negative impacts on rangelands, cattle, water resources, ranchers themselves, and the communities they live in.

By far the most serious risk faced by Colorado ranchers is the increasing trend towards more intense and frequent drought episodes, as droughts can set in motion a number of different process which, while difficult enough in isolation, can converge to utterly devastate ranching operations. The primary impact site during drought for rancher, of course, is the landscapes that they rely upon for grazing, and the numerous different plant species and other resources that they contain. When drought conditions set in, grasses produce more slowly or not at all, and natural surface water resources become unreliable. As a result, grazing lands also become more fragile, and more sensitive to long-term degradation due to grazing activity. Because of this, during times of drought ranch operators must search for supplementary feed and water resources, as well as spending more time monitoring and moving cattle to ensure that what local resource pools are available to not become over-stressed. Each of these activities bear with them additional costs, even under the best of times, in the form of both labor and capital.

Indeed, during extensive drought periods – which often occur across numerous counties and states, prices for feed can increase prohibitively as other nearby ranchers also scramble for the resources they need to maintain herd condition. As a response to these stresses, both economic and environmental, ranchers will often choose to sell off part of their productive herd. But while this can reduce stress in the short term, due to having less cattle to manage and feed, in the coming years this reduced productive capacity means lower potential returns. Likewise, selling productive stock can also reduce the overall genetic robustness of the herd, further compounding long-term drought impacts as ranchers struggle to re-grow their diminished livestock numbers. Even for those ranchers who dedicate some of their land to growing supplemental feed – and who may, ostensibly, benefit from high prices during some drought conditions – often find that these measures also fall prey to the lack of water and high temperatures that have become more common in recent years.

As current drought conditions set in, variations of the same story are being told once again across much of the state. As one observer near Ordway put it, rather bluntly: *"Area ranchers are starting to destock. Feed is getting harder to find locally. Desperation point has been reached."* [14]Similarly, southwestern Colorado rancher Matt Isgar noted while speaking to Colorado Public Radio this summer that the cost of ranching is climbing as soil moisture and landscape productivity fall: *"We're spending more material and labor fixing fences and hauling water, and we're supplementing with protein [to offset the* *poor quality of natural vegetation]. So every day is more expensive to operate."* [15] Statements like these, common across the state's ranching community, are also echoed in some ranchers' perspectives on long term trends. One sheep and cattle rancher operating in Moffat County in northwestern Colorado described to researchers working for the Bureau of Land Management how the character of drought episodes has changed since the early 2000's, noting that:

> Until this last 5, 10 or 15 years of drought, usually a drought around here didn't last more than a year or two. So you didn't really see that spike and drop in the [price of] hay. But it's got more challenging the last 10 or 15 years after 2000-2002 drought. Things really have never ... We haven't got out of it and I really think to a certain extent in my own mind that we've been in a drought since the early '90s. Yeah, there's been good years and there's been a few bad but they've been more bad. You've watched springs run dry[…] Even like the Little Snake, it doesn't flow what it used to flow.[16]

Drought, however, can also increase risks for other hazards to occur, the most dangerous of which is wildfire. Across the state, wildfires large and small, driven in large part by drought conditions, have impacted the lives of ranchers in a variety of ways. Some of these impacts are direct, with wildfires damaging or destroying homes, outbuildings, or equipment; others are more indirect, with wildfires affecting the availability of forage and requiring a variety of costly measures to protect the lives of their families and livestock. And while, statewide, wildfire risks tend to be at their greatest in the heavily forested, high elevation areas of the state, out of control fires occurring in lowland areas have also proven increasingly dangerous to Colorado ranches and nearby communities.

Case in point, the Mile Marker 117 fire, which began in 2018 – likely due to sparks from a passing vehicle – somewhere just southeast of Colorado Springs, near the small, dispersed community of Hanover. Within 24 hours, over 40,000 acres would burn, stretching from the

Fire on the Southeastern Plains

Part of a large extended family of Colorado homesteaders with deep roots in the ranching and agricultural sectors, T__ E___ runs a successful landscaping business in Colorado Springs. In the last several years, he had been slowly working to establish his own ranch just outside of Hanover, located roughly 30 miles north of Pueblo. Having had extensive experience with post-fire remediation and planning for wildfire risk as a landscape technician, he worked to make sure that his home and property were clear of debris, well irrigated, and isolated from dense vegetation. Nevertheless, when the 117 fire erupted, he ultimately found himself able to do little but watch as his home caught alight as he attempted to defend his ranch's outbuildings from encroaching flames. Though he was able to save his herd, and much of his equipment, the home he and his wife shared was completely obliterated. As he related to a local news station: "I just froze … I could tell that our house was on fire and just the shock of it… the firemen said there was nothing they could do. It was already burning up in the attic" Though he plans to rebuild, he hopes that in the future firefighters and area ranchers will be better able to cooperate and share information on the location of hydrants and other critical infrastructure, which can often be hard to discern in minimally developed rural areas.[6]

cottonwood-lined banks of lower Sand Creek near I-25 to prairies and ranchlands 20 miles to the east. Driven by extreme winds, high temperatures, and pervasive drought conditions, the fire would present significant challenges to local and county firefighters dispatched to the area, where a lack of familiarity with the area and a scarcity of readily available water forced them to pick and choose their battles amid hostile conditions and on-going dust storms. Less than two days after it began, the fire would cause significant damage, destroying 18 homes and 21 outbuildings, several among which were small farms and ranches whose entire land holdings were likewise incinerated.[17] As one resident of the area related to a Colorado Springs television station, the intensity and pace of the fire – as well as the hostile weather conditions that led up to it – made even finding the charred remains of her home a challenge: *"The wind, the smoke, and the sand, it was hard to see what was left of the house. I can't rebuild out here. I don't have enough money to do that."* [18]

And while in years past such a large, destructive, and rapidly growing fire would likely stand out for some time to come, the dry, hot conditions across the state in 2018 would mean that the 117 fire would soon be eclipsed by numerous others across the state. Indeed, as the summer set in, several large fires across the state began to burn, among them the Spring Creek Fire, which would eventually burn over 108,000 acres of mountainous, forested land between the small ranching and farming towns of Fort Garland and La Veta.[19] Although started by human activity, the Spring Creek fire would grow primarily due to vast amounts of nearby drought-parched forest and strong, whipping winds, creating conditions that some fire professionals described as "a tsunami of flame."[20] By the time of its containment – more than a month after it began – it would destroy over 140 homes, displace thousands, and involve almost 300 full time fire-fighting personnel and 1,800 emergency responders (Inciweb 2018; Kackley 2018). [21]

For local ranchers and home owners in the area, however, the Spring Creek fire would bring more than economic costs. For some, it meant losing memories, knowledge, and labor embodied in the working landscapes they had cultivated over decades. This was the case for the Morgan family, who, as they related to the Denver Post, found themselves faced with the total devastation of their family ranch and cemetery after the Spring Creek fire swept through their property in mid-July. *"That was always Grandma's house for all my kids and all my nieces and nephew, too […] So that's why it's so hard on them not being able to experience that. It's a different way of life now."* Another family member, coming home to see the family land after living out of state put it differently: "*The land is what shocked me. When we walked up to the cemetery and up through the land, I couldn't recognize it. It was like walking on another planet. It was just burned to dust."*[22]

For other working ranches, however, the loss of homes, mementos, and cherished landscapes came with the added burden of needing to care for livestock, both during and after the fire. With ranchers in many cases being forced to round up herds, arrange for alternate pasture, move animals across long distances, and pay for supplemental feeding, the combination of persistent drought conditions and charred pastures meant that significant resources had to be expended simply to keep the possibility of recovery that their herds embodied available. As a result, even in cases where livestock are not lost directly to fire, lingering effects on the landscape can continue to drive up the cost of making a living in ranching for years to come.

This is especially true in the western regions of Colorado, where ranching livelihoods are often closely tied to the availability of public grazing lands managed by the State of Colorado, the USDA Forest Service, or the Bureau of Land Management. When drought and associated wildfire conditions occur in these areas, pastures that are normally available for grazing – as well as a variety of other activities – may be restricted by the relevant agency in order to maintain ecosystem integrity and allow for landscape recovery.[23] Because of this, ranchers and other livestock operators in the western portions of the state often face heightened impacts from drought conditions, above and beyond those normally experienced by those relying exclusively upon private lands. For while all lands, public or private, may see reduced forage availability when water is scarce, careful management and livestock movement can allow livestock operations to continue at reduced levels. On public lands, however, restrictions are often total, with no access to whatever reduced grazing resources remain. Similarly, lands may also be closed off to public use if wildfire risk is high enough, regardless of whether or not specific grazing allotments have actually burned. Indeed, in the northwestern part of the state – particularly in the Moffat, Routt, and Rio Blanco areas, where livestock production is relatively high – impacts from drought and wildfire can have serious impacts on the viability of livestock operations. Given that, as of the early fall of 2018, several large wildfires (e.g., the Ryan, Silver Creek, and Weston Pass fires) continued to burn, without significant increases in precipitation over the coming winter it is likely that many livestock operations in Western Colorado will face, at the very least, dramatically increased losses due to costs associated with hauled water, supplementary feed, and sub-optimal sell-offs of herds. At worst, already vulnerable operations may be forced to either reduce operations substantially, or simply terminate their operations altogether.

Farming

Farming, like ranching, has long been tied to the economy of Colorado, and has played a role in the development of all but the most high elevation settlements in the state, shaping local history, culture, and infrastructure development in ways both dramatic and subtle. Currently, Colorado farms generate between $2-3 billion in production each year from a range of crops including specialty items like hothouse tomatoes, cantaloupe, and potatoes, as well as more common staples like wheat, corn, and sorghum. In terms of pure land area, approximately 10 million acres (roughly 16.5% of the total land area of the state) are involved in some form of crop production as of 2017, with the largest acreage totals per crop belonging to winter wheat, corn, alfalfa, sorghum, millet, and hay.[24] However, as with most aspects of Colorado, statewide averages and totals only tell part of the story. Depending on which region of the state one looks to, the role of crop production – as well as which crop types dominate – varies substantially, with the San Luis Valley and Grand Junction areas relying heavily on specialty crop production, staple production dominating the landscape in the eastern plains, and alfalfa and other livestock feed crops playing a critical role in the numerous other rangeland dominated areas of the state.

Similarly, while farms (including ranches) only represent around 1-2% of the state's employment totals, (approximately 43,000 jobs in 2016[25]), in many communities the incomes generated by farms – as well as the need for supplies and equipment – provide the backbone of the local economy. Indeed, a drive through any of the many small to medium sized towns outside of the urban Front Range tells this tale all too well, with small "main street" rows of domestic storefronts

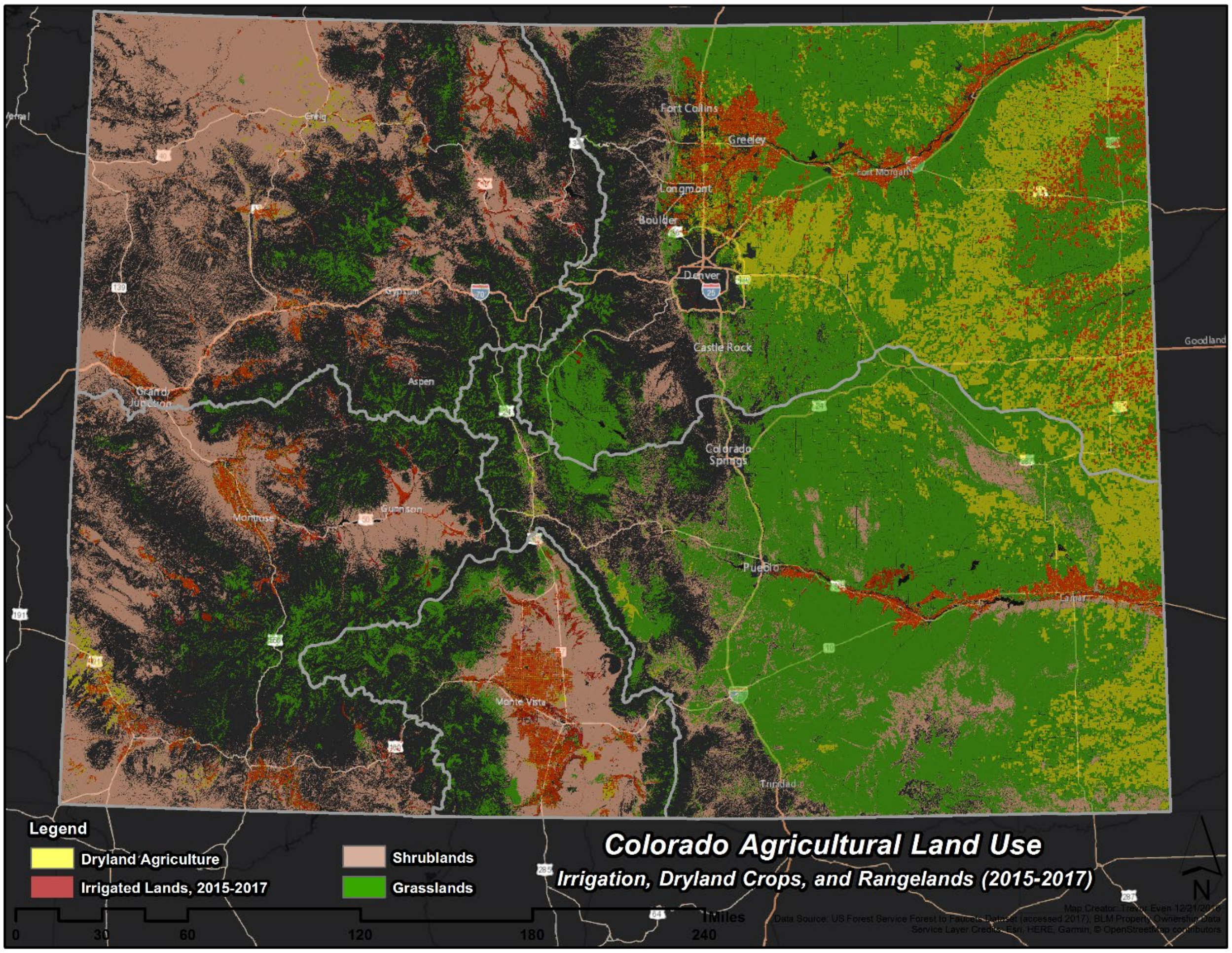

Figure 11 - Agricultural land use of varying intensities plays a massive role in the overall character of the state. In addition to irrigated and dryland agriculture, the state's shrublands and grasslands play a major role in ranching operations. In the western portion of the state, these areas also provide critical habitat for wildlife, and are home to a significant portion of the state's highly popular public lands destinations.

often ringed round by feed depots, ranch and farm equipment dealerships and repair shops, plumbing and construction supply outlets, and a variety of other agriculture-focused services, the sum of which, in many cases, comprises the entirety of a given region's opportunities for employment. Likewise, while rural towns in the state's mountainous areas are "hybridized," with recreational tourism, ranching, farming, and service industries each playing a role in local economic life, in all but a few of the rural communities in the eastern plains agricultural industries dominate both the surrounding landscape and the local social fabric. Because of this, the effects of destructive storms and drought to farms and farmlands can have impacts that reverberate beyond the confines of a particular farmer's acreage. That said, when hostile weather conditions occur, it is ultimately farmers and their families that bear the brunt of the negative outcomes.

But while farms may vary from region to region, and may differ in their ability to withstand weather impacts due to the decision-making skills of individual farmers and the specific crops they grow, one truth reigns supreme throughout Colorado's agricultural community: namely, that without *water*, there can be no crops. For farmers who produce non-irrigated, or "dryland" crops such as winter wheat, times of drought due to low precipitation or extraordinary heat can spell the end of a given year's ambitions as soil moisture levels rapidly decline. For farmers who rely on irrigation, however, the problem of drought is much less straightforward. In a generally semi-arid state like Colorado, where the state's water resources are often distant from lands suitable to planting or buried deep beneath the ground, access to water – particularly during times of drought – quickly becomes a challenge that goes beyond mere adaptation to local weather conditions, instead becoming an issue of technological mastery, legal maneuvering, bureaucratic navigation, and the

Flooding and Small Farms: Bethie S.'s Story[17]

A lifelong student and small time farmer who made her home just outside of the small farming and tourist town of Lyons, Colorado, Bethie S. was living the dream: with 11 acres of raspberries, pumpkins, and other specialty crops, she, her son, and business partners had been able to make a modest living off of what had long been her personal passion. Utilizing a small herd of goats for weed mitigation and llamas for herd protection, she and her partners envisioned an agritourism business that would allow local community members to enjoy the idyllic beauty of their streamside working farm. When rain began to fall in early September of 2013, however, much of her dream would soon become little more than a memory. While at first it seemed the small plot of land would escape the worst impacts being felt by others in the region, as rains intensified on September 12th and nearby streams swelled to unrecognizable size, she scrambled to gather her animals and valuables to safety before almost succumbing to the rising waters herself. Although able to rescue several animals, the slow slog of recovery and the area's skyrocketing housing prices would ultimately mean that she would have to give up for adoption the few animals she was able to salvage, and give up on the hopes of restoring the farming lifestyle she had worked to cultivate. Deciding instead to return to school to study sustainable agriculture, she now works through a non-profit agency to teach young farmers about traditional agricultural practices from around the world.

careful observation of statewide water balances. Put more simply, because of the state's complex system of water management and law, in which vast and varied engineering projects are managed through a system in which those with older claims on water are able to curtail water access for those with more junior rights (i.e., the prior appropriation doctrine), impacts from drought can take surprisingly indirect routes when it comes to which farms suffer and which do not. For those with senior rights, periods of water shortage can lead to placing restrictions on others within their community or far upstream by placing a "call" on all upstream junior rights holders. For those with junior rights, these calls can mean the total or partial loss of necessary irrigation water for the year, requiring either supplementation through groundwater pumping (if available), or allowing fields to go fallow in the hopes of better fortunes in the following planting season. When drought conditions are severe, the number of farmers who find themselves in this position can grow rapidly, with at least 165 calls on Colorado rivers as of September 2018, and 76 still active in November.[26] In some areas on the in the southwestern portion of the state, this has led to fruit growers spending hundreds of thousands of dollars buying water allocations from senior water rights holders, at times resulting in conflicts with local water and ditch company managers, and sparking fears that a failure in snowfall in the on-coming winter could result in a need to re-evaluate the sustainability of their businesses. As one corn, onion, and bean farmer near Olathe put it, "*This here is a tough racket, and this year is a tough one, for sure. We knew going into this season that we had enough water storage for the crop this year. What we don't know is if we'll have that next year. If we don't have water, it would devastate this valley. I'll just turn in my keys to the man at the bank and let him give it a go.*"[27] Even when farmers can weather the dry years – whether through crop insurance, federal programs, or careful saving and planning – long-term effects on soils can further hinder efforts to replant, particularly if drought conditions persist through the winter. In these cases, soils may remain without the necessary moisture for plowing and planting in the early spring.

For specialty crop growers producing tree crops like peaches, plums, pears and apples, however, drought impacts can mean the loss of trees that often represent years of investment and care. This can happen either through direct mortality due to lack of water, or through the weakening of the tree's ability to fend of pests and disease. In other cases, early warming in the spring time – so called "false springs" – can lead to fruit trees budding early, which, when late frosts occur, can cause almost total losses as the fragile flowers are damaged. As Keven Kropp, a cherry farmer on the western slope put it in 2015: *"It's every fruit-growers nightmare to have the combination of an early bloom with potential cold-fronts coming through later on in the season."*[28] Another fruit farmer in Paonia, speaking to the Delta County Independent in 2017, noted that, due to both early budding due to warming and the unpredictability of recent last frost dates, the fruit farming business was requiring the deployment of increasingly complex methods for fending off freeze damage, including installing large scale outdoor air circulation machinery. Reflecting on 20 years of experience in the area, he recalls that, if one were to talk to old timers in the area, "*they'd tell you they always had a cherry crop. Now it's the opposite. Everybody's scrambling.*"[29]

Regardless of crop types, however, changes in the onset of spring can bring challenges to farmers, even when the previous year's winter precipitation is at or above normal. For dryland farmers, early springs can mean that the soil moisture needed to make soils loose enough for planting may dry out before the last waves of cold temperatures have passed, resulting in soils that are difficult to penetrate when planting time finally arrives. Likewise, reductions in soil moisture early in the season can mean that crops are not able to germinate and accomplish early season growth as effectively.[30] For farmers who rely on irrigation, on the other hand, these issues with soil moisture can be exacerbated by early snowmelt in upstream watersheds that move water stored in snowpack downstream too early to be useful for irrigation purposes. And because water rights for irrigation are often associated with specific times of year, in years with particularly warm springs farmers may find that waters that they may, in the abstract, possess rights to use are already well on their way out of the state. [31]

But while a lack of expected water – both at the specific times when it is most needed and in

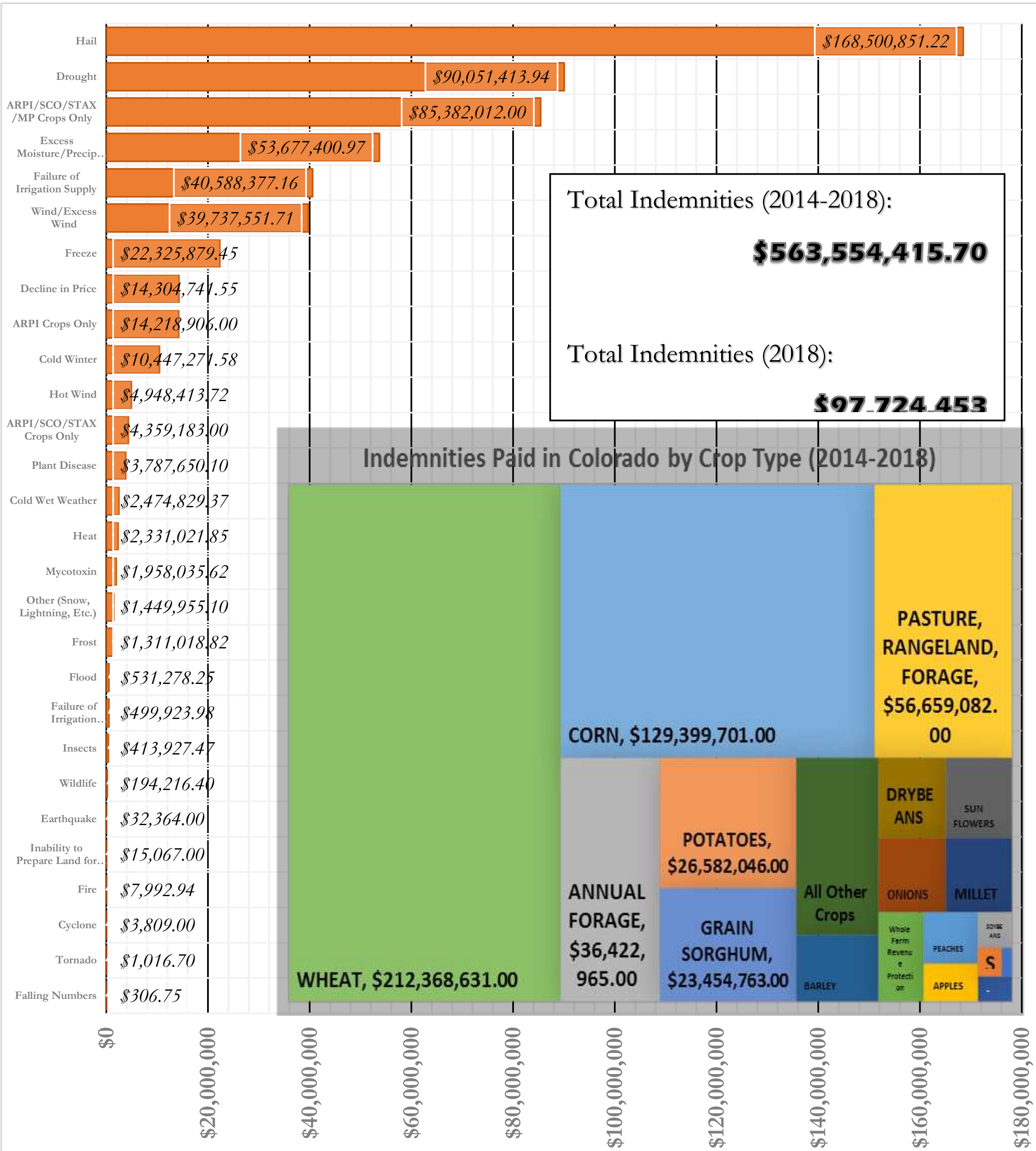

Figure 12 - USDA Risk Management Agency Crop Insurance Payouts in Colorado (2014-2018) by Cause of Loss and Type of Crop.

the more general sense - may be among the most deeply crippling outcomes of Colorado weather for the state's various farmers, too much precipitation can prove equally destructive. In 2013, when massive rainstorms brought several months' worth of precipitation to foothills and cities of the northern Front Range in a matter of days, much of the nation turned its attention to the numerous cities and mountain communities that suddenly found themselves inundated and cut off from the outside world. However, as flood waters made their way downstream, bringing with them tons of debris, silt, chemical contamination from up-turned oil and gas facilities, raw sewage from inundated treatment facilities, and biological contaminants from cattle processing and feedlot facilities, a much quieter catastrophe was unfolding in the fields of operating in the lower South Platte Basin east of Greeley. There, flood waters would bring around $5 million in direct damages to crops as over 25,000 acres of farmlands sat under stagnant water, in some places for almost a week.[32] And although exact numbers are not available, numerous reports of significant damage to farmsteads, equipment, ditches, fences – as well as lingering fears about contamination of crops that remained viable for harvest – likely resulted in millions more in costs to farmers in both direct damages and subsequent losses due to the inability to plant in the following season, with some state reports at the time estimating around $60 million in damages to irrigation infrastructure alone.[33] Adding insult to injury, because many of the smaller farms found scattered along the foothills relied heavily on local farmers' markets and organic, locally grown marketing strategies, fears of contamination and the closure of many markets drove down profits even for those who were able to salvage the year's sodden harvest.[34]

Beyond spectacular events like the 2013 floods, however, changes in the nature of the state's precipitation patterns can also have serious impacts on farmers that have relied upon the region's normally frigid winter temperatures to keep their fields and winter wheat crops free of disease. With more early spring precipitation falling as rain rather than snow, however, risks from disease like stripe rust have been noted in many areas during particularly wet spring years.[35]

Precipitation can also take a debilitating toll on agricultural operations when severe storms develop that result in the formation of hail. Such storms have long been a lamentable feature of Colorado's late spring and early summer weather patterns, with the vast majority of events occurring in the eastern regions of the state.[36] When combined with the driving winds that often accompany hail-forming stormfronts in the region, otherwise healthy crops can be reduced to nothing in mere minutes. In addition to direct destruction of crops, these storms can cause "lodging," or the breaking of stalks and failure to seed in wheat crops. If these storms occur early enough in the season, farmers may have a chance to replant their fields and hope to recover their losses. However, should hailstorms occur later in the growing period, losses may be total. As William Harman, a Logan County corn and sunflower farmer related to Denver's 9 News in 2017, late season hailstorms can result in the near total loss of a year's work, with even minor hailstorms able to significantly degrade yields through damage to sensitive plant organs: "*You put in a lot of work to get to this point, and it's all ruined in minutes… The corn was tasseling and pollinating, and that's a very crucial time. [Hail] breaks the tassles and the silk off, and the corn cannot pollinate properly. The sunflowers were budding, just getting ready to bloom, and yeah, it was about the most critical time it could hit."* As a result, his farm would see roughly $200,000 in losses, with only insurance and the hope of better luck next year to brunt the costs.[37] In 2018, a similar tale played out on the Hultrom farm located outside of Broomfield, when 200 acres of corn was reduced to ribbons in minutes. As Hultrom told KDVR reporters this July, "*It's the worst storm that I've had… to lose it all in about 15 minutes, it is tough. It's all gone."*[38] Similar reports have also come in from across the state, with some loss estimates for the 2018 crop year ranging into the tens of millions statewide.[39]

As a result of the long-standing risk of hail damage on the eastern slope of Colorado, many farmers take out insurance policies designed specifically to offset these risks, provided either by various federal government programs or private insurance companies. However, these are seldom designed to recover all losses associated with hail damage, and often pay out on a percentage basis depending on the value of a specific crop and how close to harvest it was when destroyed. Most policies are also written only for individual crops, meaning that small, diversified farms that serve local areas can be particularly vulnerable to large hail events due to a lack of insurance.[40] Insurance programs can also "max out," or reach annual payout limits due to successive destructive events, leaving farmers to deal with the tattered balance. This was the case for Hirakata Farms, a pumpkin and melon operation located in the small southeastern town of Rocky Ford. Having been prevented from planting during the spring of 2017 due to severe thunderstorms that left their fields unsuitable for furrowing, they tapped into funds available through the Noninsured Crop Disaster Assistance Program (or NAP), a program run by the USDA to support "non-insurable" crops like melons and other specialty products not covered by other major crop insurance outlets. Later that summer, however, those crops that they were able to get in the ground during the shortened planting window were severely damaged by hailstorms and straightline winds. When applying for additional NAP funds, they were told that they had reached their maximum allotment of payments for that year. As a result, the farm would see more than $300,000 in losses, a burden only heightened by this year's lingering drought.

To sum up, farmers provide an essential support to the rural communities of the state and face significant challenges to the viability of their livelihoods as a result of changes in weather intensity and variability. In some cases, this is a matter of too little water and too few of the social, technical, and economic resources needed to ensure its availability during times of scarcity. In others, it is a matter of too much water, be it in the form of floods or snow melting too rapidly to be of practical use throughout the season. In still others, weather brings direct destruction to crops and the land. In general, however, it is the increasingly unpredictable way in which these different challenges present themselves that poses the greatest challenge, as it hampers efforts to make adjustments that might help to reduce risks. As Michael Hirakata, the director of Hirakata farms put it, when asked what it means to be a farmer dealing with Colorado weather: *"Weather is getting more extreme. Though it has always varied from year to year, and every year has brought new challenges, the weather in the last 10-15 years has brought more variability than we've ever seen."*

Outdoor Recreation and Tourism

Best estimates of the current population of Colorado come in at around 5.5 million people. In 2017, roughly 38 million people visited the state for one night or more, half of which travelled more than 500 miles to do so.[41] Of these, about a quarter are estimated to be here to visit the state's growing cities, their business networks, and various casino resorts along the Front Range.[42] The rest – or just under 30 million visits – come for reasons that anyone who spends any amount of time here will easily identify: namely, *we live in a breathtakingly beautiful state*. Whether one looks to the stark prairies, wandering canyons, and desert dunes of the western slope or to the humbling peaks and forests that form the state's backbone, Colorado is known the world over as a place worth visiting. Its natural

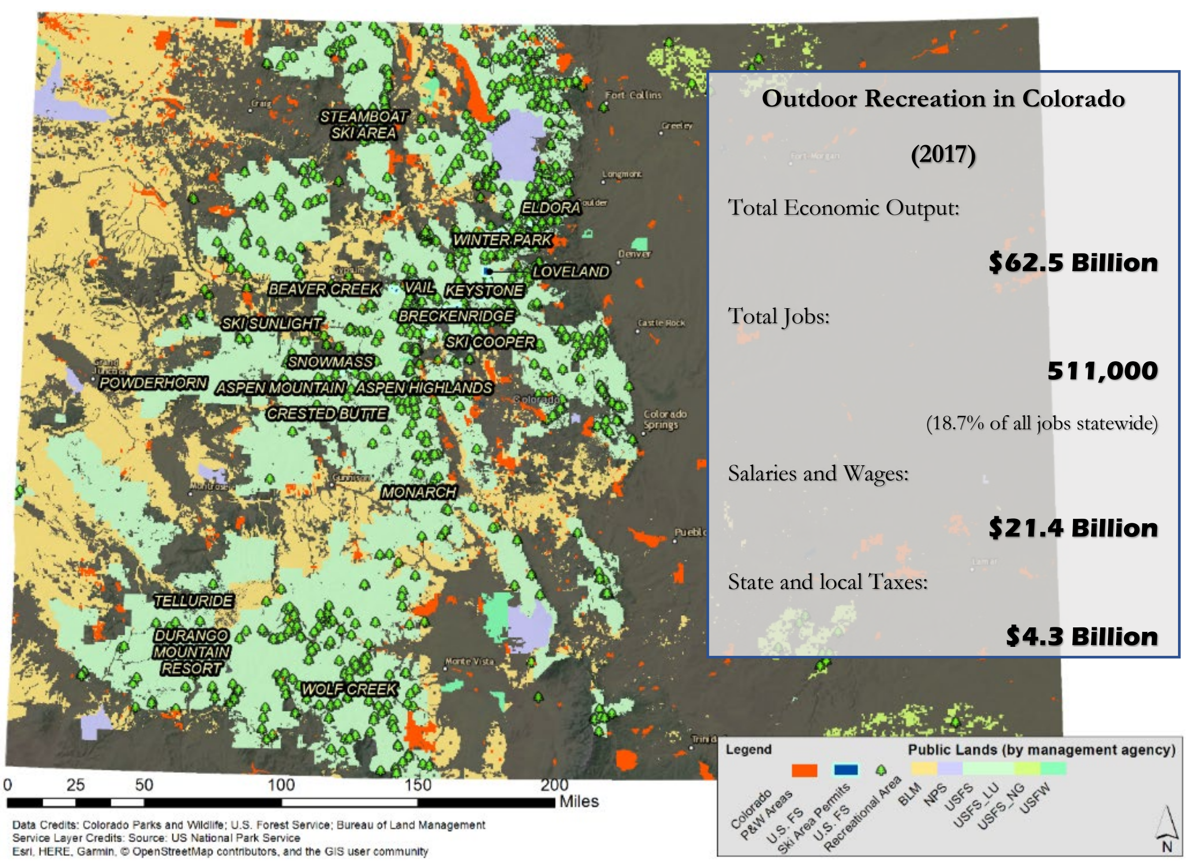

Figure 13 - Recreational land resources in the form of public lands, public recreational facilities, ski slopes (with names in all caps), and National Parks are concentrated heavily in the Western and mountainous areas of the state.
Not pictured here: the state's world famous rafting courses scattered across the upper Colorado, Yampa, Gunnison, Arkansas, and other rivers, nor roughly half a dozen privately-owned ski areas.

Silverton, San Juan County, and the 416 Fire

Tucked into a high elevation mountain valley just north of Durango, the former mining camp of Silverton lives and breathes on the state's local and international tourism economy. With around 600 permanent residents, nearly all economic activity in the town and surrounding county reliant upon tourism in some way, with over 60% of all jobs in the county in tourism related sectors. Small even by the standards of many mountain towns in Colorado, it relies heavily on the nearby national forests (88.7% of San Juan County is federally managed land), high intensity ski operations, and the Durango-Silverton Narrow Gauge Railroad, a working recreation of 19th century transport during the area's initial mining boom that ferries passenger to the town's center to shop in the various boutiques, galleries, and gift stores that make up most of the town's main street.

This year, however, has seen significant disruption to the year's normal rhythm as a result of the nearby 416 and other fires, whose smoke and resultant forest closures – as well as the closure of the Durango-Silverton railroad – meant that many local business owners were left little to show for what is normally their busiest part of the year. As one local store owner put it, speaking to the Durango Herald in June, "*It's hard on the locals. We work hard for five or six months so we can live off our own money for the winter. So, yes, I am a little worried.*" Others in town were equally concerned, with some celebrating days where sales approached 50% of normal, and others finding solace in having under-purchased inventory (Armijo 2018a). Total impacts from this summer's drought driven wildfire season aren't clear – nor is it clear whether snow packs will recover in the coming winter season. However, local estimates of total sales losses range from 15-30% of normal. [35]

wonders call out to even the most stubborn advocate of indoor living at least once in a lifetime, and more often than not experiences in the wild lands of Colorado come to play an important and cherished part in the lives of those who call our state home. As a result, while it is important to account for the massive economic impact of the vast and varied "outdoor recreation sector," it is equally important to understand that outdoor recreation – whether in the form of simple leisure activities like skiing, hiking, and camping, or more complex activities like fishing, hunting, environmental education, and river rafting – are an important part of what Coloradoans value about their state, and in many cases, a critical part of the local cultural fabric of local communities. This is especially true in the rural and mountain towns of the state, where recreational activity is both a major economic driver and central player in the making of everyday life.

Take, for example, the town of Steamboat Springs, located in Routt County. Just past the Continental Divide as one moves toward the northwestern corner of the state, it is home to the lion's share of Routt County's 20,000 or so inhabitants, and is built around welcoming visitors to their eponymous hot springs, local ski slopes, river courses, and surrounding public lands, with over a third of the jobs in the town and surrounding county coming from tourism-related industries.[43] Surrounding farms, while generally able to access regional and international markets, are nevertheless often tied closely to the local tourism economy in the area, as they sell to local establishments, draw from common labor pools of seasonal workers, and may, themselves, be involved in some form of recreational business. Similarly, specialized hunting guides, fishing guides, river guides, general outdoor outfitters, event coordinators, and a variety of local retail outlets all derive significant benefits from the attraction of the nearby ski slopes and other natural amenities, and these industries often absorb a portion of the ski resort labor force during the off season as well.[44]

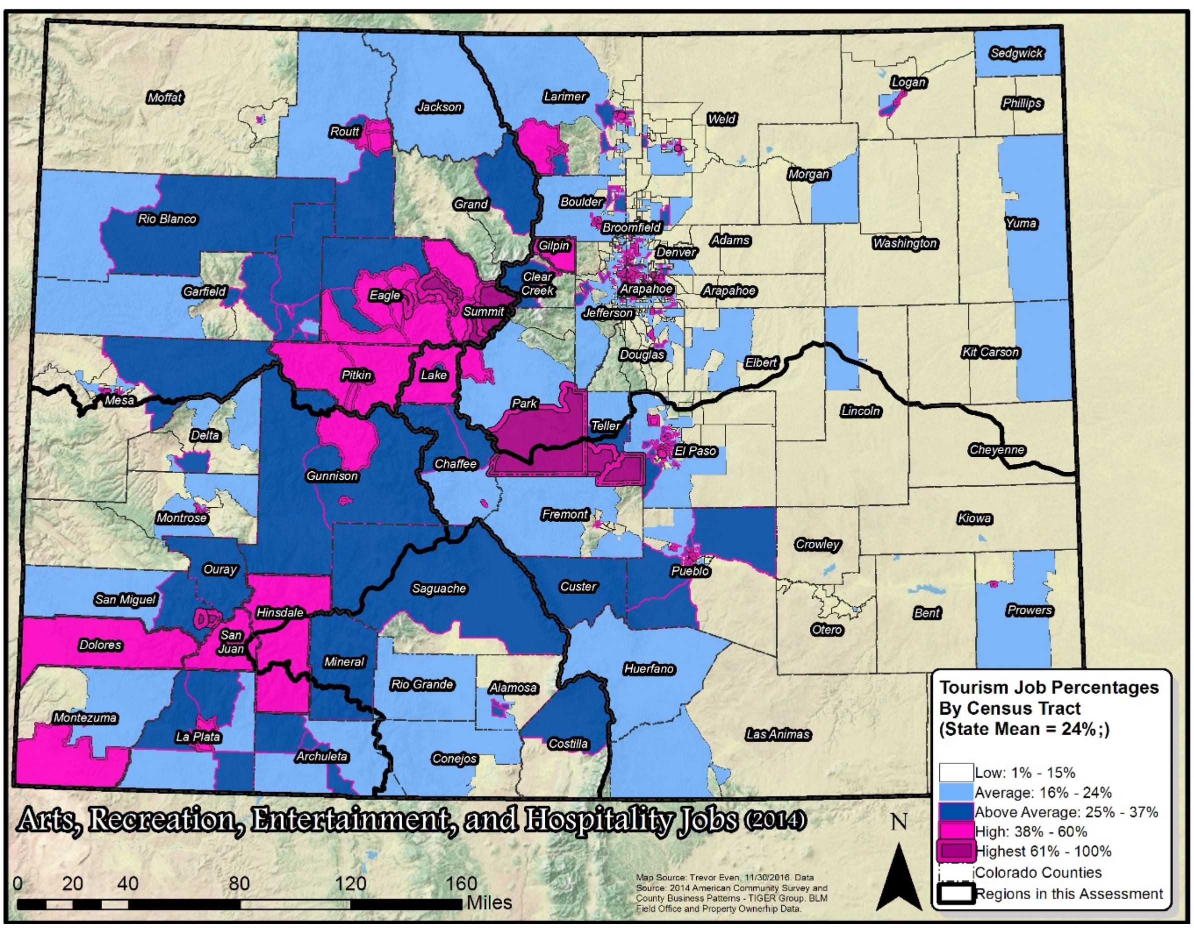

Figure 14 - In many areas of Colorado, tourism-related economic activity is the only game in town - i.e., the only option for jobs, and likewise, the main reason for living in a given town in the first place. However, these areas face significant risks when toruism spending declines, or local extreme weather events send visitors elsewhere.

Because of this, effects from drought and other weather conditions on one industry often have ripple effects in others, and particularly dry years – like 2018 – can result in multiple different types of recreational businesses facing challenges simultaneously. As below average 2017 snowfall gave way to deepening drought conditions over the rapidly warming summer, water in streams for agriculture and various recreational resources began to run dry, eventually forcing closures on the nearby Yampa River for fishing, a shortened rafting season, and – for the first time in history – a call on nearly the entirety of the river itself that reached water rights holders as senior as Sept. 16, 1951.[45] As of late November, when hunting season begins to move into full swing, restrictions remained in place in much of the surrounding region for campfires and other high fire-risk activities.[46]

What effects these challenges will have on the overall economy of Steamboat Springs and the surrounding area is unclear. The state's recreational economy overall has been growing rapidly after rebounding from declines during the last economic downturn 10 years ago, and remains strong due to both rising demand, artificial snow-making at most ski resorts, and the wide availability of alternative attractions when specific activities are not available.[47] However, statistics gathered following the 2012 drought suggest the likelihood of reduced visitation numbers across all recreation industries, with river rafting and skiing in particular showing significant declines in visitation during the high-fire risk, low water conditions of that event.[48] Similarly, reports of impacts from drought and associated wildfires have suggested that a broad range of negative effects on the recreational economy can be expected, whether from near-statewide delays to the start of the 2017 ski season; river closures along the Roaring Fork Valley; dry riverbeds in Eagle County; water levels too low for rafting in parts of the Uncompahgre Basin, Glenwood Canyon and other areas; extreme low snow levels in Crested Butte and other medium sized ski resort areas; dry waterfalls and failed mushroom harvests near Telluride, or various closures of federal lands due to the state's numerous wildfires.[49]

More importantly, it is very likely that much of these impacts will not be borne equally by all members of the recreation and tourism industry. While large, well-resourced resorts like Vail and Aspen may have the capital and diverse array of attractions needed to meet whatever demand the global economy provides, smaller, more specialized businesses like part-time hunting guides or rafting guides that work only specific rivers are likely to face sharp increases in the cost of doing business at the same time as opportunities for access shrink.[50] Simultaneously, towns further off the beaten path, such as Craig, Ouray, Walden, Gunnison, Kremmling, Salida, and others scattered around the state may lack the resources or non-tourism related income streams needed to keep businesses open during particularly rough years. Similarly, in communities where reliance upon the tourism economy is extremely high, such as is seen in parts of Eagle, Clear Creek, Chaffee, Fremont, western El Paso, and various other counties, the effects of a downturn can be devastating, even over short periods. As a result, while the tourism-based economy of the state as a whole may march on, relatively heedless of direct weather impacts, specific communities with limited resilience may face significant setbacks and a loss of the ability to meet basic needs.

These short-term shocks have come alongside growing concern across the outdoor recreation community regarding what higher temperatures, changing seasonal timing, and other more long-term shifts to the area's weather patterns mean for the industry. In the skiing industry, this has meant the large-scale adoption of snow-making technology, which utilizes water stored in reservoirs and electricity to generate artificial snow when natural precipitation fails (or falls as rain). However, these rely upon water reserves that are themselves subject to the state's prior appropriation system for governing water diversions, meaning that successive years of drought like those experienced in 2002, 2012, or 2018 could defeat even the most efficient snow-making efforts. As a representative from the Colorado Association of Ski Towns noted when speaking with researchers on this project, unpredictability in the start of the ski season can also have more complex impacts, such as those seen during the early 2017 season, when delayed starting dates at most resorts meant that ski towns had to find resources for the large influx of seasonal workers who, as a result of these delays, found themselves in a generally very expensive place to live with no means of earning an income. As a result, the social service resources of the surrounding towns and counties – be they food banks, heating assistance programs, rent subsidies, or job placement resources – found themselves suddenly stretched to the brink.[51] Similarly, as winters in the mountains become more mild and the weather becomes overall warmer, many mountain towns face the double edged sword of increasing real estate development and settlement by (generally high-income) retirees. While this type of influx can be beneficial to local tourism-dependent communities, it can also cause significant rises in housing prices in areas with limited land suitable for development, forcing lower-income workers to either seek alternative places to live, migrate elsewhere, or take part in development that further erodes the wildland-development interface.

Similar long-term effects of warming weather and shorter winters can be seen in the state's iconic forest ecosystems, which contribute both directly and indirectly to the overall appeal of Colorado tourism destinations. Acting as a sort of living infrastructure for ski resorts, mountain water utilities, and as habitat for wildlife critical to a broad host of recreational activity, the state's forests are undergoing rapid transformation. Some of this is due, of course, to the many high profile and historically enormous fires that have burnt in the decade or so. Most of the transformation, however, comes in the form of insect and drought driven mortality in Spruce, Ponderosa, Douglass and other evergreen tree species found surrounding nearly every community in the western half of the state. According to a recent report by the Colorado State Forest Service, over 5 million acres of forest statewide have been affected by just Mountain Pine Beetle and Spruce Beetle alone since 1996, with roughly a half million more affected by other, less pervasive species. Driven in part by decades of fire suppression that left forests particularly vulnerable, these insect and disease related impacts have also been noted to be greatly assisted by the lengthening of the frost free season, which allows insects to reproduce more effectively and overwhelm most tree species' natural defenses.[52] The result is that many mountain town resorts look out upon forests that are up to 50% dead and mostly standing trees in the surrounding mountainsides, with serious implications for forest management, wildfire risk, and the intangible aesthetic values of a given community.

In river-related industries, the increasingly rapid onset of spring and subsequent intense runoff that has been characteristic of much of the last two decades has meant the need to find new ways to provide both safe access and to cope with unpredictable resources (see next Section). In rafting, this has come as a result mainly of the amplification and shortening of the rafting season in many headwaters areas, which result in less time for the specific conditions that different types of

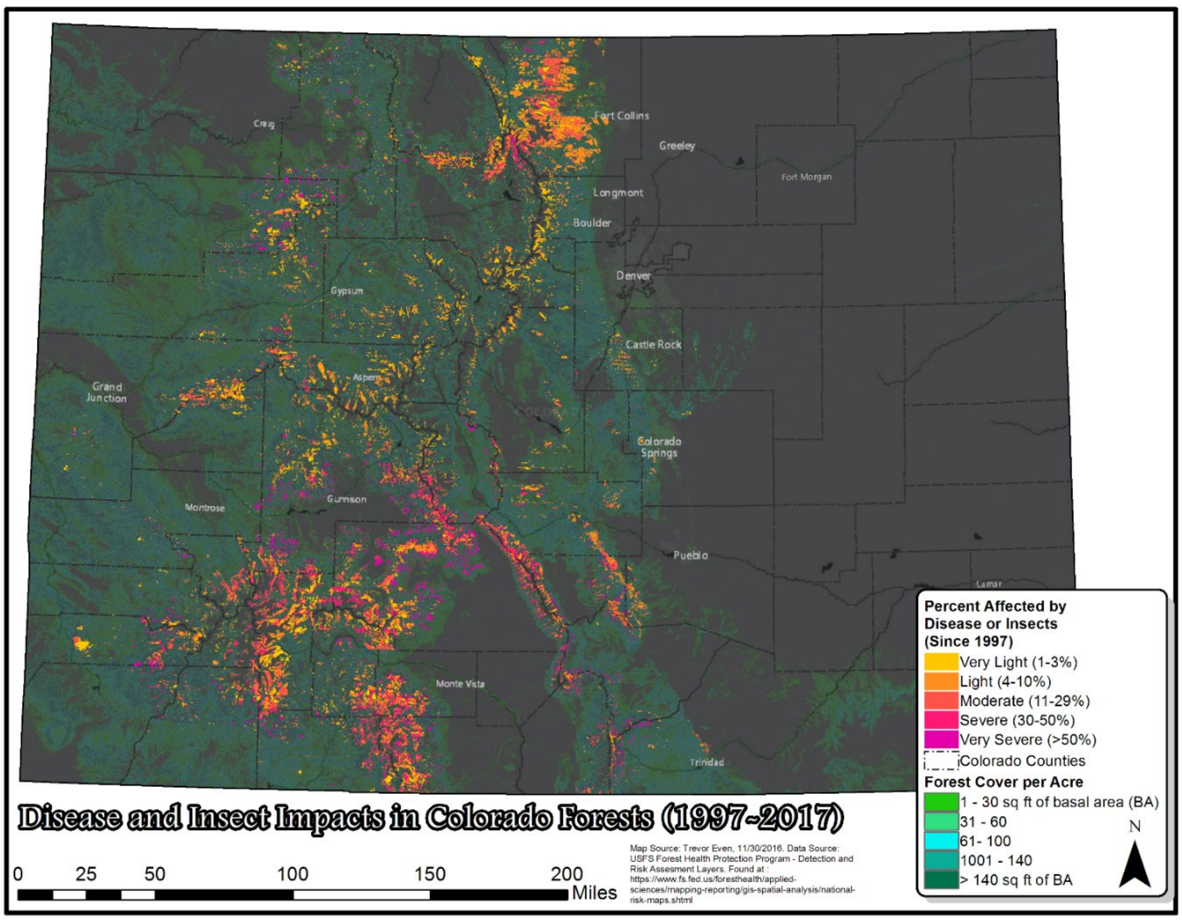

Figure 15 - Insect and disease mortality of trees in Colorado's forests are just one sign of changing weather patterns, with longer, warmer winters playing a central role in allowing pests to spread and reproduce more rapidly. At the same time, forest management has also played a role in heightening the virulence of these issues, with many forests in need of significant restoration.

rafters seek.[53] In some cases, because of either high flows that make rivers too dangerous to attempt, or low flows that prohibit boating altogether, business simply does not occur. For some operations, it has also meant expending more energy and travel time as they must seek out alternate courses during localized severe drought conditions.

Fishing guides and outfitters for self-guided fisherman have also begun to voice serious concern regarding the impact of warmer temperatures, shorter winters, and incessant drought conditions, as these can all have significant impacts on the health and abundance of numerous important native and stocked fish species. The most basic of these effects come, as they have this year, from stream levels depleted by drought and upstream diversion to levels too low to support fish populations.[54] For some species like the rainbow and cutthrought trout, however, warming water temperatures associated with these low flows presents as much a problem as low flow levels themselves, as they put the fish under enormous stress and can quickly lead to fatality. Even when catch and release restrictions are in place, catching fish at all can prove deadly if water temperatures rise above the mid-sixties in some species.[55] The result of these poor fishing conditions has led to a variety of voluntary and non-voluntary closures of rivers to fishing and other activity. However, over the long term, there is concern that the loss of cold-water fish habitat will be permanent if higher temperature trends continue. Similarly, drought conditions and associated wildfire can also have serious impacts on fish populations and river conditions, as post-fire landscapes allow for rapid erosion, and often transport large amounts of debris and ash into nearby streams. In these cases, the chemistry of the water itself can be altered to such a degree that fish die off in huge numbers, both near to the fire and far downstream.[56] In 2018, this has resulted in Colorado Parks and Wildlife and a variety of volunteer organizations working to rescue fish from the Animas River and other streams heavily affected by post-wildfire runoff-induced toxicity as die-offs mount in many prized fishing areas.[57]

Impacts on hunting over the last two decades have been more mixed than in other sectors, mainly due to the extreme adaptiveness of both hunters and the hunted, respectively: in many cases, short term drought conditions can actually improve the likelihood of the success of a given hunt, as wildlife congregate on smaller areas of water and remaining vegetation. Similarly, most hunted wildlife species – which include elk, mule deer, whitetail deer, brown bear, mountain lion, and numerous others – are able to mitigate the impacts of locally poor forage or water availability through movement. However, longer term changes to the landscape and the weather – when combined with continued encroachment from development – may prove to be more than some species can handle. For example, droughts that last for a year or more can lead to subsequent "forage droughts" for species like white tailed deer, mule deer, elk, and antelope, which make up for much of the state's hunting activity. In 2002, for example, when much of the state was in severe or extreme drought, Colorado Parks and Wildlife increased cow elk licenses in an attempt to mitigate impacts on already threadbare forage, in hopes that it would allow those elk that remain to better weather the coming winter. At the same time, bear licenses were decreased in response to field reports of poor female bear body condition entering the hibernation season.[58] Early springs that are followed by late season frost might also present challenges to wildlife, as it can lead to both the loss of animals directly and the reduction of fruiting bodies on shrubs and trees.[59] However, severe winter storms that occur during the normal time frame can also affect hunting, for while they are generally welcomed in the area for the moisture they bring, they can result in significantly increased mortality if herds are unable to move out of high elevation browsing grounds in time.[60] That said, both of these types of pressures also come at a time of rapid population growth and development in many areas across the state, meaning that impacts from weather are heightened as herds are pushed into smaller and smaller areas, potentially increasing their risk of disease at the same time as their access to resources is reduced. [61]

Changes to the onset and character of winter can also create complications for planning hunting trips – and for hunting guides, ensuring success – as migratory species like elk and deer generally follow the weather, rather than the Colorado Park's and Wildlife's permit schedule. As one outfitter operating out of Maybell told Guidefitter magazine in 2017, "*In their normal migration pattern, they'll start out in late October or so and they'll move to the mid-section on the mountain. They'll hold there for awhile and then as the weather progress they'll start moving on down to the lower winter ground. The last few years here, I don't know it it's been because of drought conditions that we've been having, but they've come down a lot later."* [62] This year, the Colorado State Extension service is already issuing warning of degraded habitat conditions for most wildlife species, as well as increased risks of wildlife-related vehicle accidents as ungulates take to browsing on the green bands that normally form in drainage ditches.[63] Reports from hunters from various sources have noted that, in addition to poor body condition, drought years (or even poor forage years) such as these can have serious effects on bull elk maturation and can result in poor antler formation.

These more gradual impacts in various specific industries all share several aspects in common: when water is scarce, more effort must be undertaken to utilize what remains, getting to it might be cost-prohibitive, and what remains can lead to competition. Likewise, risks increase that visitors – or merely those attempting to enjoy a private hunting, skiing, fishing, or boating trip – will be faced with conditions that are either dangerous or simply not worth the journey. For ski resorts and other mountain towns that rely on providing a wide array of recreational activities, wildfires, whether nearby or at a safe distance, cause serious negative impacts as tourists shy away from the visible hazard these events represent – and may well cause direct damage to resources that local communities rely upon as part of their business strategy. Moreover, as pressure from human communities increases apace with pressures from shifting weather patterns, the species and ecosystems that make the state so spectacular and memorable are also at risk of losing the capacity to cope with weather extremes. As with ranching and agriculture, the conditions presented to Coloradoans by the 21st century are causing a variety of changes in how the state's tourism economy survives, and where it sees itself going in the future. In the next section, we will explore some of the pathways that have been laid out.

Adaptation and Innovation in Rural and Mountain Communities

Given the wide range of risks they face – as well as the seriousness of the impacts from weather related disasters that the last 20 years have already brought to bear – it is becoming increasingly clear that rural and mountain communities in Colorado must engage in a new phase of adaptation. For communities that rely upon ranching, farming, and the diverse landscapes that define our state, the future seems to put forth a simple, if daunting challenge: either adapt, or face the consequences. Granted, for anyone who has spent even a little time making their living off of the land, this is hardly a new challenge. The true question, then, is whether or not the ingenuity and determination that have served Coloradoans in the past will prove up to the task of facing down the new challenges presented by changing weather in the 21st century. According to the global scientific community, much of the road ahead remains profoundly uncertain, and will rely upon technological, social, and political transformations taking place from local to the global scales. For ranchers, farmers, and businesses that rely upon the natural environment in Colorado, however, what these changes mean on the ground will depend upon every scrap of creativity, determination, and innovation that we as a statewide community can muster. Luckily, Colorado is no stranger to change, and in many ways, its historically challenging and diverse climate has prepared us – perhaps better than most – to marshal the will needed to chart a new path forward.

Indeed, as is often the case in land-based livelihoods around the world, practitioners across the state are already taking steps to strengthen their operations against the rising challenges of weather-related disasters and extreme variability. In some cases, these innovations are purely technological, relying upon newly discovered methods for understanding the weather, crops, and the broader environment to maximize operational viability. In others, they rely upon changing practices, ranging from new ways of looking at the role of soil in agriculture to novel approaches to promoting and protecting the economies mountain tourist destination. In still others, communities are returning to time-tested principles of collaboration and communication to face down otherwise insurmountable resource challenges.

In this section, we attempt to collect just a small handful of these newly emerging – and, in some cases, newly rediscovered – approaches to ensuring the viability of rural livelihoods, both with a mind to share insights from those working on the ground to implement these practices, and to inform those in a position to set policy and make wide-ranging decisions about options already available. For while it is likely that the most important changes to practices will take place due to the independent action of farmers, ranchers, recreators, and other rural economic actors, it is also clear that even the most clever adaptations will require the support of decision-makers at all levels of authority, be they municipal leaders, state lawmakers, non-profit organizations, or our representatives within the federal government. In order for this support to be effective, however, it is critical that decision-makers – whatever their standpoint – are informed about action already taking place on the ground. To do so in a straightforward manner, we address specific adaptations in terms of the specific sectors to which they apply. However, as what follows will show, many of the strategies and approaches described here have surprising parallels, both in terms of the specific approaches applied, and in the change in perspective required for dealing with times of increasing variability and extremes.

Ranching

Dealing with harsh weather conditions is a normal part of keeping livestock, and as a result Colorado's ranchers are apt to use just about any tool that makes sense for their continued operation. As a result, a number of types of adaptation and innovation in the ranching sector are already underway, both in direct confrontation of weather-related risks and due to the overall uncertainty of the ranching sector in a globalized economy. These range from technological approaches to maximizing productivity to radical diversification of rangeland utilization and dramatic changes in traditional models of ranch operations. In this section, we cover but a small slice of statewide adaptation activity.

The most important of these come in the form of efforts to manage water. Although exact statistics are not available, it is generally well known that ranches in Colorado heavily upon groundwater withdrawal for stock water, particularly in the eastern plains where surface water availability is confined to a few major streams and seasonally flowing creeks. Traditionally, this was accomplished with first wooden and then steel windmills attached to basic pumps, which would then fill accompanying above ground tanks or artificial ponds. In many places, this form of water management persists, and has proven a cost effective means of providing water for livestock across the entirety of a given ranch's range. Now, however, windmills are often accompanied by electrically powered pumps and pipeline systems, that allow for single wells to distribute water across a broad area. In some areas, ranchers are creating "intelligent" well control systems that allow them to turn on and off specific tanks of water remotely, and by doing so, effectively moving cattle across the range automatically in areas where pumped water is the only available resource. Water can also be hauled in tanks using trucks, although this is generally viewed as both costly and onerous.

However, water for livestock is only one part of the equation: management of the vegetation and overall landscapes that livestock rely upon for the vast majority of their food is just as critical. With more frequent drought putting many rangelands in a more fragile state, ranchers have had to take a variety of measures to ensure the long-term sustainability of their operations. The most basic of these involves simply reducing the amount of range needed, either through purchasing supplemental forage, or growing one's own feed in the form irrigated alfalfa, dryland hay, and other feed crops. When these reserves prove insufficient – or too costly – ranchers may also sell off a portion of their herds. Unfortunately, when drought occurs, demand for supplemental feed spikes, and likewise, the glut of cattle and other livestock on the market drives prices per head downward. In particularly bad droughts, alfalfa and hay crops might also fail if they do not receive enough irrigation or rainfall, further heightening impacts. Because of this, managing rangelands during drought episode is an area of significant research, both academic and otherwise, as reactive measures like those listed above can only work for so long before costs become overwhelming.

For some ranchers, this has meant taking a more drastic approach to the usual practice of moving herds from one pasture to the next. In southeastern Colorado, for example, numerous ranchers have begun loading their cattle onto trucks following the early corn and wheat harvest in Kansas, Oklahoma, and Nebraska, and trucking them there to graze on the remnants. Others – specifically, the more prosperous ranches with the ample resources needed to do so – have taken a different approach, in which smaller properties are purchased in a spread-out manner (sometimes over distances of hundreds of miles), allowing for the ability to take advantage of diverse local conditions in times when one area is under stress. This has followed alongside a general recognition in many ranching communities that many working rangelands are seeing consolidation – or the formation of especially large ranches as others close and are bought out – in many areas, notably southeastern Colorado where land values have remained relatively low despite rising prices elsewhere in the state. Simply put, having more access to land provides flexibility in decision-making on every level of ranch operations. However, whether in purchase prices, leases, or transportation fees, all of these strategies bear significant costs, meaning that they are generally more useful for solidifying an already strong position than recovering from a poor one.

One strategy being widely utilized by Colorado ranchers to deal with the numerous uncertainties involved in ranching (weather-related or otherwise) is to *diversify*. For some, this means simply taking on additional, non-ranch work in nearby towns or with other local businesses.[64] In other cases, this means the diversification of the ranch itself, usually through the addition of business models other than livestock production to an overall portfolio of land utilization and stewardship. For example, many ranchers in northwestern Colorado are involved in some way or another in the local hunting economy, either through hunts conducted on their own land or through hunting guide businesses.[65] Other, perhaps more extreme examples include: the James Ranch, located near Durango, which, in addition to a grass-fed beef operation, also produces chicken, pork, cheese, vegetables, and other products alongside an active environmental education tourism destination, farm-to-table restaurant, and special event facilities.[66] Similarly, Sylvan Dale ranch, located in the mountains just west of Loveland, also produces grass-fed beef as the central component of a full-scale recreational resort model featuring wedding and other event facilities, guest cabins, equestrian training, and other recreational activity.[67]

At the same time, a number of ranches of varying size across the state are taking on new strategies not just for how their ranches are organized financially and across space, but how they approach the management of the various natural systems that make up the ranch itself. Although these methods go by various names, including holistic ranching, ranching for ecosystem services, ecological ranching, conservation ranching, ranching for wildlife, ranching for soil health, or simply, intensive (or *extensive*) rotational grazing, these new approaches to running a ranch are united in the

Ranching for the Future in Northwest Colorado: L____ Ranch and V____ Sheep Company

Two standout examples of how taking a holistic approach to rangeland and ecosystem management in Colorado, Ladder Ranch and V_____ Sheep Company represent how private land owners operating at the interface between wildlife dominated landscapes and federally managed lands can sustain ranching livelihoods through novel approaches to understanding the environments that livestock depend upon.

At Ladder Ranch, located on the Wyoming-Colorado border just north of Steamboat Springs, 2014 Leopold Conservation award winner P__ O'T____ works as a 4th generation rancher to maximize sheep and cattle productivity in the midst of a living landscape, organizing his fencing, rotation, and supplementary feeding practices to allow for abundant wildlife habitat, riparian ecosystem restoration, and the preservation of the surrounding landscape for future generations. With both he, his wife, and various other family members being extremely active voices in the Colorado and Wyoming agricultural communities – as well as avid partners with environmental and agricultural non-profit organizations - they also work to make sure that the issues of rural America remain at the forefront in discussions of resource governance and use across the arid west. In so doing, he has managed to maintain the viability of future generations of the O'T___ family to maintain ties to the ranching way of life, and to ensure that the mosaic of private and public lands he manages are sustained for future generations to learn from and enjoy.

Just southwest of L____ Ranch, in Moffat County, the V_____ Sheep Company utilizes a variety of environmentally-minded and ecosystem-centered approaches to ranching to ensure that the mix of public and private lands they utilize are able to maintain productivity and vitality both for their own business interests and those of the broader hunting, fishing, and outdoor recreation economy. Utilized a "forage-based" range management approach, in which the soils, plants, and wildlife of the range are viewed as the central component of successful ranching operations, they have been able to achieve remarkable conservation and ecosystem restoration goals in what have been historically viewed as arid wastelands. Also a Leopold Conservation awardee, the V_____s are also active participants in the Colorado Parks and Wildlife Habitat Restoration Program, and host a variety of hunters and anglers from around the world each year. As Gary V_____, the current ranch manager told the Sand Creek County Foundation in 2013, "*I love the land, I love seeing the wildlife, and I love the livestock as well. I can't imagine a universe without it all there – it would be boring. When you love the land, you don't destroy it, you want the next generation to be here, and to be able to see what I've been able to enjoy."* [8]

basic idea that landscapes and ecosystems take a central role in the planning, implementation, and evaluation of overall ranch goals. As a result, the measurement of a given ranch's success comes from evaluating both the health and quality of cattle sold and the resilience of the various plants, animals, and soil biology surrounding them.

Or as Grady Grissom, an ecologically-focused rancher operating out of southeastern Colorado put it in 2017: *"Ranchers are not outside the ecosystem managing it; they're* in *the ecosystem, trying to survive."*[68] As a case study on his family's ranch, published in the journal *Rangelands* in collaboration with researchers from Texas A&M noted, this style of ranching requires intense focus on developing and implementing the variety of monitoring and ecosystem management tools needed to meet specific ecological goals. This includes changes to the distribution and style of fencing (i.e., using temporary electrical fences to make shifting pastures less labor intensive), making time for the monitoring of various rangeland vegetation and wildlife species, forging connections with ecologists and other scientists to assist in understanding the ecosystem process at play within the ranch, and consistent adaptive planning efforts that allow for the ranch to pro-actively address issues like drought by controlling stocking rates *before* rangelands become overly affected.[69] Another important part of this approach is changing how ranchers understand and interact with soil systems, both in terms of their cycling of minerals through the planting and grazing of specific species, and with regards to how these planting and grazing decisions alter how soils absorb, store, and redirect water across the landscape. Because of this, there is significant evidence to suggest that, by cultivating the surrounding ecosystem for resilience with the same tenacity with which most ranchers attempt to

Innovation on the Science-Agriculture Frontier: Community-driven Agricultural Research in Colorado

In addition to a wealth of innovative approaches to running ranches and farms, Colorado is also blessed with an academic and scientific community world-renowned for its dedication to changing the way that scientists and other experts interact with on-the-ground practitioners. Notable among this community is the work of Justin Derner and various collaborators at the USDA Agricultural Resource Research Service and Climate Hub, whose work focuses on partnering with ranchers and farmers to develop real world experiments aimed at better understanding how landscape conservation, agricultural production, and western ways of life can achieve their goals in synergistic ways. A vocal advocate for soil- and ecosystem-centered approaches to agricultural production, his current work aims to develop a wide ranging network of active experimental farms and ranches where researchers from around the world can collaborate with local agricultural producers to develop innovative practices and maintain the sustainability of the world's food system for future generations.

Another notable figure in the Colorado land-based livelihoods research community is Maria Fernandez-Giminez, whose work out of Colorado State University aims to put ranchers and farmers in western Colorado at the center of efforts to understand pressing dilemmas in the management of rangelands and public land resources. Using a community-based, participatory approach, she combines social and ecosystem science methods to explore how local values and environments interact with global markets and weather-related impacts, and how lessons learned therein can be utilized to ensure that future generations can both utilize and enjoy working rangelands around the world.

maximize stocking rates and livestock weight gain, they are able to create a landscape that is both able to support the Grissom family's livelihood and to absorb the shocks of extreme weather events and variability.

Indeed, one broadly applicable theme to emerge from research on ranching in this region is that the idea of *land stewardship* is highly consistent across the state. Although individuals vary, the basic concept that lands used for ranching are environments that should be *stewarded*, managed, kept whole, and preserved for future generations is commonly encountered, even among those who oppose the imposition of federal regulations such as the Endangered Species Act or other forms of outsider "environmentalism". Because of this, several notable programs exist that either assist or compensate ranchers in efforts to operate rangelands for reasons other than livestock production, exclusively. The largest and most notable is perhaps the Colorado Parks and Wildlife [CPW] Ranching for Wildlife, which has been in operation since 1986. Putting it simply, this program creates partnerships between large private ranches (12,000 acres or more) and CPW to provide access to privately owned hunting grounds. In exchange for a portion of the fees from hunting licenses, ranchers agree to develop and implement plans for wildlife habitat restoration on their properties. Currently, 27 ranches are enrolled in the program, opening access and improving conservation values to over 121,000 acres of private land that might otherwise be sub-divided and sold or more intensively grazed.[70] By siting these partnerships strategically, CPW has also managed to maintain numerous important wildlife corridors between large private ranches and public lands. As a result, in addition to diversifying their sources of income, these ranchers are also able to help create larger, interconnected landscapes that support a variety of other livelihoods and cultural activity in the region and may potentially provide a buffer for highly valued wildlife in times of drought or other stress.

Efforts by ranchers to maintain healthy landscapes as a means to contend with drought and other weather challenges can also be found in a number of non-profit and ranching organization award programs active in the state, which provide both recognition and various monetary awards to ranchers who demonstrate innovative and environmentally beneficial land stewardship practices. The Aldo Leopold Conservation Award, supported by the Sand Creek Foundation and various state Cattleman's Associations across the west, for example, has highlighted multiple Colorado ranchers who have successfully engaged with conservation and ecosystem rehabilitation efforts, often due to a change in land management after significant weather-related impacts revealed vulnerability in old models. The 2011 award winners, the McEndree family and Pipe Springs Ranch, demonstrate this well. Operating out of the extremely arid and highly variable area around Springfield (in the far southeast corner of the state), they emphasize how land conservation strategies have served as a ranch resilience builder. Due in part to the much more dynamic grazing model utilized in their rapid rotational scheme, as well as a focus on the relationship between water, soils, and diverse plant communities has allowed their ranch to achieve continued growth despite the region's intense exposure to extreme drought conditions over the last 20 years. As the McEndree family puts it, "*Focusing on conservation has allowed the land to flourish even when Mother Nature has not cooperated.*"[71]

Significant experimentation and research remains to be done in the arena of ecosystems-informed ranching (and various derivations thereof), both in terms of its ability to improve the lives of ranchers, and in its capacity to produce more resilient natural landscapes. However, because any process of adaptation requires that those doing the adapting must learn from the systems they are adapting to, the heightened awareness of environmental characteristics and response patterns that comes with these new types of ranching strategies appears quite promising, both as a means of further adjusting to weather-related impacts as well as learning what different environmental conditions mean for rural livelihoods more broadly.

Farming

Maintaining the viability of the agricultural sector in the face of weather- and pest-related hazards is the focus of numerous multi-billion dollar corporations, millions of scientists and researchers worldwide, and, in the United States, is the target of a variety of subsidies, insurance programs, and other federally supported resources for education and operation improvement. Colorado farmers, like farmers across the country, are therefore limited mainly by personal capital, on-farm flexibility, local access to non-financial resources, and the demands of global markets when it comes to integrating new technologies and practices into their operations. Weather-related losses have been a part of agriculture since its invention over 13,000 years ago, however, and still remain a relatively absolute force in the lives of farmers: If you farm, you must accept and plan for the possibility of weather-related losses, no matter how optimized your farm might otherwise be in terms of maximizing the production of calories per unit of water and land available. Given the vast size of many modern farms in the state and their reliance on large plots of homogeneous crops, they are inherently vulnerable to wide-scale issues like hail, drought, tornadoes, insects, mold, and other insults to plant productive processes. To survive in the face of such challenges, farmers have traditionally relied upon savings, alternate crops, emergency planning, and, ever more increasingly, federally-subsidized and private insurance plans. That said, a number of Colorado farmers are undertaking efforts to move beyond the incremental technological and genetic improvements that have characterized much of the development of modern, industrialized farming, be it in terms of how they plan, plant, and manage crops, how they integrate farming into overall livelihood strategies, or how they operate within local markets. In this section, we will cover a few of the more notable and potentially expanded upon innovations that have taken root in Colorado, as well as some of the broader context that shapes adaptation decision making (at times in somewhat counter-intuitive ways).

Although non-irrigated, “dryland” agriculture is a critical part of the state’s overall crop production, the generally semi-arid conditions found in most of the areas suitable for agriculture in the state require farmers to irrigate their crops. This is accomplished in two main ways: either by flood irrigation, in which waters pumped or directly diverted from surface streams are allowed to completely inundate the root zone of crops and saturate soils at critical growth stages, or through the use of sprinklers, most commonly seen on center-pivot armatures that allow a single pump to provide water for an entire field. A third type of irrigation, known as drip irrigation or

Community Leadership for Agricultural Resilience: The Community Agriculture Alliance

Colorado’s ranching and farming communities have proven highly capable in organizing at a variety of levels to support the viability of their livelihoods, especially at the local and regional level. One example of these efforts comes in the form of the Community Agricultural Alliance, operating out of Steamboat Springs. Lead for the last 15 years by Marsha D_________, a Routt County rancher and feed farmer, it engages with local and regional communities on a variety of fronts to ensure the sustainability and viability of Routt County agricultural operations. This includes organizing community events and farmers markets to promote local agricultural producers, educational programs for non-farmers and new farmers, and county-level lobbying on a variety of issues. For example, in the last several years, the CAA has sought new ways to partner with recreational businesses and other local institutions to ease conflicts between newcomers to the region and the agricultural community over issues like bicycle traffic, land access, and trail development. Noting both the need for a new generation of farmers as well as the rising prices of agricultural land, they have worked to improve the efficiency of permitting and other processes related to establishing greenhouses and other “micro-farming” establishments that aim to serve the area’s local restaurants, and allow a new generation of agricultural producers to enter the field. They also currently operate an on-line farmer’s market, bringing locally produced farm products, vegetables, and beef. Although she is now retired from her position as CAA Executive Director, D_________ continues to advocate for efforts to improve the resilience and well-being of Yampa Valley farmers and ranchers. In conversations with project researchers this summer, she noted four key areas where work remains to be done in terms of improving the agricultural community’s ability to deal with extreme weather and change:

1) There is a need continued support and expansion of programs to provide farmers and ranchers with accurate information on weather risks and management practices that allow for adaptive responses. This also includes better support for general agricultural education programs and mechanisms to support new farmers.
2) Find ways to improve funding security and capacity for extension agents, especially local USDA staff that provide a critical conduit of scientific information and practical innovations to rural agricultural operations.
3) Improving coordination between Federal, State of Colorado, and county officials, as well as between the U.S. Forest Service and the Bureau of Land Management, which oversee public lands used for cattle ranching and recreation.
4) Finding ways to insure against or expand coverage under existing aid programs for multi-disaster years, such as when drought is followed by serious hail damage, as these remain a serious threat to farm viability.

“microirrigation”, is also used to a much smaller degree, and utilizes tubes laid on or just below the soil surface to deliver precise amounts of water to each plant individually. In terms of absolute water use efficiency, flood irrigation is the least efficient, with up to 50% of diverted water being lost to surface runoff, or “tail” water. Sprinkler irrigation is more efficient, with losses to wind, evaporation, and deep percolation ranging between 10-40%; drip systems, on the other hand, are even more efficient, with up to 90% of water applied arriving and staying in the target plant’s root zone.[72] However, costs in terms of initial installation, maintenance, and additional work during harvesting may be higher in more efficient systems. Though there are ongoing discussions regarding the building of additional water storage facilities, or developing a system for re-utilization of processed water from cities, these options have yet to be realized, and face significant uncertainty.

As such, if one were planning a hypothetical farm, then it would simply be a matter of cost comparison between different irrigation approaches based on the cost of water and the desired production outcomes. However, in the real world, farms must deal with decisions made by those who came before them, and must deal with the specific soils and topography that they already have access to. Because of this, changes to patterns in irrigation systems and other farming practices are generally slow to occur, as the investments made by previous generations of farmers often make large scale alterations generally too costly or inconvenient to implement, even if financial gains could be made over the long term. More importantly, because Colorado is a state whose water rights system values a given diversion right on the basis of the water actually used by a given crop, switching from one irrigation system to another also requires some degree of interaction with the State Water Engineer and water right adjudication system, i.e., the Colorado Supreme Court, as new water use, loss, and groundwater interaction values will have to be determined and affirmed by the various parties involved, including any downstream parties that might be affected.[73]

Because of all this – namely, the very real tradeoffs between water use efficiency and operational costs, as well as the tangled process of changing irrigation methods while maintaining the entirety of a given (increasingly valuable) water right – simply pursuing more efficient methods of agricultural water use are not always the best option for farmers in the state, even as continued droughts put the predictability of water supplies in serious question. More importantly, because of the way in which the state's laws handle water shortages, wherein rights holders with junior rights are subject to the demands of those with more senior appropriation dates, the ability to acquire necessary water for irrigation or other uses can become less a matter of applied hydrology and engineering than one of careful negotiation between the various parties involved in a given reach of stream or aquifer. For example, as research in the Yampa-White Basin examining the impacts of the 2002 drought found, social capital in the form of trust, communication channels, shared goals, and

C___ Farms – Farming for Soil Health

A staunch advocate of what he calls "regenerative farming," Curtis S____ sees the landscape on which he produces dryland wheat, rye, and beef as more than just a parcel of land and natural resources. Rather, he sees a complex ecological system, in which wheat, cattle, and other directly beneficial organisms are but one part of the overall diversity of living and non-living components that make the system as a whole viable over the long-term. In addition to no-till practices and on-going efforts to eliminate fertilizer and other inputs, he also incorporates long-term grazing rotation plans in which cover crops on fallowed fields are used as forage for small, constantly moving cattle herds. Meant to mimic nutrient and carbon cycling seen under historic bison-dominated ecosystems, these practices are managed with the goal of restoring farmlands degraded by almost a century of traditional industrial agriculture by ensuring soil microbial health, soil structure, and biodiversity both below and above-ground. Working out of drought-prone Kit Carson County, he views these practices as also providing the additional benefit of reducing the risk of dust storms, minimizing erosion during the area's intense late summer rains, and helping soils to lock in as much moisture as possible due to improved soil structure.

As he notes, however, his efforts at C__Farms do come with added costs For example, while he has been experimenting to some success with companion cropping systems, in which nitrogen-fixing peas are combined with cereal crops, existing insurance programs do not cover such planting arrangements. Likewise, the task of understanding the complex – and often only slowly realized – effects of different soil-health focused practices requires both constant attention and tremendous patience. As a result, he sees a clear need for better support for this type of on-farm research and development, both in terms of federal and state programs, and more robust links between the scientific community and experimental farming operations.

the ability to cooperate in times of scarcity can prove just as important as the ability to construct dams, floodgates, and other infrastructure. In that case, community members from the agricultural, recreational, municipal, and industrial sectors in Moffat, Routt, and Rio Blanco counties enlisted a variety of informal mechanisms (such as meetings and town halls) to address extreme drought conditions in the region, doing so in a manner that allowed for the Yampa River, junior irrigators, and the small town of Craig – which faced potential water shortages due to downstream senior rights – to receive reduced water allocations without the need for official legal calls that might have otherwise devastated the local economy.[74]

One particularly profound example of people working together to solve region-wide water management problems can be found the San Luis Valley in south-central Colorado, where farmers, ranchers, and other groundwater users have established a novel model for maintaining the aquifers upon which they depend for irrigation and other uses. As it would happen, this example also followed from the 2001-2004 drought. In this case, however, it came not as the result of an unprecedented shortfall of surface water, but instead from an extremely dry area suddenly realizing that an old strategy for dealing with precipitation shortfalls, namely, the unregulated pumping of groundwater by individual farmers and households, would no longer be able to be relied upon. The reason why was simple: from 1976 to 2002, this unregulated pumping – though described by many as a water source of last resort – had resulted in widespread declines in the water levels of the area's large underground aquifer. So much so, in fact, that many shallower wells were no longer able to function. Partly in response to the situation in the San Luis Valley, as well as groundwater supply overuse issues elsewhere in the state, the State of Colorado began to draw up additional regulations for groundwater found in non-tributary aquifers, with the intent of metering and potentially shutting down many wells like those found in the valley. In the face of the potential loss of this critical adaptation strategy – to say nothing of the tightly interconnected agricultural community that it supported – local community members set to work: Beginning with the formation of the Rio Grande Water Conservancy District, a wide array of concerned community members began a long and laborious process of developing a legally binding and financially self-sustaining mechanism for the self-governance of the San Luis Valley's groundwater resources. Ultimately, by leveraging assistance from the Federal Conservation Reserve Enhancement Program, the Colorado Water Conservation Board, the State of Colorado, and other regional sources, they arrived at a market based mechanism for groundwater control. In this new scheme, groundwater users would be charged a fee by the San Luis Valley Sub-District for each acre-foot of water pumped each year, which would be paid to the Sub-District itself. Likewise, should they choose to leave their fields fallow during drought periods to reduce their pumping needs, they would be compensated at a reasonable rate. In this manner, farmers would be able to weather drought periods while also maintaining the long-term sustainability of the aquifer: while they would pump less, they would not as easily face the risk of total shut-offs. Indeed, according to recent reports on their efforts, the combination of fees and fallow payments has resulted in over 30% reductions in groundwater pumping, and the widespread transition towards less water-intensive cropping systems.[75] These community level collaborations have also resulted in a number of "spin-off" innovations, as well, with projects underway to work with agriculturalists and ranchers to restore local river channels and riparian areas, protect local natural attractions, and improve the area's access to real time meteorological and climate data.

This case, while unique in the sophistication and the legal scaffolding for community decision-making that it was able to build, is by no means alone. Statewide, farmers and agriculturalists of varied sorts have been increasingly involved in a variety of organizations meant to protect their livelihoods, ways of life, and to improve the sustainability of Colorado agriculture more generally. Perhaps the most visible example of this is the state's "Colorado Proud" program, which allows Colorado agricultural producers to more effectively market within the state through the use of special signage and labeling in grocery stores and other outlets. Run by the Colorado Department of Agriculture, this program, in addition to providing labels and other marketing resources, also coordinates special events, educational opportunities for customers and farmers, and a variety of other support tools.[76] Similarly, the Colorado Food Policy Network, a non-profit research and coordination coalition aimed at addressing issues of food insecurity, dietary quality, access to fresh, healthy food, and a variety of other initiatives undertakes significant work aimed at improving the health of Coloradoans and the farms that feed them.[77] At the same time as these "top-down" organizations are reaching out to communities, within communities themselves there are also hundreds of local, regional, statewide, and national agricultural sector or adjacent advocacy organizations currently active in the state, as well as a growing number of active year-round farmer's markets.[78] How much these potential sources of social, psychological, and financial support have directly impacted the lives of Colorado farmers has not been readily quantified. However, the significant and seemingly growing role of grassroots level organization around various industry interests suggests that there is demand within the system for solutions that go beyond existing institutional mechanisms. Through growing educational and other outreach programming, concerted lobbying, and significant inter-organizational cooperation, Colorado agricultural advocacy networks have demonstrated significant capacity to provide a platform for helping the state's growing population learn about the realities and importance of farming, and for helping rural agricultural communities influence how policies are made around water use, water infrastructure planning, and various other statewide decision-making processes with implications for the ability to deal with weather-related downturns. Whether this will prove sufficient to buffering the Colorado community against this year's and future shocks is unclear, of course, but it is likely that rapid developments in this area will continue apace.

In addition to building and utilizing social and cultural capital, a growing number of farmers across the state have also been long engaged an evolution of thinking with regards to how they manage and sustain the environments in which their farms are located. Much as is the case with ranching, this movement goes by a variety of names, ranging from simple "no till" farming to conservation, sustainable agriculture, restorative farming, soil farming, or eco-agriculture. Whatever the label, however, this movement generally tends to orbit around several key principles and practices developed in response to the vulnerability and excessive environmental impacts of traditional industrial agriculture. Perhaps most critical in this broader movement has been what agricultural researchers have called the "soil revolution," in which living, complex soil ecosystems are seen as the central component of a healthy agricultural landscape.[79] Also common in this area is the use of planting and field preparation techniques that minimally disturb the soil structure, which in turn can allow for more effective soil water storage, more rapid absorption following storms, and better nutrient cycling for crops.[80] Another common feature is the use of cover crops rather than bare fallowing, with species like clover and other nitrogen fixers serving to restore recently harvested soils while simultaneously protecting topsoil layers from erosion.[81] These efforts are often also utilized alongside weed control techniques that utilize diverse, native plant communities to pro-actively exclude common agricultural weeds and pests, as well as to attract and sustain healthier populations of pollinator insects. As a result, advocates of this approach argue, farmers are able to simultaneously reduce negative environmental impacts from fertilizer runoff and other pollutants, increase the resilience of the ecosystems on which they depend to drought and flooding, and maintain livelihoods.[82] Simultaneously, they improve and sustain local environmental values, in both cultural and financial terms. Sustainable farming and various derivations thereof have proven a powerful set of marketing tools, as well, as consumers in many markets become increasingly concerned about the impacts of their food consumption. By embracing sustainable agriculture approaches, then, farmers may be able to mount more effective defenses against the various hazards they face, be they weather- and pest-related or driven by the rapid social and economic change seen across the state.

These shifts in the practice of agriculture are also occurring alongside efforts by many farms to diversify their business models, either through on-farm sales, or by opening up their farms during certain parts of the year for various tourism-related activities. These range in character from classic corn mazes and pumpkin patches during the fall season to full-scale education and agricultural training facilities. Seen by many as a bridge between growing urban communities – who often know little to nothing at all about how food is grown – and the sprawling rural landscapes that farmers call home, these efforts allow farmers to supplement their incomes and generate community support, both of which are critical assets during times of weather-driven stress. Along these same lines, a number of farms, ranging in size from small 1-acre microfarms to larger, more conventional operations are also strengthening partnerships with local restaurants and other bulk food consumers as a means to leverage broader trends towards a preference for local food and "farm-to-table" dining options. These efforts are especially notable in the state's numerous mountain and resort towns, where restaurants may face both elevated import costs and significant demand for ethically produced livestock, vegetables, and grains.

These are just a few of the technical, social, marketing, practice, and business planning innovations taking place within Colorado's 30,000+ farms. Though significant challenges remain – be they in the form of increasingly intense weather, increased pressure from urban growth, aging farm communities, or limited services in rural areas – these efforts represent a move toward resiliency in communities that might otherwise be facing down rapid livelihood and community decline. As policy makers consider how best to aid adaptation efforts in the agricultural sector, then, it is critical that they address not only the technical side of farming (i.e., crop varieties, watering technology, labor-saving tools, etc.) but the mechanisms that allow farming communities to organize, advocate, and pursue development in ways that mesh with their unique local values. For while weather and other risks will likely always be a part of farming life, it is the networks of supporters, customers, friends, and families that make up Colorado's farming communities that provide the most critical mechanism for pressing forward amid uncertainty. Likewise, while the importance of crop insurance programs and other federal subsidy programs is a necessary part of doing business in a changing world, so too must be programs that enable communities to innovate *as communities*, and develop the skills needed to work together to solve mounting problems of water scarcity, land use change, and the myriad of other challenges Colorado farmers face.

Outdoor Recreation and Tourism

Adaptation in the recreation and tourism sector in rural and mountain communities is extremely varied, both as a result of the many different business types captured therein, and because of the diversity of communities themselves. However, several themes have emerged over the last several years that bear recognizing here, as they too operate at the intersection of state and federal policy-making processes. Among the most important of these is that, given the overall dependency of the Colorado tourism economy on national and global economic processes and states of affairs, its ability to provide livelihoods can be seriously impacted by forces beyond local adaptations. Second, because of the way in which it is structured, with several extremely large and well-capitalized resort corporations operating alongside thousands of much smaller organizations ranging from local restaurant chains to part-time hunting guide operations, impacts from weather-related or external forces will almost always be borne unequally. From this, policy makers must also understand that strategies that prove viable for large, well-resourced operations may not be either feasible or functional in smaller businesses. Similarly, because of the diversity of economic structuring across the various tourism-dependent communities in the state, decision-makers must be able to tailor responses to specific community needs.

That said, several major adaptation strategies with implications across the sector are already underway. The most prominent and visible of these is snow-making, or the production of artificial snow. Used by all but a few ski resorts in the state, snow-making has allowed most operations to maintain full season operations despite extremely late starts to winter and dramatic shortfalls in total snow. By using water stored in reservoirs – usually gained via purchased senior water rights – in combination with electricity and specialized infrastructure, ski resorts have been able to buy back winter from the claws of drought for the time being. For those at lower elevations, such as Howelson Hill, future rises in temperature could mean a shortening of the period where

Photo 1 - Ducks swim near river rafters in Browns Canyon National Monument. Credit: U.S. Department of the Interior (Wikimedia.org), 2015.

snowmaking is effective. However, unlike other water uses across the state, controversy about the utilization of snow-making is generally minimal, as water lost to sublimation is relatively low, and all water used for snow eventually re-enters local watersheds at times when downstream communities need them most. As with other operations that rely upon stored water (and the rights needed to store it) however, even the most robust snow-making operation may struggle to be effective if several drought years occur in sequence.

What this has meant thus far for ski resorts and the towns that surround them is a need to figure out how to generate sufficient revenues from shorter, more unpredictable ski seasons. Thus far, they have been generally successful in this regard, with overall visitation and revenues at

Colorado ski resorts continuing to climb despite slight dips in attendance in 2017.[83] This intensification of the ski season has not come without setbacks, however, as the unpredictability of ski resort opening times due to the variable beginning of snowmaking (and normal snowfall) and extraordinary pressure in most mountain communities in terms of developing and securing affordable housing for workers. Granted, this comes amid already serious pressure on the housing markets of Colorado and mountain communities in particular. In the narrow valleys and highland parks that characterize most mountain resort towns, real estate development, relatively small areas of easily developed land, and the rapid subdivision of large land holdings for luxury second homes all combine to drive prices out of the range of most service and tourism industry workers. Though many large ski resorts like Vail and Aspen are themselves are working through a variety of programs to address this issue – including, in some cases, simply building or acquiring employee housing themselves – it remains unclear how these same pressures will be alleviated in towns where resorts lack the free capital to engage in this sort of civic engineering.[84]

Part of the reason housing costs – or rather, the ability to house a workforce – has become so critical for ski resorts is that, as another response to less predictable ski seasons and the variety of recreational opportunities Colorado provides, many resorts and mountain tourism communities are attempting to transform from simply "ski towns" and into year-long, all season tourism destinations. Indeed, many have already largely done so, with most large resort towns offering some form of year-round attraction or array of attractions, ranging from golf courses to more traditional activities like rafting, tubing, and fishing. As a result, however, this means that towns that normally dealt with a large seasonal worker pool must now also find ways to ensure that a growing number of year-round employees are able to afford local housing at a time when international investors, second homeowners, and real estate speculators of every stripe are driving prices upward.

Part of the transition to yearlong recreation and tourism plans for mountain communities, however, has meant that they are thereby exposed to all the varied stressors that Colorado's increasingly hot and often dry summers can bring with them, particularly during years of drought and following widespread environmental damage from issues like wildfire or insect-induced tree death. In Salida, home to Monarch Ski Resort, partnerships between the resort, the local community, and the U.S. Forest Service have been undertaken to remove standing beetle-killed forest in the area for mulching and sale to local lumber yards.[85] Similar efforts have occurred in the numerous recreational areas affected by beetle-kill in northwestern Colorado, where large concentrations of bark beetle mortality have long been an eye-sore and seeming wildfire threat for local residents and visitors. There, funds from the American Recovery and Reinvestment Act and Colorado State Forest Service were utilized to establish beetle-killed lumber processing chains around 2010, albeit with only limited operations continuing today.[86] For although other numerous operations are on-going to find ways to capitalize on beetle-kill timber, the state's extremely small logging labor force (around 1,200 employees statewide) and lack of large, efficient lumber processing facilities make similar lumber from other states more cost effective for the large retail outlets on the Front Range.[87]

Looking beyond the ski industry, adaptation in other types of recreational businesses is also taking place at a variety of scales. At the individual operation level, many recreational outfitters in hunting, rafting, fishing, nature tour, and other similar "guided recreation" businesses are undertaking a similar strategy of diversification seen in ski towns and agriculture. In this case, however, it comes in the form of both diversifying the type of services offered – many operations, for example, offer hunting and fishing tours; guided hikes and education; etc. – and in terms of the actual sites utilized. For example, several operators interviewed as part of research on the recreation sector in the Craig, Steamboat, and broader Gunnison basin found that many larger operations maintain a portfolio of destinations in the form of owned lands, leased private lands, and permitted public lands.[88] As a result, they are generally able to avoid areas undergoing localized shocks, thereby ensuring that their customers are satisfied under all but the worst weather conditions. River rafting outfitters are also looking at changing the way they schedule and organize their various types of runs, using periods of low flow for more family-oriented outings, and utilizing careful monitoring of river conditions to identify periods of the increasingly rapid spring runoff period are ideal for more intense rafting experiences.[89]

Perhaps the most impactful efforts to adapt to changing resource variability in the broader recreation sector has come through cooperation with various state, county, and federal entities by different recreational industry advocacy groups. In the fishing, rafting, and general environmental recreation area, the State of Colorado's Instream Flow Program is one particularly notable example. Conceived as a means to work within the existing water rights adjudication system to maintain flows in Colorado's numerous rivers and streams, the In-Stream Flow program involves various state laws, statutes, and court rulings that allow the Colorado Water Conservation Board (CWCB) to develop and acquire water rights designed for the purposes of restoring and maintaining existing ecological process in stream channels. Among the first of its kind in the nation, this program allows the CWCB to place calls on junior water rights holders when stream levels fall below desired conditions at specific stream gauge or other monitoring sites. As a result, fish, wildlife, and plant communities – as well as the numerous businesses that rely upon them – are able to enjoy some degree of security, even drought conditions would otherwise cause rivers to run dry due to upstream diversions. Although a subject of significant controversy among those who feel such water is "wasted," and legal challenges from various different water user groups (e.g., agriculture, industry, municipalities) who feel that the Instream Flow Program represents a threat to historical use maximization orientations in the water sector, the program has demonstrated significant success in maintaining river levels in both upper watersheds and lower elevation areas. However, it is in play mostly in the western half of the state, and when enacted, can seriously hinder other types of water users (as they did this year in the Yampa basin).[90]

Alongside efforts to maintain water levels in streams for wildlife and other environmental purposes, several examples of water providers, reservoir operators, and other authorities acting to maintain stream levels for recreational purposes have been noted over the last several years. This year saw particularly notable efforts in this vein on the Arkansas River, where extremely low snowpack levels threatened to shut down rafting, fishing, and other recreational activity earlier this year. Working within established agreements between users of Arkansas water in Colorado Springs, Pueblo, and at numerous downstream diversion points, the Arkansas Basin Roundtable implemented its Voluntary Flows Program to transfer water held in mountain reservoirs into the river itself. As a result, rafters, fishermen, and other river users were able to enjoy the Arkansas and its headwaters for much of the summer despite incessant drought conditions in the area as a whole. Bob Hamel, a representative from the Arkansas River Outfitter's Association – whose advocacy efforts have been a critical part of developing the Voluntary Flows Program – noted that such diversions relied heavily upon a common sense of fate among different Arkansas River users. Likewise, part of the program's continued success relies on consistent efforts to educate the public about how the program works, and the various ways that it might be utilized to protect recreational and wildlife resources. Further, while it has proven effective in maintaining river levels for rafting activity, continued research and monitoring will be required to ensure that the program is utilized effectively for the maintenance of fish and other wildlife populations.

Part of this type of effort's success might be explained by the overall character of the state itself: surveys by Colorado Parks and Wildlife conducted as part of the Statewide Comprehensive Outdoor Recreation Plan (SCORP) in 2013 found that 90% of Coloradoans participated in some form of outdoor recreation at least once per year, with roughly two-thirds of respondents (n=1,405) doing so more than once per week. In this same survey, 69.6% of respondents ranked "*Wilderness areas or open lands with little to no development and opportunity for solitude*" as very or extremely important.[91] Other work by the SCORP advisory group in 2014 also found that just under 40% of all visits to tourism related businesses in the state are by Colorado residents themselves, some of whom regularly travel hundreds of miles to do so.[92]

Equally important, no doubt, has been the work of the state's numerous outdoor industry advocacy organizations, and the variety of different community, non-profit, government, and environmental advocacy group connections that they have been able to establish over the last century. For example, the Pikes Peak Outdoor Recreation Alliance – focused solely on the region centered just to west of Colorado Springs – includes over 40 such organizations, including numerous cities, government agencies, resorts, and outdoor gear manufacturers. The Colorado Association of Ski Towns, a similar organization, brings together the municipal governments of most of the state's ski resort locations to share information on problem solving in a variety of areas, from developing effective urban infrastructure in mountainous areas to how to more effectively minimize impacts to surrounding wildlife as a result of population growth. Colorado Ski Country USA, as the name suggests, represents a coalition of 24 of the state's ski resort areas that works actively to influence public perception, media discourse, and legislation on behalf of Colorado resorts.[93] The Colorado Wildlife Federation, in operation for 65 years, represents *"anglers, hunters, wildlife viewers, wildlife photographers and other who believe in the stewardship of a wildlife population that defines our state heritage and traditions",* and does significant state and federal level lobbying work around issues of concern regarding species habitat protection, funding for public lands, and protections for endangered species.[94] Colorado Trout Unlimited, a cold-water fisheries, river restoration, and conservation advocacy group is highly active in the state on a variety of fronts, and has played a major role in multiple important court cases surrounding water use, environmental management, and specific programs like the Instream Flow Program.[95] The Rocky Mountain Climate Organization, a newly formed research and advocacy group in state, has recently put out a comprehensive report on climate-driven risks to the headwaters basins of the state for the Northwest Colorado Council of Governments, a regional coalition representing 6 of the state's most heavily trafficked recreational tourism counties.[96]

The list goes on: these are just a few of the numerous activity- or regionally-driven advocacy groups that interface with – and often act to directly benefit – the outdoor recreation industry. Given the broad scope of this project, it remains unclear just how well these various groups are enabling adaptation on the ground, particularly in the case of the thousands of small businesses and part-time recreational outfitting operations that make up the majority of the state's recreational workforce. However, what it does demonstrate is that the industry as whole has shown a proven capacity to influence political and natural systems at impressive scales, and will likely continue to do so until drastic changes occur. While deepening drought, particularly spectacular wildfire seasons, or catastrophic mountain flooding might cause serious impacts over the short term, and in specific places, it would seem that the recreational sector as a whole possesses a variety of mechanisms for reconfiguring itself in the face of the variety of shocks it has seen thus far. Whether or not this will be sufficient over the long-term remains to be questioned. However, it seems likely that, whatever transpires, the natural and recreational resources the industry relies upon will continue to be defended by a wide array of advocates at a variety of levels.

Conclusion: Empowering Innovation and Adaptation

Given both the broad scope of risks faced by rural communities and the range of strident adaptation efforts already underway, the task of empowering those hoping to innovate and adapt in rural areas is far from simple or clear. At the same time, the degree to which truly adaptive efforts are taking place in all rural areas should not be overstated. Though many communities and individuals are taking action to better cope with and respond to the increasing challenges brought by 21st century weather – and may, indeed, provide valuable lessons for those seeking to do the same – many rural communities, small agricultural operations, and low population mountain towns in Colorado may lack the basic financial, infrastructural, technical, and scientific capacities needed to enact even the most straightforward adaptation strategies. Moreover, strategies that may be applicable in the eastern plains may not apply to the mountainous western portions of the state; likewise, rural areas within the reach of future urban growth and demands for water may face challenges that go beyond local level adaptations to change. If it is the goal of decision-makers – be they policy makers, land managers, or government employees – to support the vitality and resilience of all Coloradoans, significant efforts at a variety of scales and using a variety of methods will need to be undertaken. Generally speaking, those interested in assisting and empowering adaptation processes will have to tailor their efforts to the needs and views of the diverse rural communities they hope to support, and in doing so find new ways to work alongside at times fiercely independent, deeply rooted communities. Here, we present some of the directions that such efforts might turn to, based both on the recommendations of on-the-ground actors in rural communities with which we spoke as well as the broader findings of this report.

- **Improve the capacity of leaders and decision-makers to identify areas of high vulnerability and low indicators of adaptive capacity as a means to strategically support the highest vulnerability areas.**

Not all rural communities face the same risks, nor are they all equally capable of responding to the risks they face. Given limited resources, the ability to target program funds, technical expertise, and other efforts in places where the greatest impact can be achieved is essential to maximizing overall adaptive success. In many cases, however, it is the areas with the greatest financial, social, and political resources that are best able to take advantage of state and national programs. As efforts to plan for Colorado and the nation's future continue, finding ways to engage these least-resourced communities in the conversation will be critical to ensuring that those who need the most help are not left behind.

- **Support existing collaborative networks and advocacy efforts focused on rural and mountain communities well-being, and encourage the development of such networks where they are absent. At the same time, develop ways to connect with existing local leaders and other community gatekeepers.**

Rural communities may be rightfully resistant to efforts by outsiders to transform their communities and ways of life. As a result, working within existing organizations – ranging from sector advocacy organizations to local community groups – can help to bridge cultural and conceptual gaps, build trust within communities, and provide accurate information on the specific problems at play in a given area. These networks, in addition to assisting in the process of adaptation, itself, can also provide a critical resource during periods of disaster or other weather-related hardship in both tangible and intangible ways.

- **Maintain and/or expand funding and capacity within existing knowledge sharing mechanisms, such as the Colorado State University Extension Service, and improve their ability to engage communities on issues of weather and climate risks.**

The CSU Extension, USDA field offices, and other existing conduits for transmitting scientific and technical innovations to rural areas have long been a critical asset to farmers, ranchers, and others working with Colorado lands. In addition to having the trust of the communities in which they work, extension agents and their counterparts also often have a highly developed understanding of local-scale issues in need of addressing. However, the ability of these organizations to educate and inform communities on issues related to weather and climate risks is limited. New funding streams and programs may need to be developed within these organizations to address these issues to ensure that existing responsibilities can still be met.

- **Support and encourage innovative approaches to locally-driven sustainable resource management and governance, especially in terms of water and public land resources.**

Efforts such as the San Luis Valley's novel approach to self-governance around groundwater and the collaborative work happening between local governments often require careful navigation of existing legal and policy frameworks at the state and national level. In addition to capturing the lessons learned in these types of efforts, programs to disseminate these lessons and improve overall community understanding of complex topics (such as Colorado water law and basin-scale hydrology) have the potential to ensure that community level efforts are not stymied by factors at play at scales beyond their normal range of concern.

- **Improve the capacity of existing insurance and disaster relief programs to address the real needs of Colorado agricultural and recreational operations**

As noted by several participants in this project, Colorado's farming and ranching landscape is already transforming in ways with serious implications for its ability to face down future weather-related risks. However, existing programs for crop insurance and disaster relief in agriculture focus largely on large-scale commodity crops, leaving diversified, specialty crop, microfarming, and other sorts of innovative agricultural businesses with limited options following extreme weather impacts. Although national policy hurdles may be insurmountable at this time, future efforts to protect agricultural operations may benefit from taking a more sophisticated view of the types of agriculture that is supported by government subsidies and other programs, and find ways of encouraging adaptive, sustainable practices through these mechanisms. In addition to finding ways to insure these "non-traditional" types of agricultural operations, programs might also be developed to further incentivize Colorado consumers to support local agricultural activity.

- **Encourage participation of farms, ranches, and recreational operations in scientific research and development**

As discussed in previous sections, many farms, ranches, and other land-based livelihood practitioners are constantly engaging in different types of experimentation as a means to improve the viability of their operations and ensure their capacity to pass on healthy landscapes to those who come after them. However, at this time much of this type of activity occurs in isolation, with valuable lessons and insights often being left to the individuals themselves to record and share with others. Through improved engagement by the scientific community with local level operators, it is possible that the overall ability ot the agricultural and recreation industries to learn about and appropriately respond to weather-related risks will be improved. That said, such a strategy would require both financial resources and the improvement of the ability to the scientific community to collaborate with those who make their living off of the land. Improving efforts within the state's universities to train researchers and scientists in applied, collaborative research may therefore be required.

- **Continue to develop and improve programs that reward long-term perspectives and approaches to ensuring both business and ecological sustainability**

As noted above, one of the most important strategies being utilized by farmers and ranchers to cope with issues like drought and flooding are those that involve a shift away from the pursuit of short term commodity gains and toward a more holistic, long-term view of the well-being of the landscape that their livelihoods rely upon. However, the benefits of these types of approaches may take significant time to be realized, and costs associated with adopting such approaches may be prohibitive to farmers, ranchers, and others who are already suffering under the burden of weather and economic stress. Grants, loans, and subsidies – as well as mechanisms for informational and social support – should be developed that help to encourage approaches to land and natural resource use that improve community resilience and promote the long-term sustainability of the state's ecosystems and agricultural productivity.

Granted, these are only some of the many, more detailed, more place-specific approaches that will likely be required should communities hope to truly adapt to current and future weather-related risks. Nevertheless, we present these suggestions here in the hopes that they will encourage the imagination and creativity of decision-makers at various levels as they work to address the needs of both rural and urban Coloradoans. In terms of research, future efforts should continue to explore and widen awareness of the local level dynamics at play in rural communities, as it is only through understanding how these communities view, value, and move through the world that we can develop ways to support their well-being. Similarly, given the significant risk of conflict that exists between growing urban populations and the rural areas surrounding them, these efforts should also look to new ways of bridging the urban-rural divide, and to make sure that the rapid innovation and adaptation efforts happening within large cities can translate effectively to the small towns and isolated communities where weather-related risks may be more acute.

Endnotes

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PART II: CONCEPTUALIZATIONS AND VALUATIONS OF WATER IN THE SOUTH PLATTE BASIN OF COLORADO

Introduction

The threat of water scarcity presents perhaps one of the most primordial and potentially catastrophic risk factors confronting humanity in the 21st century. Already, conflict, displacement, and the stark deprivation of well-being that follow from water scarcity affect between 2 and 4 billion people worldwide for at least some part of the year, with the potential for billions more to be affected by mid-century as a result of increases in demand, temperature, precipitation variability, and the prevalence of hydrological drought. (Burek et al. 2016; Hameeteman, 2013; Mekonnen and Hoekstra 2016; Gosling and Arnell 2016) In some regions, such as the Middle East and portions of Africa, this scarcity is absolute: put simply, not enough water in the form of rainfall, groundwater, or other precipitation makes itself available in a given year to support adequate food production and direct use by the population present, resulting in the need to import water from outside the local hydrological catchment or to engage in migratory behavior (Oki et al. 2001; Rijsberman 2006; Kummu et al. 2010; Schyns et al. 2015; Damkjaer and Taylor 2017). For most, however, water insecurity stems not from a physical absence of water, but from the failures of existing systems of water governance, sanitation, distribution, or allocation to make adequate clean water resources available to those within their domain, or from the operation of these systems in such a manner that denies individuals the ability to access such resources as are biophysically available (e.g., Aguilera-Klink et al. 2000; Langridge et al. 2006; Kallis 2010; Mehta et al. 2011; Johnston et al. 2011). That is to say, although the consequences of not having enough water are among the more grimly biophysical phenomena we can experience as human beings, these privations are seldom driven exclusively by climate and hydrology. Rather, they are the work of human beings, working both in good faith and otherwise, as they live within societies, imagined economies, and systems of cultural values whose combined articulations have brought into being vast machines of water manipulation, redirection, transformation, and utilization that come to shape the essential features of our lives. As a result, if we wish to understand and effectively address water system risks and the scarcities they threaten to generate, we must understand the motivations and ambitions that drive them as well as the technical, biophysical, and economic realities that they bring into being.

In academia, there has been a growing effort to act on this insight for some time, with substantial research across a variety of disciplines ranging from hydrology, ecology, sustainability science, and natural resources management to anthropology and social psychology over the last decade endeavoring find ways of centering the human dimensions of water systems – in terms of values, beliefs, cultural systems, social norms, and their often complex socio-economic hierarchies – within previously purely technical efforts to understand water management challenges. (See von Korff et al. 2012; Daniell et al. 2010; Hohenthal et al. 2017; Suskevics et al. 2018; Marcotte et al. 2019) Throughout, the underlying hope seems to have been that in doing so, researchers might thereby improve upon the ways in which efforts by power holders and infrastructure experts in the water domain interact with and, hopefully, honor the values and ambitions of the populations that they serve, with a number of scholars working directly on frameworks and approaches for reimagining or outright up-ending traditionally top-down, hierarchically-determined forms of water infrastructure development and water resource problem solving. However, adoption of this sort of community-driven, "bottom-up" approach to water resource management and infrastructure development has been halting and piecemeal, especially in those systems where historical imbalances of power and economic inequality have been the primary determinants of natural resource decision-making processes. In areas where their adoption has been undertaken – or at least, enshrined in policy mandates – existing systems of power and generalized presumptions regarding the values of society by power-holders and influential actors have led to systems that, while ostensibly committed to various forms of "multi-stakeholder engagement" and collaborative, cross-jurisdictional decision making, are nevertheless faced with consistent challenges as status-quo understandings of the social mandates of water management systems confront consistently diverse and ever-more conflicted cultural values in society at large. Put another way, even in situations where both intentions and legitimate forums – and even, in some cases, high-level policy mandates – aim to engage in the meaningful integration of diverse viewpoints and values within water resource management domains, the array of water sector experts, industrial leaders, political representatives, and legal scholars that find themselves engaged professionally in such work often lack the tools necessary to adequately understand the cultural systems they are, ostensibly, attempting to honor. Beyond the well-documented risks of elite capture – or the cooptation of multi-stakeholder spaces for the duplicitous legitimization of agendas of the powerful (Menard et al. 2019; Pahl-Wostl 2020; Rajasekhar et al. 2018) – the time, effort, magnanimity, and openness to dissonance that navigating and understanding culturally diverse populations requires are often beyond the capacities of even the most well intentioned leaders engaged in water system decision-making. As a result, there is a need to bring the variety of theoretical frameworks developed in the interdisciplinary sciences into real-world domains, and to develop ways of gathering, critically analyzing, and communicating information that can build both cultural competency and provide a more robust and earnest accounting of the value systems at play within the complex socio-hydrological systems that dominate the Anthropocene. Put more simply, it will be necessary to help socio-ecological and socio-hydrological systems learn about themselves and the cultural systems that give them life –that can begin through an effort to listen and learn directly from those whose work and ways of life rest at the intersection of humans and the water systems they rely upon.

In the U.S. state of Colorado, where water supplies rely heavily upon mountain snowpack, groundwater reservoirs, and highly variable lowland precipitation, and are therefore, extensively managed, issues relating to the social construction of water scarcity and abundance are especially acute. As the compound threats of local climate change, rapid population growth, and risks faced by neighboring downstream states mount however, the surprisingly stable water management systems that have evolved in the region face unprecedented challenges to their viability. Moreover, because of these threats, efforts by state and local governments to address present and future water scarcity concerns have taken form as what are fundamentally cultural programs of water management, which, though at times presented in the guise of large-scale infrastructure projects overseen by the cold calculus of technical experts, ultimately rely upon the activation and manipulation of the value systems of its citizens and the wide variety of water users that call the state home. Codified in the 2015 Colorado Water Plan, various related acts of legislation, and devolved onto an array of hydrological basin-specific "Implementation Plans," this government-led effort puts forth a collaborative vision for the management of the state's water resource future: one in which the widest possible network of stakeholders is drawn into what is meant to be a cooperative process of social learning, problem solving, planning, and project implementation. Developed through a variety of expert-driven stakeholder feedback processes and outreach efforts over the early 2000s and 2010s, it puts forth the main "Water Values" as aspirational guidelines for work by water entities in the state. These are:

- A productive economy that supports vibrant and sustainable cities, viable and productive agriculture, and a robust skiing, recreation and tourism industry;
- Efficient and effective water infrastructure supporting smart land use; and
- A strong environment that includes healthy watersheds, rivers and streams, and wildlife. (CWCB 2015)

In this, it bears with it the generalized assumptions that a) these values reflect the genuine priorities of the people of the state and the various actors within its water systems, and b) that how actors operating within the various valued systems named interact with and understand water systems in ways that align or are compatible with those of other actors, i.e., that environmental protectors, recreational businesses, farmers, and city builders all see and feel similarly about the "smart" use of land and water. This research takes these assumptions as its key point of departure.

For, as numerous observers within the state – and this research – would argue, these goals in fact do little to resolve the numerous inherent conflicts that exist between the various components outlined therein, be it in terms of conflicts between urban demand for water and land and associated vulnerabilities in the agricultural sectors, conflicts between both the former and the latter and the health of regional ecosystems, the maddeningly vague and contentious meaning of "smart land use," or the likewise heavily coded – and ill-defined – term "sustainable cities." Put more plainly, while the Colorado Water Plan and associated work put forth a somewhat ambitious model for collaborative, participatory water management, the diverse interpretations of these water values that exist within the state's basins remain a relatively unclear dimension of the system's evolution. More importantly, as temperatures continue to rise and drought conditions become ever more common, finding ways to bridge the gaps between the multiple systems of meaning that operate within the state becomes an ever more critical matter, both for keeping the peace with regard to water related conflicts, and to enabling to the state to prepare for the onslaught of change the coming century is likely to bring.

To hasten a process of evolution in the ways in which critically important experts and leaders engage in the work of shaping and understanding the human and natural systems they are a part of is, of course, beyond the scope of a dissertation. What this document represents, however, is an attempt to establish a foundation for such work, through the examination ways in which the diverse systems of valuation and conceptualization surrounding water in one Western U.S. hydrological basin both come together and split apart as actors at various levels of the water system attempt to come to terms with the meaning of its biophysical and socially-constructed scarcity. Specifically, it looks towards a wide array of stakeholders and decision-makers in the South Platte Basin in

Colorado, an increasingly populated, culturally diverse, economically unequal, and infrastructurally sprawling sub-unit of the state of Colorado's water governance system.

Its central question is: **How do actors operating from the various key vantage points suggested by the Colorado Water Plan perceive, understand, and value water?** Further, how do these modes of valuation differ given the specific ways in which they interact with water, i.e., as a commodity, as an input in physical systems, as a part of a valued way of life, or as a hazard vector, etc.? Finally, how do these value systems express themselves in process of socio-hydrological formations, such as infrastructure projects, water allocations, patterns of governance, and public support for different types of water use and water management projects?

Taken together, this work aims to establish a basis for understanding the varied socio-ecological and socio-hydrological connections within the basin, both from a physical, spatially explicit, or "top-down" point of view, as well as in terms of the on-the-ground feelings, thoughts, beliefs, and desires of those living and working to make its complex systems come to life. To this end, I utilize a mixed methods approach to qualitative inquiry, including in-depth interviews with key water system stakeholders, analysis of secondary data gleaned from public conversations about water, and examination of the available biophysical and demographic features of the basin as a whole.

The presentation of this effort is organized as follows: First, I review a selection of the relevant literature pertaining to the complex dynamics that emerge between human beings and the water systems that they rely upon, as well as what appear to be valuable innovations in participatory modeling efforts relating to these types of systems. Next, I provide a cartographic and narrative summary of the basin's socio-hydrological features – that is, the accumulated interactions between human populations, hydrological networks, and the infrastructure and other modifications that link the two - including its population, its built and natural hydrology, and various ecological and social indicators of its overall water use dynamics and the governance systems relating to them. Third, I lay out the specific methods utilized in this study, which build upon long-established anthropological and social science approaches adjusted to the spatial and governance scales appropriate to water systems. Fourth, I outline the broad thematic findings of this research process, with a focus on major sites of valuation their interactions with water management decision-making across key viewpoints within the water system. Finally, I reflect on these findings in the context of the pertinent literature, doing so with a mind to derive a series of recommendations for improving the cultural consonance and management efficacy of the collaborative water management mechanisms currently in place in the region.

Theoretical Background

Culture and Water in Climate Change Adaptation and Socio-Ecological Systems Research

The complex interplay between society, water, and the eventual fates of both has provided a prolific site of research throughout the history of the social sciences, ranging from Wittfogel's (1956) Marxist reading of water administration systems as a prime mover in the development of states to more recent examinations of water as a mechanism for the entrenchment and expression of unequal power relations (Donahue and Johnson, 1998). At the broadest level, work within anthropology has tended to focus upon relations between the cultural systems of water management and utilization in traditional societies, mainly in developing countries, whose close ties to various agricultural lifeways make water an overriding feature of social organization and expression (Orlove and Caton, 2010). In much of this work, water is analyzed as a formative component of a given society's holistic cultural system, acting as both a resource requiring careful management (and extensive conflict mediation), and as a substrate – in combination with local ecological and climate patterns – for the development of far-ranging systems of expression, apprehension, and mutual co-adaptation (e.g., Geertz, 1972; Lansing, 1987; Lansing and Kremer, 1993; See also Wateau, 2011). Other researchers, moving beyond such relatively straightforward functionalist or adaptations approaches, have attempted to unravel how the essential nature of water makes it a consistent site of contention and the embodiment of cultural systems of marginalization, with access to and control over water becoming one of numerous mechanisms involved in the creation of systematic resource insecurity (Wutich et al., 2014b; Eichelberger 2014; Willermet et al. 2013; Donahue 1997). Whatever the focus, however, social science research on water-human relationships is clear on both its critical role in a variety of biophysical, agricultural, and technological systems, and its capacity to serve (thereby) as a locus of cultural construction and expression. That said, critical questions remain regarding the conditions necessary for the development of novel water management or allocation strategies within societies where cultural systems of water relations are deeply rooted within the broader social system. Likewise, much remains unclear about how broader cultural dimensions – especially those increasingly imbricated within systems of popular culture and technology that distance individuals from the dynamic natural resource flows they rely upon – ultimately shape transitions toward more sustainable and equitable hydro-social arrangements (see, e.g., Tabara and Ilhan, 2008).

On a broader level, a growing body of inter-disciplinary research focused on issues of climate change vulnerability and adaptation has also begun to examine how the vital weight of water in global socio-ecological calculi is and will continue to shape the biosphere in the coming century. By and large, this research has been focused primarily on how perturbations in the global climate system will result in impacts to social systems at global, national, and economic scales. However, because the intensity and destructiveness of various climate change impacts will ultimately be determined through interactions with the sensitivities and characteristics of human communities, there has been a steady and growing effort to integrate social science methods into broader assessments of risk and potential adaptive pathways (Adger 2003; Adger 2006; Adger and Vincent 2005; Adger et al. 2005). Only recently, however, have explicit considerations of how different cultural configurations differ in their apprehension of risk and propensity to adjust according to climate-driven signals been brought to the forefront of this effort (Adger et al. 2012; McNeeley and Lazrus 2014; Crate 2011; Crate and Nuttal 2016). In this body of research, culture is seen both as a substrate upon which impacts are realized, apprehended, and transmitted within human systems, as well as a key mediant in the construction of vulnerability and the development of adaptation strategies. As a result, significant questions remain regarding which strategies are most effective for the communication of risk-related science, the collaborative development of adaptation strategies between experts and various community stakeholders, and how, within systems of entrenched economic and political inequality, to ensure that efforts to reduce vulnerability are able to address the vulnerabilities that those inequalities produce. More importantly, because of the somewhat laggardly response by various U.S. governments to the risks of climate change, actual implementation of the lessons learned in the last two decades of social science examinations of climate change risks have been largely absent from most government and state-level planning (see, e.g., Thompson et al. 2015). Though numerous promising frameworks have been developed and a number of small-scale case studies have been undertaken (e.g., Knapp 2014; McNeeley and Shulski 2011; McNeeley 2014; Murphy et al. 2015; Murphy et al. 2016), there nevertheless remains a need for approaches to gathering cultural data that provide both scalability and broad applicability to diverse adaptation settings.

Alongside work focused specifically on integrating cultural values and diversity in efforts toward adaptation to climate- and global environmental change, significant advances have been made in the last decade within research that attempts to incorporate cultural considerations into efforts to improve the sustainability of socio-ecological systems. In this, they expand upon foundational frameworks and ideas developed by Elinor Ostrom and colleagues (e.g. Ostrom 2009; McGinnis and Ostrom, 2014) that noted but largely obviated the powerful role that cultural systems play within the complex, adaptive networks of co-dependence and co-evolutionary linkages that make up socio-ecological systems. In contrast, these works attempt to center the complex interplay between values, ideas, knowledge, behaviors, and power dynamics in both theoretical analysis and practical efforts to improve systemic sustainability (e.g., Brondizio et al. 2009; Cote and Nightingale 2012; Chan et al. 2012; Cole et al. 2013; Diaz et al. 2015; Ellis 2015). A particularly notable example of this Poe et al. (2014), which utilizes the varied linkages between fishing communities in the Northwestern United States and the varied terrestrial and oceanic aquatic ecosystems that they live within. In it, they argue that the socio-cultural well being of humans and the wellbeing of environmental systems are inextricably linked, with each ultimately informing the other for good or ill as both evolve over time through both perceptual and physical feedbacks. As such, they put forward five key dimensions of cultural-ecological connections, each of which weaves together with the other to create the living substrate in which land, water, and wildlife management decisions are made and acted upon. These are: meaning, values and identities; local systems of ecological knowledge and practice; livelihood dynamics in both formal and informal sectors; systems of governance and the differential power relations determining who has access to governance decision-making; and bio-cultural feedbacks, both in terms of food web connections and varied psychological and behavioral that specific environmental context allow. Although by no means exhaustive, they argue that practitioners hoping to develop policies, restoration programs, or adaptation initiatives can do so more effectively by accounting for these dimensions, as they provide the foundation for human well-being and the pathways through which changes to human-environment interactions can be made. Thus, alongside traditional quantitative and empirical methods for assessing ecological integrity and program goals, focus and expertise on the varied dimensions of sociocultural wellbeing should be utilized to more effectively work with and through communities confronting unsustainable socio-ecological situations (see Figure 16).

Another line of research with acute relevance for this study is that of Tiffany Morrison and colleagues, which attempts to turn a critical eye on systems of polycentric governance and the power dynamics that undercut its ability to address complex socio-ecological threats (Morrison et al. 2019; Morrison et al. 2017). Seen by some as having significant promise due to their purportedly higher levels of scalability, flexibility, and adaptive capacity, polycentric governance models came into vogue following work by Ostrom (2010; Nagendra and Ostrom 2012) and others noting that top-down methods of managing common pool resources and other issues of human-environmental connections often fail as a result of their centrally organized and hierarchically empowered manner and its inability to adapt to local conditions, compel local compliance, and thereby, to devise

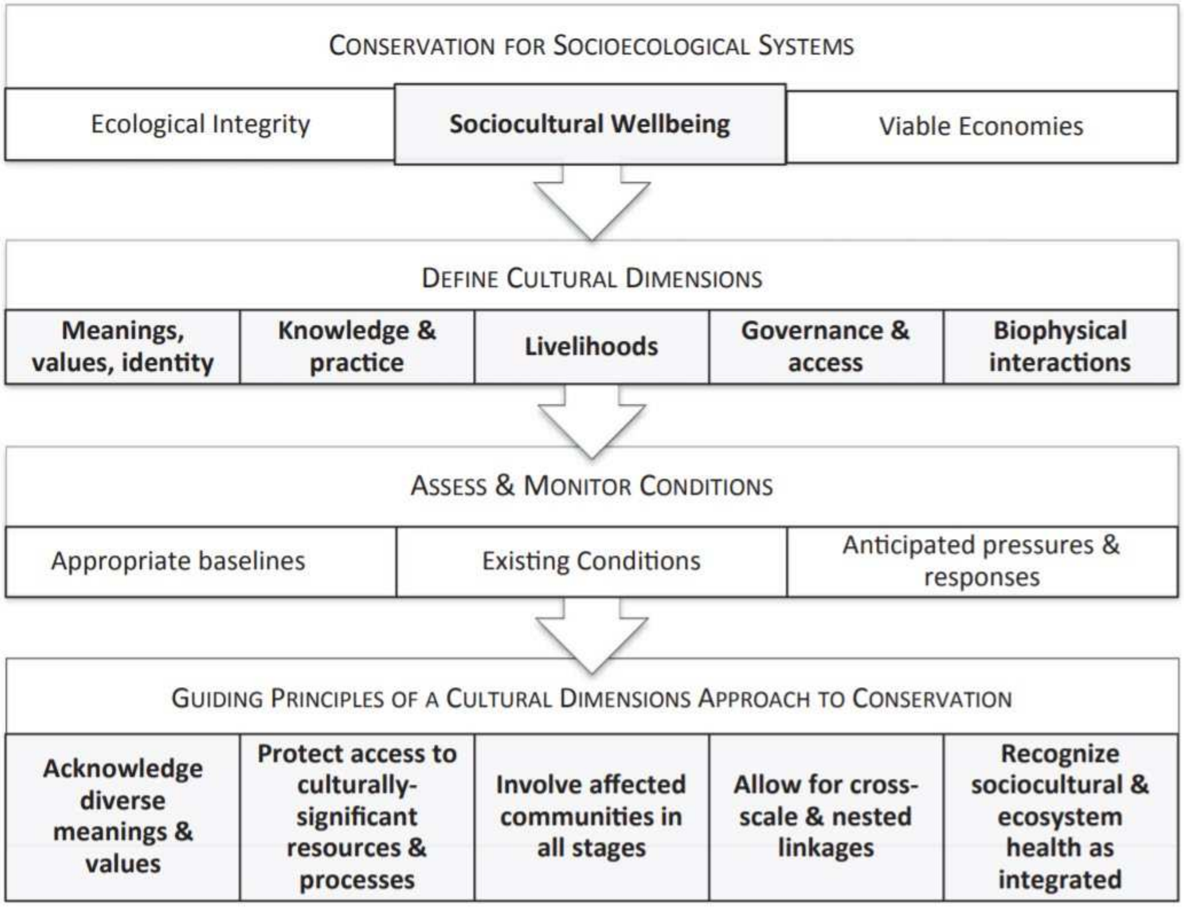

Figure 16 - From Poe et al. 2013; Guiding principles for incorporating cultural dimensions into SES conservation processes.

solutions that have the flexibility needed to apply across multiple locations and across the natural and social gradients that occur within complex human-environmental linkages. Polycentric systems, by contrast, operate across multiple levels of authority (local, regional, state-wide, system-wide, etc.) in a nested fashion, and through multiple sites of governance across the biophysical and land use gradients of a system, leading many in the resource governance and adaptation world to suggest that they might be better suited to addressing the "wicked", often diversely embodied challenges of global environmental change and ecosystem degradation. As Morrison et al. note, however, they are not without their own problems. Specifically, these types of systems have proven to be particularly vulnerable to imbalances of political, economic, and cultural power, leaving them open to corruption by minority actors and obstructing their ability to develop solutions that span across large, interconnected systems. In order to disentangle the complexities of power as they operate within socio-ecological systems, they argue that multiple types of power must be considered when analyzing its dynamics within governance systems, noting that *power by design,* such as the capacity of a state to make laws, is often heavily shaped by both the *pragmatic power* of wealthy or well-positioned actors as well as the *framing power* of influential actors operating through social and cultural networks to alter governance landscapes (see Figure 17). In the context of the South Platte Basin system – which embodies numerous traits of a polycentric governance system due to its multiple levels of governance (federal lands managers, state law, the CWCB, municipal water providers, city governments, ditch operators, large water users, environmental advocates, and so on) – this framework suggests the need to better understand how narratives about the water system are utilized

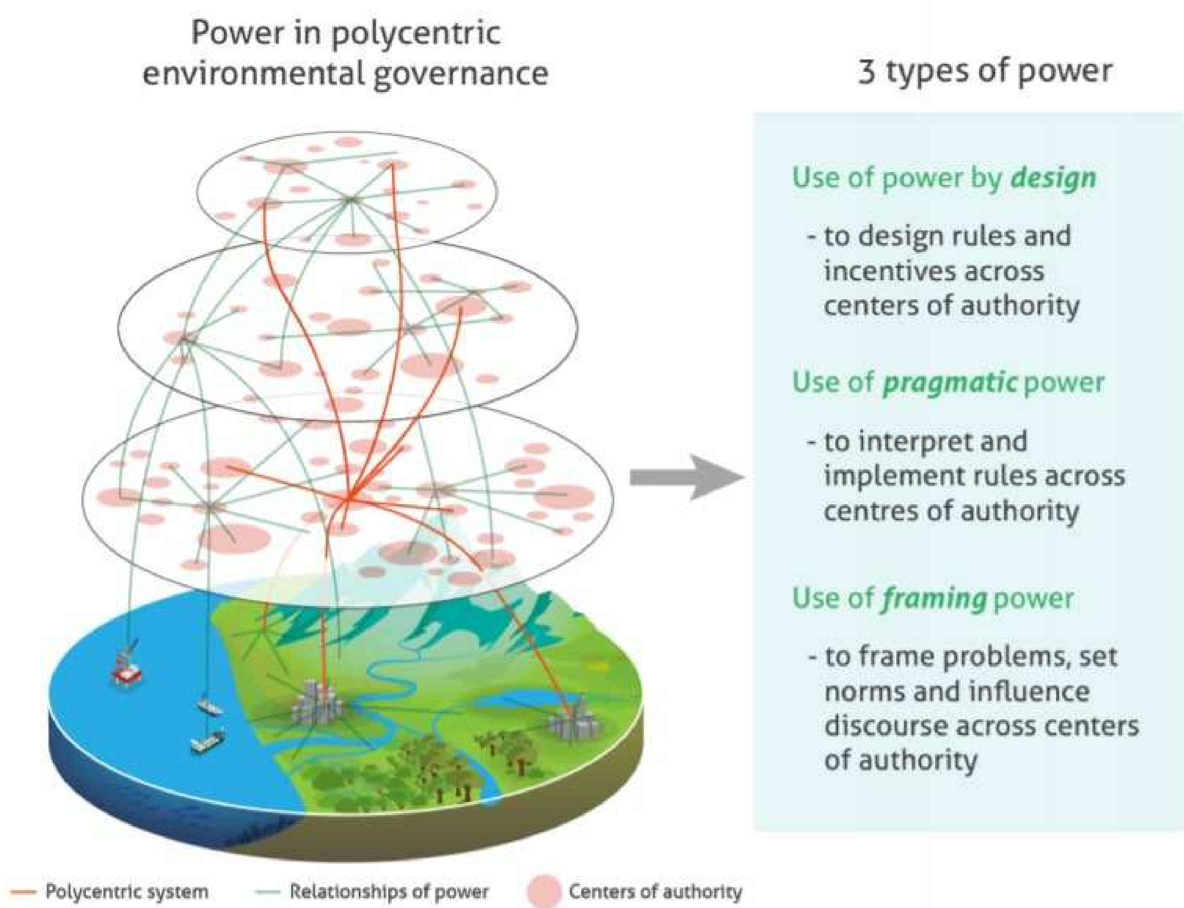

Figure 17 - From Morrison et al. 2019; Key concepts and dominant interpretations of power relevant to polycentric systems of environmental governance.

to influence both high-level spending priorities, large-scale infrastructure, and municipal level conservation, among other factors.

Hydro-Social Studies

In this study, I hope to explore how people operating from diverse positions within an interconnected water system use, feel about, think about, and manage water resources. Because of this, questions of assessing cultural connectivity between people and water – in the form of systems of discourse, legal proceedings, political acts, access restriction, infrastructure plans, and so on – are central to the overall process, as is understanding the impact of differing core value systems on activity within these different structural domains. Unfortunately, although sociologists, anthropologists, and geographers have long understood the powerful role of water resources in the shaping of society and culture (see Schmidt 2014; Bannister 2014), much of the history of water research in Western academia has been the domain of physical scientists such as geologists and hydrologists. This has led to the dominance of the view that water systems and hydrodynamics should be understood mainly through water's chemical, physical, and – via its use in agriculture, industry, and trade – economic properties (Linton and Budd 2014). As a result, theorists working under the label of "hydro-social theory" argue, modern systems of governance and scholarship surrounding water have "desocialized" water's roles in social life, both in terms of its ability to shape the history of societies as well as in terms of how conceptualizations and understandings of water systems reflect on broader dimensions of cultural life (Swyngedouw 2009). Moreover, because the management of water in these systems is left largely in the hands of various powerful state actors, engineers, and scientific experts, water in modern systems is largely conceived of as a purely "natural", i.e., *not* social, phenomena, the ultimate result of which is the delegitimization and marginalization of cultural understandings of water that view it as more than a mere resource to be exploited, or environmental component to be managed (Budds et al. 2014). As a result, these theorists argue, water science and engineering (perhaps unintentionally) have engaged in a broad de-politicization of water management, which, in addition to generating considerable myopia with regards to imagining ideal water management solutions, has also led to a failure to account for how social systems for the management of water affect different social groups both positively (as in the case of farmers able to redirect river flows to their fields) and negatively (as in the case of groups negatively impacted by canal or levee construction, such as was the case in New Orleans in 2005 (Freudenburg et al. 2009)).

It is against this purely hydrological reading of water and its role in society that hydro-social theorists position their approach, which explicitly aims to situate water and society as almost helically joined components of a larger hydro-social system, with water shaping society and society, in turn, reacting to hydrological dynamics through its management and alteration (Swyngedouw 2009). Critical to this approach is their conceptualization of the hydro-social cycle (in contrast to the hydrological cycle), in which water and social systems operate as intricately linked components whose characteristics form a hybridized, socio-natural system (Budds et al. 2014). Drawing heavily on the work of Bruno Latour (2012), these authors attempt to unravel the modernist illusion of nature/society dualisms that shape much of 20th century academic work, instead hoping to examine how systems of water governance and management are shaped by the confluence of power inequalities, historical experience, local knowledge, and spiritual practice (Bannister 2014). As such, the hydro-social cycle could be seen as both nested within and existing outside of the traditional hydrological cycle, with annual and decadal variations in precipitation and other forms of "natural" water movement occurring within and around similarly cyclical processes of learning, valuing, constraining, utilizing, and transforming the results of hydrological dynamics within human-altered natural systems (Meehan 2014; Fig. 18).

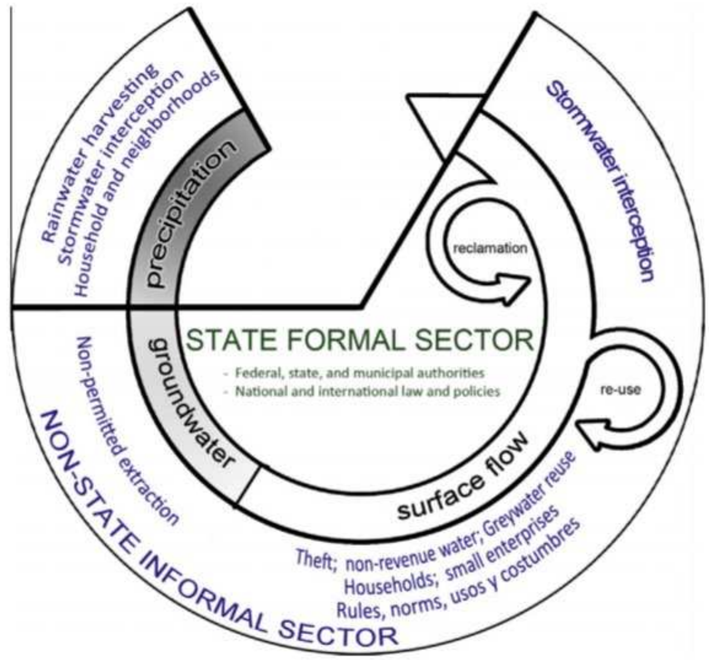

Figure 18 - From Meehan 2014: The Tijuana Water Cycle, in which water is utilized by diverse state and non-state actors as a site of subsistence, state power, traditional management authority, and economic subversion.

Indeed, as Meehan (2014) observes, water use and redirection, through its ability to generate incomes and subsistence, can be seen as a political act in and of itself, acting as a signifier of the porous nature of state power in areas like Tijuana, Mexico, where numerous failures of international governance have left many communities without reliable access to otherwise abundant water resources. In this, she touches on one of the central aspects of broader hydro-social theory, namely, the attempt to delineate how access to and control of water resources operates as a source of political contestation. In other words, where traditional hydrology asks questions like "Where is the water?" and "Where will it flow?", hydro-social research looks to questions of for whom water is directed, who benefits from such efforts, and who decides where, when, and how technical or land use solutions are utilized to determine hydrological dynamics (Swyngedouw 2009). Boelens et al. (2016) take this approach further, noting that while water often circulates within and through the entirety of a given socio-ecological system, only certain discursive and/or geographic domains give rise to contestation over its use. Terming these areas "hydro-social territories," they argue that, much like water management as a whole, the ways in which different social and political systems control where and how discourse surrounding water takes place shape not only how water is governed, but how those governance systems interact across scales of the broader social system (Boelens et al. 2016).

In related work, Barnes (2014) shows how traditional top-down systems of understanding water systems and feedbacks fail in the face of the complex interrelations of water users in the Nile Delta of Egypt. Here, recent concerns over water scarcity have led to the development of a widespread water pumping and reuse scheme, which draws used agricultural water from flooded fields for reutilization on late season crops, the result of which has yielded a roughly 20% increase in the area's total water supply. Although hailed by powerful state actors as a triumph of efficiency and as a tool for economic development, interactions with local heavily fertilizer dependent cropping systems and tight networks of neighboring farms has led to an unexpected effect, namely, increasingly high concentrations of salts and other fertilizer by-products not filtered in between each reuse cycle, creating both immediate health risks and long-term threats of land degradation (Barnes 2014). In other words, where the traditional paradigm focused largely on how to direct more water to where it was needed for economic production, it failed to understand how water, acting as a medium of transfer and solvent, was transformed – albeit gradually, perhaps, at each step – until finally it became inimical to the very process it was meant to serve. Similarly, Carey et al. (2014; See Fig. 3), note that power relations can also serve to obfuscate reality and scientific information in their examination of the impacts of glacial retreat under climate change and its role in the overall future dynamics of the Santa River in Peru. Observing that glacial losses due to rising temperatures have been blamed by high level officials for water supply problems in the surrounding farms, they conducted a basin wide social/hydrological analysis, analyzing both changes in water supply and use over the last several decades. In this, they note that, while glacial retreat has contributed somewhat to decreasing water supplies, and will likely do so in the future, contemporary water shortages are driven almost entirely by increased urban and industrial use in the area's growing cities, as well as increasing watershed degradation due to rapidly expanding mining operations (Carey et al. 2014). In other words, natural processes – driven, in this case, by anthropogenic climate change – provided a convenient tool for the obviation of more pressing debates about the economic and cultural development of the region. As a result, their model (Fig. 19) for basin-scale hydro-social interactions incorporates climatic, biophysical, social, and cultural systems, with cultural values, knowledge, and behaviors interacting with stratified systems of governance, technology, land use, and other variables to direct infrastructure and create water demands of various types. However, while their paper itself brings to light the heterogeneity and conflicted nature of human-water interactions, and the varied value systems involved, the social system is ultimately abstracted to a unified system made up of these diverse actors in various diagrams, and in the analysis of the overall system.

In summary, hydro-social theory, including the examination of hydro-social cycles and territories, attempts to situate humans and water as actants within broader networks of power,

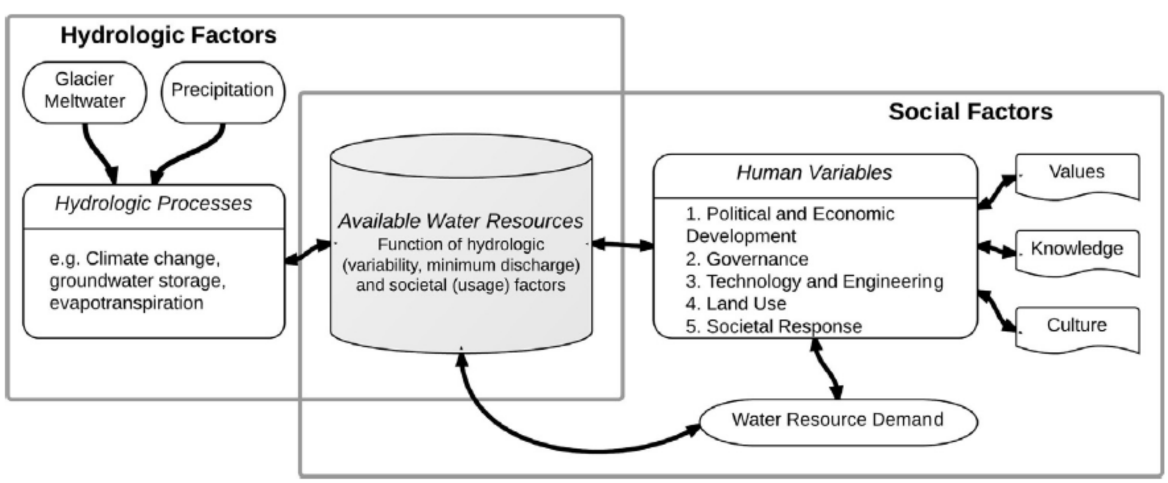

Figure 19 - From Carey et al. 2014: Demonstrating interactions between human and hydrological variables in the Santa Rosa basin, the authors attempt to reconcile how historical development patterns have shaped local level water access, narratives of water shortages, and how discourse on climate change interact in unequal power structures.

capital, values, and knowledge, in which differential access to legitimacy and resources among groups shapes both how they interact with water resources and, thereby, how power relations are recreated through time (Swyngedouw 2009; Budds et al. 2014; Schmidt 2014; Boelens et al. 2016). In this, it provides a valuable framework for understanding contemporary water governance struggles, both in terms of how they reflect broader inequalities within society and how differing groups, through their interactions with the water system, come to hold often dramatically differing views of what water means. That said, much like the political ecology frameworks from which it draws (Swyngedouw 2009), it could be argued that, with some notable exceptions (such as Carey et al. 2014, discussed above) its highly critical and largely qualitative and theoretical approach causes it to elide a more detailed analysis of the underlying physical and chemical processes taking place within the systems of power and value it examines.

Socio-Hydrology

Socio-hydrology, much like hydro-social theory, attempts to integrate social, political, and behavioral factors into analyses of hydrological systems. However, unlike the various geographers, political ecologists, and anthropologists cited above, socio-hydrology owes its roots in the physical sciences, namely hydrology, water resource management, and civil engineering (Sivapalan et al. 2012). Conceived of as a "use inspired sustainability science for the Anthropocene" (Sivapalan et al. 2014), it aims to improve upon existing hydrological science and modeling by taking into account how human populations respond to and transform differing hydrological systems. It does this by focusing on three main factors 1) structure and dynamics, such as the presence of dams or natural floodways; 2) values and norms that influence water management decisions and patterns of use; and 3) outcomes in terms of well-being, both for humans and ecosystems valued thereby (Sivapalan et al. 2014). Central to this approach is a marked future orientation – specifically with concerns for long-term system sustainability under global environmental change – both in terms of improving climate projections and helping to shape water management policy and infrastructure decision making. As a result, it focuses on problems largely foreign to traditional hydrology, such as the paradox of efficiency (in which increases in the efficiency of water use in agricultural and industrial operations leads to higher profitability, and thereby, higher overall water use) and global virtual water flows, wherein water resources used to grow food or manufacture goods are "exported" through global economic systems (Sivapalan et al. 2014). This is combined with a greater understanding of the need for a hydrology that hinges its understanding of hydrological systems as inextricable from histories of human alteration, processes motivated both by biophysical limits and needs as well as by the political, cultural, social, and economic practices of the human populations involved (Blair and Buytaert, 2015). In the context of this project, socio-hydrology provides a number of robust inquiries into the quantitative and process factors to consider when investigating basin scale sustainability and vulnerability. At the same time, it provides a view of the domains of action considered by engineers and hydrologists when attempting to integrate the needs and impacts of human activity into their models.

To wit: many of the models and analyses developed under the banner of socio-hydrology in the last few years have attempted take stock of how differing approaches to land management, economic development, and other factors interact with long-term hydrological dynamics. For example, Elshafei et al. (2015), in an examination of the Lake Toolibin catchment in West Australia integrated land use management variables (i.e., whether or not land was cleared, planted for agriculture, or left in its natural state) to examine how future precipitation projections will interact with surface conditions to determine regional water supply and rates of land degradation due to salination. In it, they found that human activity and management decisions could radically alter the hydrological dynamics of the basin over time, particularly when high levels of land clearing and the removal of deep-rooted grasses and other ecological buffers occurs. Further, by programming limits to human activity – namely, water contamination from salination or losses of water availability due to groundwater depletion – they were able to demonstrate a long-term panarchy cycle, in which expansion of agricultural activity was followed by degradation, eventual abandonment, and finally, recovery of local ecosystems (Elshafei et al. 2015). In other, more empirical work, Gober and Wheater (2014) examine how development, mining, agriculture, and climate have and will likely interact in the Saskatoon river basin. In this, they find that economic booms related to mining and rising temperatures (improving conditions for agriculture in the region) have already begun to result in troubling water quality issues across the broader basin, with phosphorous levels already reaching dangerous levels in many areas. As a result, they argue, future infrastructure planning (i.e., dam building) in the region will have to consider both water resource needs as well as basin-scale human-environment interactions with implications for the nature of water being managed (Gober and Wheater, 2014).

Other work within socio-hydrological modeling has taken a more ambitious approach, seeking to incorporate models of social learning, trust, risk perception, and other cultural variables into long-term simulations. In Di Baldassarre et al. (2013), for example, the authors attempt to capture the dynamic interactions between floods, human populations, and infrastructure development in a model basin. Building upon observations from the social sciences that note how technological solutions such as levees and dikes drive seemingly paradoxical increases in long-term flood risk, whereas various natural or "green" flood mitigation strategies can reduce overall flood losses despite allowing for more frequent flood episodes, they attempt to evaluate a variety of differing development scenarios for maximal losses over time. In this, they also integrate variables relating to the "memory" of the simulated human populations, noting that the more frequent but less severe flood regimes of naturally managed floodplains can lead to higher overall long-term levels of flood understanding (Di Baldassarre et al. 2013). Similarly, in Viglione et al. (2014), the authors attempt to integrate variables for collective memory, risk-taking, and trust as components of a coupled social-hydrological flood model. Here they find, in concert with broader sociological and anthropological findings, that flood regimes with a rapid recurrence can lead to increased adaptive behavior through their ability to keep memory of flood episodes fresh in the minds of populations. At the same time, however, over-confidence (in the form of high trust variables) can lead to a cancelling effect on flood memory due to overconfidence in technological flood controls (Viglione et al. 2014).

Granted, these presumably early entries into the field represent, at best, crude representations of the dynamic ways in which human populations learn from and respond to hydrological events and processes. That said, they present an intriguing opportunity for further inquiry into how long-term climate and hydrological processes might interact with changes in human systems, whether in terms of risk culture, political stability, institutional trust, or economic development priorities. At the same time, these approaches allow for situating contemporary analyses (such as those discussed in the section above) within a long-term temporal view, potentially allowing for both a better understanding of where contemporary human-environment dynamics might lead as well as for encouraging imagination on what – and how – changes can be made to ensure better overall social-ecological sustainability.

Participatory Agent-Based Modeling

Another burgeoning area of research with dramatic potential to reshape how communities and researchers understand socio-ecological and socio-hydrological systems comes in the form of novel approaches to modeling and analyzing complex system interactions and outcomes known as agent-based modeling. In most of the examples listed above, the various models utilized relied upon traditional, process-based modeling approaches, in which equations describing the different interactions and flows within the modeled system are linked via fixed, generally highly abstracted model components, with system elements operating in an inherently consistent and homogenous manner. For example, in Elshafei et al. (2015), the coupled social-hydrological model described utilizes a series of equations to related aspects such as hydrological flow to erosion, land conversion potential, and economic growth, with each model component being fed variables derived from previous equations in the series at each time step of the model's run. While useful for examining simplified systems or systems whose interactions are well understood and consistent through time, the complexity of socio-ecological systems – which include multiple feedbacks, individually meaningful actors, and a variety of contextually driven thresholds for behavioral change – means that purely process-based models such as this are limited in their ability to capture or represent the various stochastic, at-times highly heterogenous elements involved.

Agent-based models [ABMs], by contrast, build upon existing process-based approaches through the incorporation of individually modeled "agents" or system actors whose behavior is determined by local-scale inputs and whose behavior can adjust to changing environmental conditions within the simulation space (Railsback and Grimm, 2012; Moss and Davidson, 2001). As a result, they have drawn increasing attention from researchers and practitioners hoping to better understand and simulate complex socio-ecological systems in which feedbacks and interactions between individual human agents, social networks, hydrology, ecosystems, land use change, or other emergence-driven phenomena are of interest (O'Sullivan et al. 2016; Berglund 2015 – see Fig. 20; Filatova et al. 2013; Matthews et al. 2007). As Boone and Galvin (2014) argue, ABMs are particularly useful for efforts that hope to integrate both macro-level systems thinking (such as normally seen in disciplines like geography, hydrology and ecology) with insights from the more micro-scale social science investigations, as agents representing individual humans, the institutions they create, the

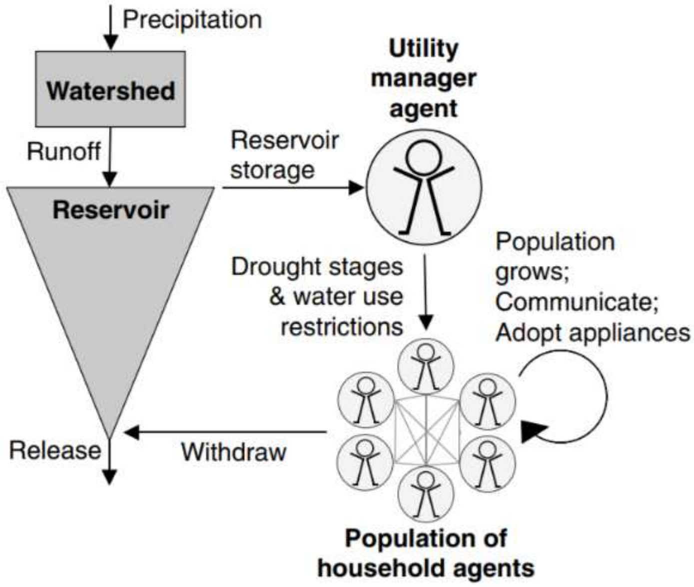

Figure 20 - From Berglund (2015). An example of a simplified basin simulation. At the basin scale, human agents interact at a variety of social scales and through a variety of technological and behavioral mechanisms to shape water resource flows. ABMs can capture these complex interactions under a variety of scenarios, and incorporate decisions made by individuals and organizations.

settlements they form, *and* the various ecological and biophysical forces within their environment can all be brought together within a single programming and analysis framework, with each component acting independently based on its specific behavioral programming.

This ability to capture complex system features – as well as to operationalize system elements at a variety of scales – has perhaps unsurprisingly made ABMs highly attractive to a variety of scholars hoping to examine human-water relationships. For example, one of the more influential early works in the field of ABM stems from efforts to better understand how the seemingly complex and carefully timed and large scale water management systems seen in traditional Balinese irrigation practices developed over time, and how centralized water authorities (water temples) and individual farmer decision making influenced this development (Lansing and Kremer, 1994). Similarly, Axtell et al. (2002) utilized an ABM framework incorporating spatially explicit river basins, household level decision making and farming models, and land degradation components to investigate how settlement patterns in the archaic American southwest shaped the evolution – and eventual downfall – of the Anasazi culture.

Alongside these retrospective investigations, the use of ABMs to investigate contemporary questions of water system management sustainability has grown substantially over the last two decades, particularly in light of global concerns over water security stemming from the dual threats of rapid population growth and climatic change (Berglund 2015). In this work, ABMs play less a role in testing and refining speculative theories of cultural evolution and human-environment interaction than in assessing how different water management approaches, infrastructure development schemes, and social system configurations (e.g. in the form of land and water use) can affect water quality and supply. Emblematic of this approach is the work of Claudia Pahl-Wostl and various colleagues, whose broader research agenda of developing methods for adaptive water governance and socio-ecological sustainability has relied heavily upon a variety of simulation and agent-based modeling approaches (see, e.g., Schluter and Pahl-Wostl 2007; Bellaubi and Pahl-Wostl 2017). In this work, ABMs are utilized as a platform for scenario analysis and social learning, with varying forms of governance, land use, and technology dissemination among water users (among numerous other variables) being modified within the simulation framework to evaluate different outcomes of interest for the water systems as a whole, be it the resilience of agricultural systems or the sustainability of ecosystem services under different demand profiles (see, e.g. Cosgrove et al. 2015; Fig. 21). Similar work, focused, in most cases, on specific land and water use questions embedded in a variety of diverse global contexts, has utilized ABMs to evaluate different management scenarios for water pollution control due to agricultural runoff (Arbab et al. 2018); agricultural communities' ability to adapt to drought and climate variability (Pope 2018); the sustainability of forest wildlife, agriculture, and downstream aquatic ecosystems under different conservation scenarios (Miller et al. 2010); and

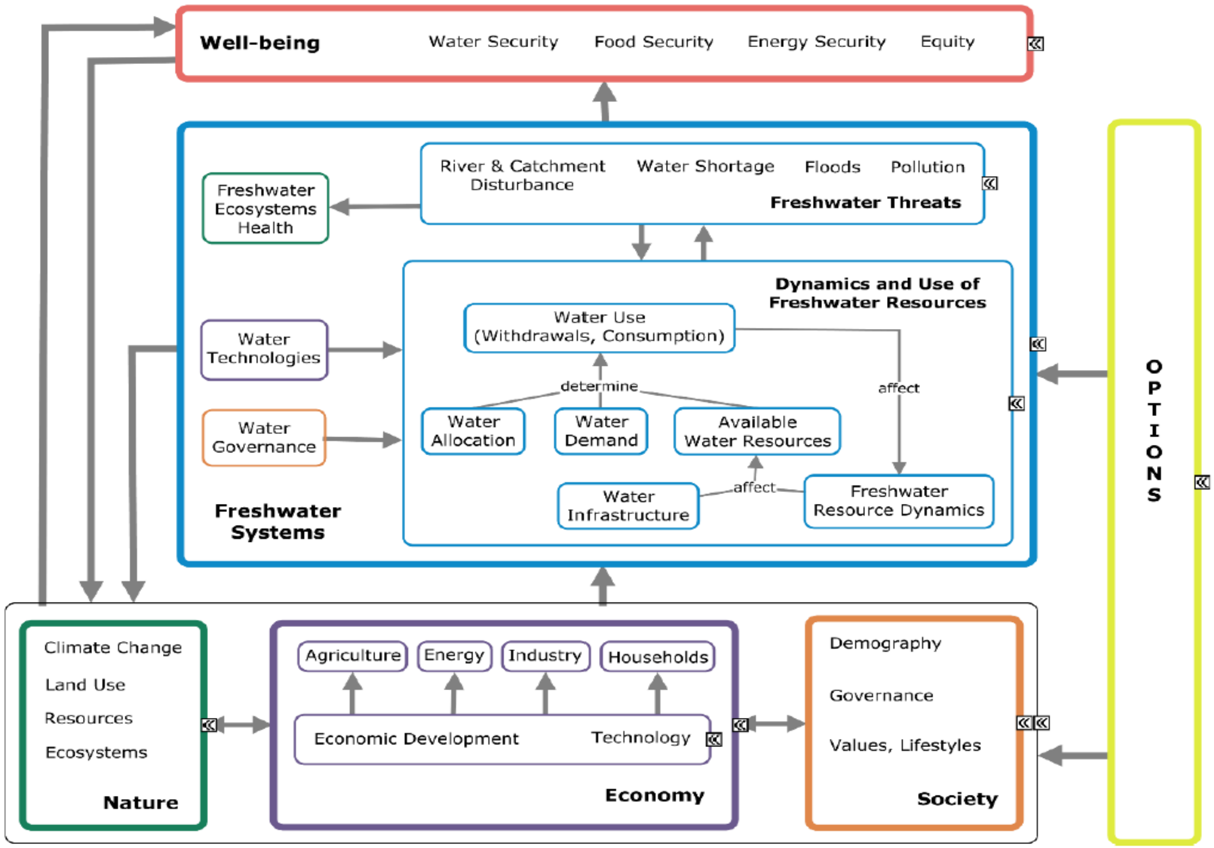

Figure 21 - from Cosgrove et al. 2015. Future-oriented ABM research (and scenario planning more generally) relies upon the development of both comprehensive SES models and a variety of action options and outcome scenarios determined by different social system values and goals. Because of this, input from outside of the research community is critical to project salience and applicability.

the interaction of diverse settlement typologies, migration, and development schemes on urban water demand and infrastructure burden (Galan et al. 2009).

A critical aspect of ABM work that focuses on evaluating potential future scenarios and outcomes, however, goes beyond the already complex task of defining and accurately operationalizing socio-ecological systems in the purely quantitative terms that all modeling approaches require. After all, it is not enough to simply speculate on abstract possibilities when the ultimate goal of the research effort in question is to improve understanding and action in present day resource management systems. Rather, the futures and scenarios considered must possess both relevance to current decision-making possibilities and the salience relative to the desired outcomes that contemporary actors seek in making various management decisions. Because of this, much of the work in this arena is grounded in a participatory ethos, in which local actors – be they farmers, water managers, developers, indigenous communities, or government officials – are brought on as both sources of information on model parameterization and as collaborators in the development of model scenarios (Pahl-Wostl 2002; Pahl-Wostl et al. 2007; Downing et al. 2000; Doll et al. 2013; Le Page et al. 2012; Pope 2018; Halbe et al. 2018). For example, in Doll et al. (2013), the authors used interviews and iterative scenario development workshops to first parameterize and then refine their basin-scale model examining social, economic, and environmental well-being outcomes of different potential environmental regulation regimes. Similarly, Pope (2018) utilized a number of workshops and informal survey sessions to develop decision-making models among southwestern U.S. farmers as part of efforts to examine how economic activity and environmental degradation might shape riparian areas over the next century.

At the same time, as Stringer et al. (2006) point out, the meaningfulness of participation by different actors can vary widely depending upon the social and cultural context, whether in terms of its truly equitable nature, the ability of various stakeholders to contribute effectively to the modeling process, or the ability of researchers to effectively elicit meaningful behavioral models and scenarios. As they detail, undertaking participatory modeling work can face a variety of distinct challenges, whether in the form of distrust between community members and researchers, the need for integrated cooperation across varied levels of given social hierarchies, or in the form of on-going conflicts between different actor groups (Stringer et al. 2006). Because of this, researchers must be careful in determining how, when, and in what settings various stakeholders are brought into the modeling process, and how to ensure that equitable measures are undertaken when modeling and explicating different development and outcome scenarios. In the case of settings like the South Platte Basin, where many water stakeholders and actors are known to harbor feelings of animosity or highly divergent value systems, it may be necessary to solicit feedback in separate sessions or workshops in order to ensure that participants are able to feel they can speak freely. Similarly, it may be necessary to take extra measures to ensure that whatever marginalized groups feature within the overall policy and decision-making network have their perspectives included.

Conceptual Models – Cultural Forces and Flows within Socio-Hydro-Ecological Systems

In order to integrate lessons learned across the broad array of interdisciplinary research on water management, water sustainability, water politics, and climate change adaptation discussed above, the proposed research project relies upon a series of conceptual models relating to the study basins various physical and cultural systems. In this section, I present these models briefly, as well as the overall research model for the project as a whole. Given the exploratory – and hopefully, participatory – approach undertaken, these models are meant only as preliminary abstractions, and should not be taken as either comprehensive or necessarily salient with regards to the models held by the various participants meant to be engaged with the project.

Drawing upon SES models developed by Eleanor Ostrom (2009) and later expanded upon by her student, Michael McGinnis (2014), I conceive of the study basin as a nested system wherein global economic, cultural, and climatic flows surround and shape the basin's internal dynamics (see Fig. 22). Within the basin, water resources in the form of surface water (derived from precipitation) and alluvial groundwater are passed through and utilized by ecosystems at the same time as they are captured (along with bedrock aquifer groundwater) by the various human systems of governance and infrastructure found interlaced therein. These systems of water management are then turned towards supplying the demands of various distinct – but often interconnected and overlapping – water end uses, including agricultural irrigation, domestic consumption, industrial applications, oil

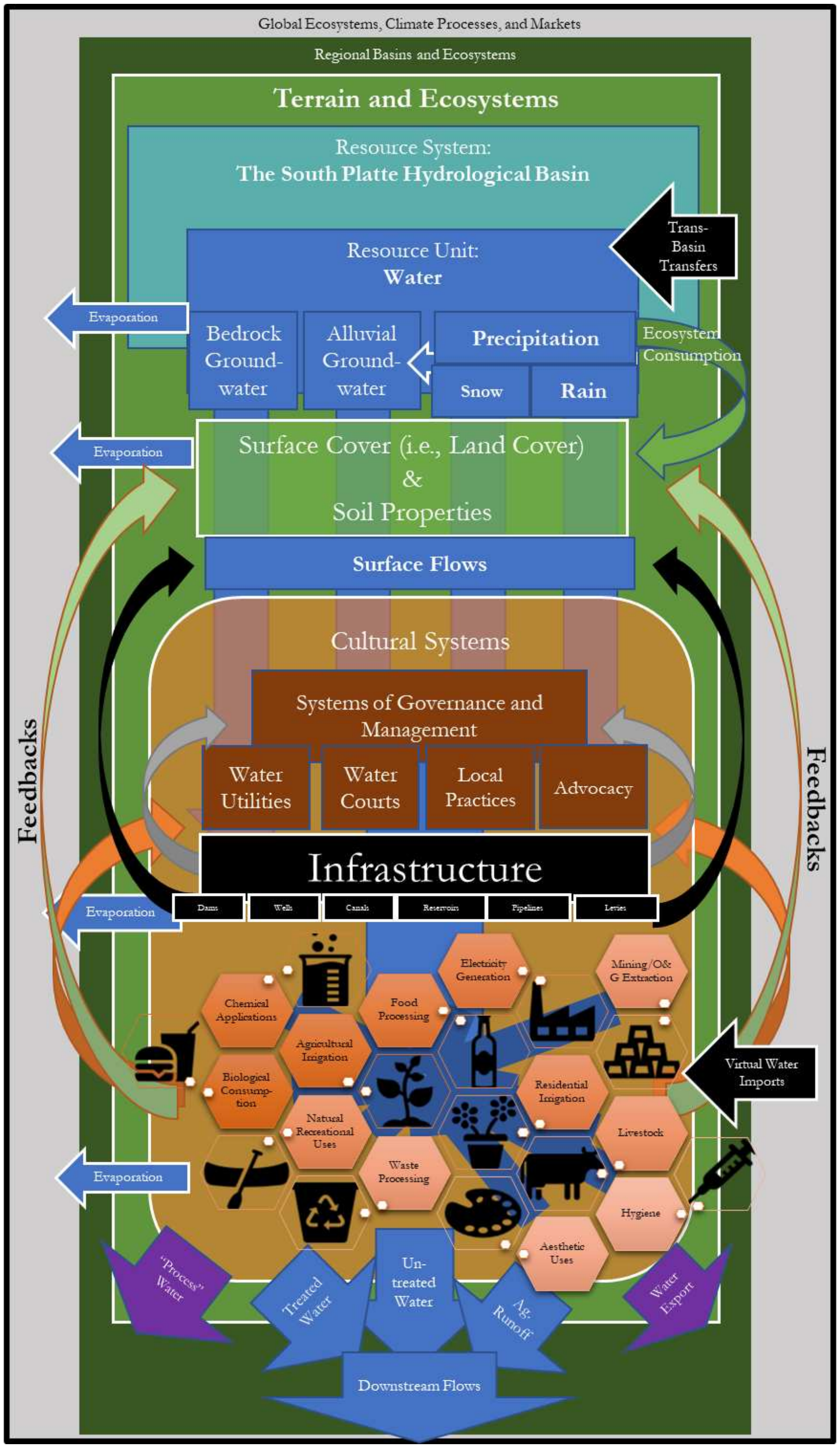

Figure 22 - A proposed model of socio-culturally mediated hydrological flows at the basin scale.

and gas extraction, and so on. As a result of these different water uses, effects accumulate in the surrounding environment, surface waters, and soils, resulting in ecosystem and land cover change, the accumulation and distribution of pollution, and the eventual alteration of the overarching governance and infrastructure systems. Ultimately, then, waters flow out of the system, both in unaltered and altered forms. At the same time, connections to regional and global markets allow for significant imports and exports of virtual water – in the form of finished goods, food products, and chemicals – that supplement the operations of the various cultural/social systems. Throughout, water is lost to the atmosphere to varying degrees, depending upon the climate and the specific application to which the water is put.

In the model above, specific water uses – i.e., chemical and physical alterations of water and their deposition in different biological and technological systems – are seen as being utilized, to varying degrees, by a multitude of differently positioned system actors. Similarly, the cultural systems at play within the SES are conceived of not as being embodied entirely by any one discrete group, i.e., members of a given homogenous, unifying "culture," but rather as a networked agglomeration of knowledge, beliefs, attitudes, patterns of ideation, narratives, and perceptual models that may be utilized to differing degrees by diverse actors across the system. While specific constellations of values and ideas (and in general, nodes of cultural function) may be more tightly clustered, and potentially ascribed to specific sub-groups within the overall basin (e.g. agricultural communities may share a more or less consistent set of cultural components), no particular clustering of cultural components exists in total isolation from the others. Rather, they exist in an array of networked relationships, some of which are hierarchical (with some values and ideas viewed as less worthwhile in certain settings), some of which are conflicting, and some of which are merely existentially incommensurate (i.e., value holders of different groups who seldom interact for some reason). Individuals, then, exist within social and cultural networks that draw upon different cultural components throughout their lifecourse, and can alter the cultural components they draw upon within different social and environmental contexts. Likewise, the environmental, climatic, economic, and geopolitical context surrounding these cultural networks can alter how different individuals access or disuse specific cultural systems. Ultimately, however, these variously diffuse engagements with different cultural value systems add up to different forms (and magnitudes) of water use. For example, agriculturalists with high education and active engagement with water science may be willing to take risks by installing more efficient irrigation technology, while similarly educated but differently ideologically inclined farmers may place more trust in existing approaches. Similarly, urban residents, whose water use is often largely "cultural" in that it is not for survival per say, can possess values that lead them to adopt either minimal water outside of the home (e.g., by landscaping with drought tolerant perennials) or living in an apartment. Alternatively, if they preference more suburban aesthetics, and concern themselves with neighborhood presentation, they may utilize more water for things like lawns and water features.

The research project, then, seeks to examine the interactions and interconnections of these mutually dynamic systems at the basin scale, utilizing water management, control, treatment, alteration, and valuation as anchor points for the overall analysis. Arrows – outlined in red in the figure below – define interactions and feedbacks of direct interest to the study. Large arrows, filled in in grey, depict feedbacks of interest wherein contemporary or past outcomes shape alterations within the governance and cultural systems. Specifically, it examines the cultural valuations and conceptualizations surrounding water and the ways in which specific use complexes, livelihoods, and operational viewpoints of actors within the basin exist in their current form, and how their interactions play out in the context of water decision-making arenas. (Fig. 23) Assumed to be diverse in nature, these systems of valuation and conceptualization are seen as existing in a networked fashion, with different water user groups and/or system actors operating via both their own, centralized systems of valuation as well as through reactions and potential integrations of the viewpoints of others. Further, these valuations and conceptualizations are seen as shaping how the tangible and intangible dimensions of water systems outcomes – be they solid infrastructure, psychological distress among pressured livelihood actors, or collaboration between groups to engage in watershed restoration or water resource distribution problems – ultimately come about and are interpreted by those same actors.

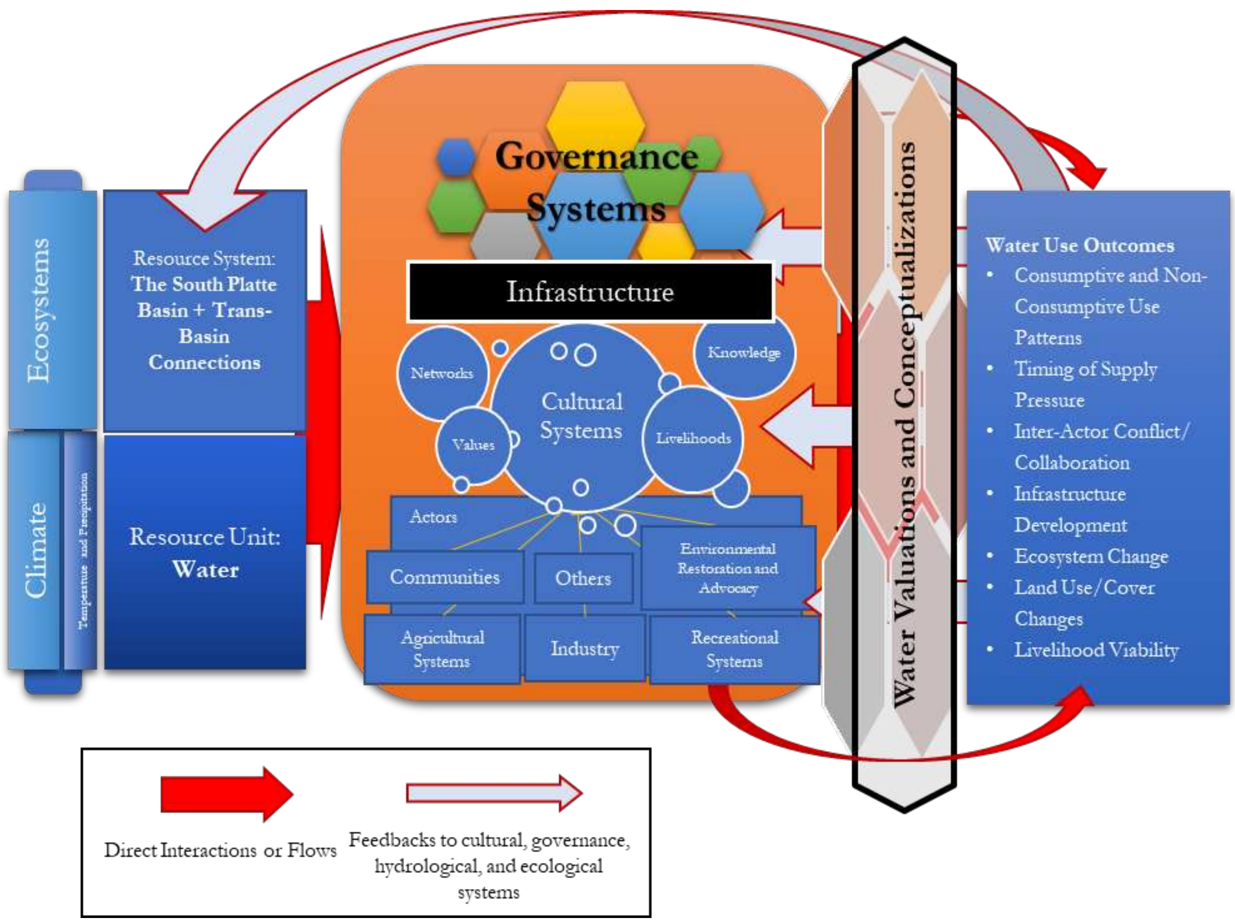

Figure 23 - Research Model for this study. Water valuations and conceptualizations are taken to occur at the interface of governance, infrastructure, cultural, and water use systems, and play a mediating role in both producing water use outcomes and their feedbacks to those same systems. Specifically, how people perceive, understand, and communicate about the world determines, in this view, how outcomes are perceived and acted upon, as well as how systems of governance respond to patterns of outcomes both in terms of human-wellbeing and the functionality of the resource system.

Study Context – The South Platte Basin in Colorado

In order to understand the context in which this research takes place, it is critical to understand both the scope and character of the South Platte Basin, and more specifically, the 18,930 square mile portion that falls within the state of Colorado. An intensively and extensively human-altered hydrological system, it encompasses a wide array of topographical, climatological, ecological, hydrological, political and social heterogeneity, and presents a number of challenges, be it as a unit of analytical reference, as a jurisdiction of water governance, or as a subject in efforts to improve the sustainability of the human and non-human systems within it. In this section, I attempt to provide a broad overview of its major biophysical and socio-hydrological features.

Biophysical Features

The South Platte Basin is a roughly 24,000 square mile hydrological unit located between -106.2, 38.8 at its southwestern-most point and -100.6, 41.3 at its northeastern terminus at the confluence of the North- and South Platte River in North Platte, Nebraska. Spanning three states, it forms the entirety of the drainage area for the South Platte River and its numerous tributaries, with the majority of its land area and watersheds falling within the northeastern portion of Colorado. Topographically, it is defined in the west by the rugged mountain peaks and slopes found along the eastern face of the North American Continental divide, which range in elevation up to a maximum of 14,274 feet above sea level at Grays Peak, located at the heights of the Clear Creek watershed east of the city of Denver. Moving eastward, its elevation drops sharply as the South Platte River and its various major tributaries wind their way into and through numerous urban areas along the Colorado Front Range and out into the vast rolling hills of the Colorado Eastern Plains, reaching a low point near North Platte, Nebraska of around 2,800 ft. above sea level (See Figure 24).

Figure 24 - Surface hydrology and topography of the South Platte River Basin.

This dramatic topography significantly influences its climate as the mountain ranges act as a sort of atmospheric rake, pulling moisture out of the various continental-scale weather patterns that converge over the region and casting the plains to the east in a vast rain shadow. As a result, precipitation varies substantially between the higher elevation and lower elevation areas of the basin, with areas in the mountains receiving on average over 50 inches of precipitation per year, mostly in the form of snow, while the plains areas may receive as little as 10 inches per year, mostly in the form of late summer thunderstorms (See Figure 25). As a result, the quantity and character of its surface water flows vary dramatically throughout a given year, with streamflows peaking usually between late May and early June before falling off substantially as the mountains' annual reserves of snowpack diminish as temperatures warm each year. At the same time, the area is subject to significant inter-annual and decadal variation in precipitation, as its central continental position leave it dependent upon multiple stochastic weather processes whose combined behaviors can significantly alter its hydrological character, resulting in dramatic drought periods, intense, rain-driven flooding episodes, and generally high coefficient of variation within what are considered its "normal" precipitation patterns.

In terms of temperatures, the area also displays a significant variation along its topographical gradient, with the higher elevation areas at its western boundary along the continental divide experiencing historical average annual temperatures in the range of 25 deg F (-5 deg C) while the lower elevation areas in the foothills and plains enjoying significantly warmer temperatures throughout the year, averaging around 50 deg F (10 deg C) (Figure 26). What the relative mildness of these average temperatures mask, however, is the region's dramatic intra-annual variation in temperature, with many areas on the eastern plains seeing extreme high temperatures into the 100's

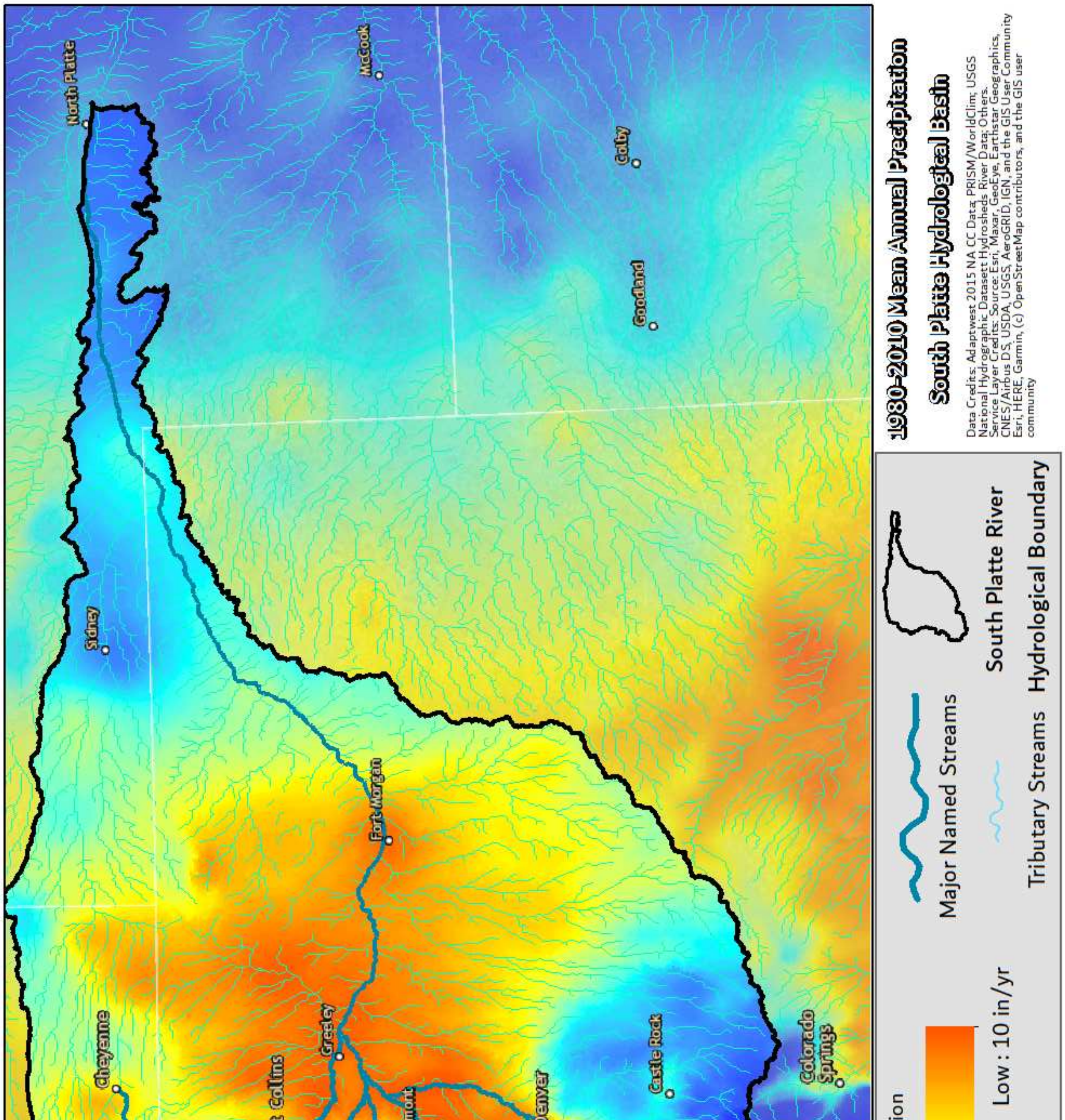

Figure 25 - 1980-2010 Average Annual Precipitation for the South Platte Hydrological Basin and Surrounding Area.

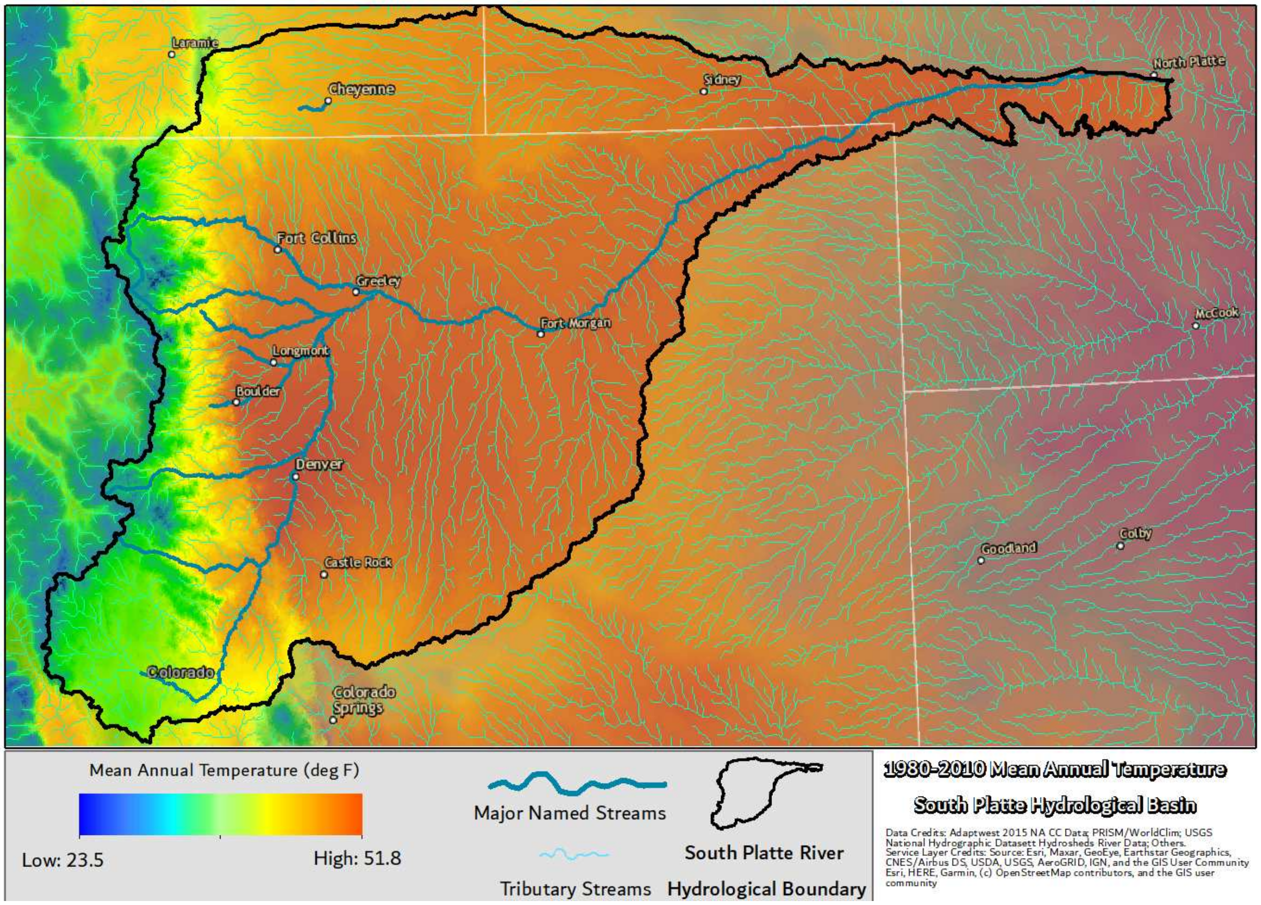

Figure 26 - 1980-2010 Mean Annual Temperature for the South Platte Hydrological Basin

(F) during the late summer, as well as sharply rising temperatures in the spring and sharply falling temperatures in the fall as the interplay between the oceanic, sub-tropical, and arctic weather systems that converge over the area shifts from one dominant force to the other. This high degree of seasonal and basin-wide temperature variation means that while the basin as a whole may see as much as 20,000,000 acre-feet of precipitation inputs in a given year, fully 90% of that precipitation will evaporate as a result of the sublimation of snow, or through a combination of heat, wind, and low relative humidity (Dennehy et al. 1993). Moreover, because of the stark contrast between the high and low elevation portions of the basin in terms of precipitation, the overwhelming majority of the region's surface water supply and surface stream flows rely heavily upon the slow melt of mountain snowpack, and thereby, the diverse natural systems of vegetation and land cover that dominate its mountainous headwaters. In the lower reaches of the basin, return flows from agricultural diversions and cities begin to play a more dominant role in streamflow levels, supplemented in part by late summer precipitation and resulting surface runoff.

As with river systems and basins around the globe, the climate of the South Platte Basin in Colorado is changing rapidly, with regional mean average temperatures having increases roughly 2 degrees Fahrenheit since 1900, with an additional increase of 10 degrees possible by the end of the century if on-going global greenhouse gas emissions continue to follow their current trajectory (Adaptwest Project 2015; Lukas et al. 2014 [2018]; Gordon and Ojima 2014; Woodbury et al. 2012). In addition to increased temperatures overall, this could lead to significant increases in the number of extreme heat days (Saunders et al. 2016), reduced streamflow due to increases in evaporative loss (Woodbury et al. 2012); continued reduction in headwaters snowpack and the percent of precipitation falling as snow each year, and the increased incidence of hydrological, agricultural, and ecological drought conditions (Lukas et al. 2014 [2018]). The consequences for the basin's hydrological function as well as the managed water system overall have potentially grave implications. Among those recognized in the South Platte and Metro Basin Roundtables' 2015 Basin Implementation Plan are: reductions in overall surface water supply, disruptions of normal reservoir function and operational timing, increased agricultural water demand, negative impacts to water quality following wildfires and during drought episodes, negative impacts on stream ecology and wildlife habitat function, and a variety of other serious issues (SPMBRT 2015:). Taken together, these risks portend serious if not catastrophic outcomes in an already over-appropriated and intensively managed system.

The basin's highly variable climate and diverse topography also lend themselves to a similarly heterogenous pattern of natural ecosystem distribution, with significant consequences for the ways in which precipitation finds its way into surface water bodies, streams, and underground aquifers. At the highest elevations, barren rock peaks gradually give way to alpine tundra ecosystems where frigid temperatures, intense, drying winds, and highly variable insolation combine to preference sturdy, low-lying herbaceous plants, lichen, and, in pockets of well-developed soils, grasses and sedges. Below roughly 11,000 ft. in elevation, however, various forest land cover types predominate, ranging from spruce-fir mixed forests at the tree line to lodgepole pine, ponderosa pine, and mixed conifer forests as the basin's mountain slopes give way to the shrubland dominated foothills below. Given the relatively narrow range in which alpine vegetation systems occur, their role in the region's water balance and hydrology are relatively small compared to the to the extreme snowfall and harsh atmospheric dynamics that define their niche. In the forested regions, however, vegetation plays a number of critical roles in determining both downstream water quality and quantity. First, trees and other forms of forest vegetation consume water, and further transmit a portion of this water via evapotranspiration back to the atmosphere. More importantly, however, they intercept, shade, and in general slow the movement of water across and into surface soils, serving the dual function of both mitigating the intensity of downstream runoff surges following high elevation rainfall and seasonal snowmelt, as well as ensuring that surface precipitation often undergoes a significant process of natural filtration before it finally finds its way into the numerous high elevation tributary creeks and streams that feed the basin's major rivers. When these same forests burn during what have become increasingly common wildfires, however, they can significantly degrade downstream water quality, as introduced ash, particulates, and other contaminants resulting from reduced vegetation cover and increased erosion find their way downstream.

Beginning at around 6,000 ft. in elevation, human-controlled ecosystems begin to dominate, with areas of low-to-high density urban development, managed open spaces, and agricultural refugia making up the vast majority of the basin's lower-elevation land cover west of the South Platte River mainstem confluence east of Greeley. Across the basin as a whole, roughly 4 million people can be found on any given day, both in permanent residence and as part of the region's significant "transient" community of tourists, business travelers, and long-distance commuters, with the overwhelming majority of both types of residents usually located within the major cities and suburban sprawl of the Front Range (See Figure 27). In areas of particularly low development and at the margins of crop cultivation areas, grasslands, shortgrass prairie and sandsage ecosystems are also found, with significant portions under use for cattle and other livestock grazing. At a much finer scale, artificially cultivated and maintained urban tree canopy also provides an important array of ecosystem services, with many municipalities requiring or otherwise encouraging tree planting and maintenance in areas of residential and commercial land use. In residential areas – which are dominated by single family homes and other forms of low-density housing – extensive irrigated landscaping is also common, with non-native grass lawns, shrubs, and annuals commonly seen throughout the region. In recent decades, the dominance of this landscaping style has been attenuated in some areas by the growth in popularity of "xeriscaping", i.e., the use of native drought-tolerant plants to minimize the need for landscaping irrigation, but this type of "low-impact" landscaping remains in the minority in most communities.

Moving further eastward past the sprawling cities of the Front Range, vast tracts of privately-owned and operated agricultural lands dominate the landscape throughout the lower portion of the basin. The most intensive irrigated operations, with few exceptions, are found clustered along the South Platte River's main watercourse east of Kersey and overlaying the South Platte alluvial aquifer, with an estimated 850,000 acres currently under irrigation in a given year (CWCB et al. 2019). Non-irrigated crop lands and livestock grazing pastures make up most of the remainder of the lower basin, with some counties (Adams, Elbert, Logan, Morgan, and Weld) having over 80% of their land area under the control of some type of farm operation. In total, an estimated 14,324 farms with an average size of 487 acres make up the roughly 6.9 million acres of farmland in Colorado South Platte

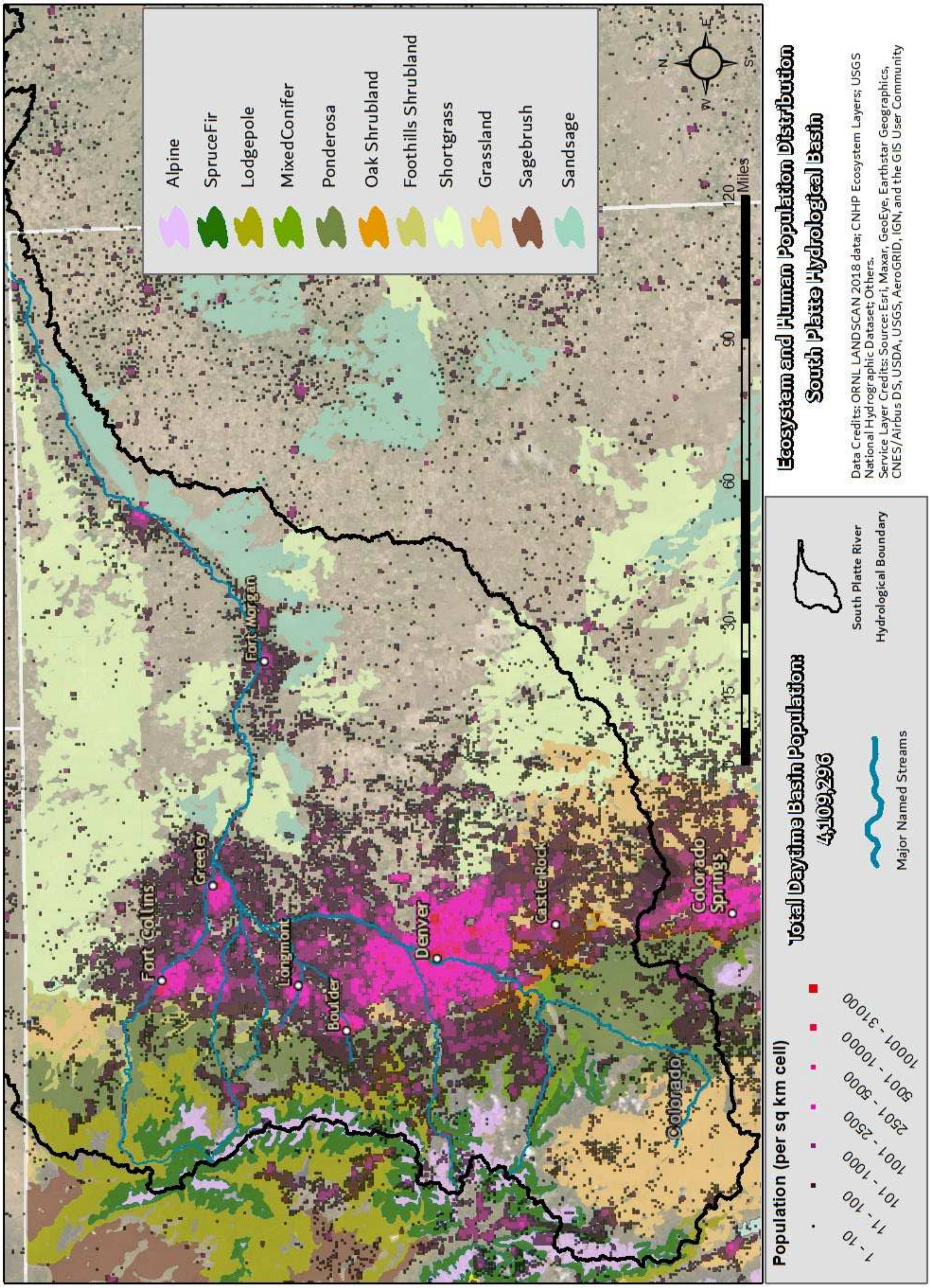

Figure 27 - Human Population and Ecosystem Distribution for the South Platte Basin in Colorado

Basin Counties, amounting to approximately 58.1% of the region's total land area (Headwaters Economics 2020). Contrary to intuition, however, the role of the region's vast farming systems in the region's food systems is not straightforward, as only a minority portion of the basin's total agricultural acreage is actually involved in the production of crops for human consumption, only a portion of which are consumed locally (USDA ERS 2015; See Figure 28). Rather, the majority of land is engaged in what is better described as agricultural commodity production, with the majority of acres overall and irrigated acres specifically being dedicated to the production of livestock feed, biofuel feedstock, oilseed, and other globally traded crops. Many of these commodity crops are involved in national and global export chains, while others serve the region's extensive cattle ranching, feedlot, and dairy production systems.

Interestingly, while in some communities agricultural operations may dominate both local cultural identities and the landscape itself, employment from farms across the Colorado portion of the basin is meagre, with less than 1% of all jobs within Colorado South Platte Basin counties stemming from agricultural labor or proprietorship (Headwaters Economics, 2020). In some counties, however, the importance of agriculture is much higher at the local scale, particularly in Sedgwick (25.1% of all jobs being in ag), Elbert (14.1%), Logan (9.5%), and Morgan (8%). Taken together, sales of agricultural products in the basin range upwards of $4 billion as of the 2017 USDA Census of Agriculture – or roughly 1.4% of Colorado South Platte Basin counties total 2018 GDP of roughly $260 billion (USDA Census of Ag 2017; BEA 2018)

As will be discussed in following sections in more detail, however, this relatively minor contributor to the basin's economic systems plays an enormous role in its socio-hydrology, both in the past and in the present moment as citizens, leaders, and water managers look toward the future of the region. This is because, more than any other land use and livelihood type, agriculture is

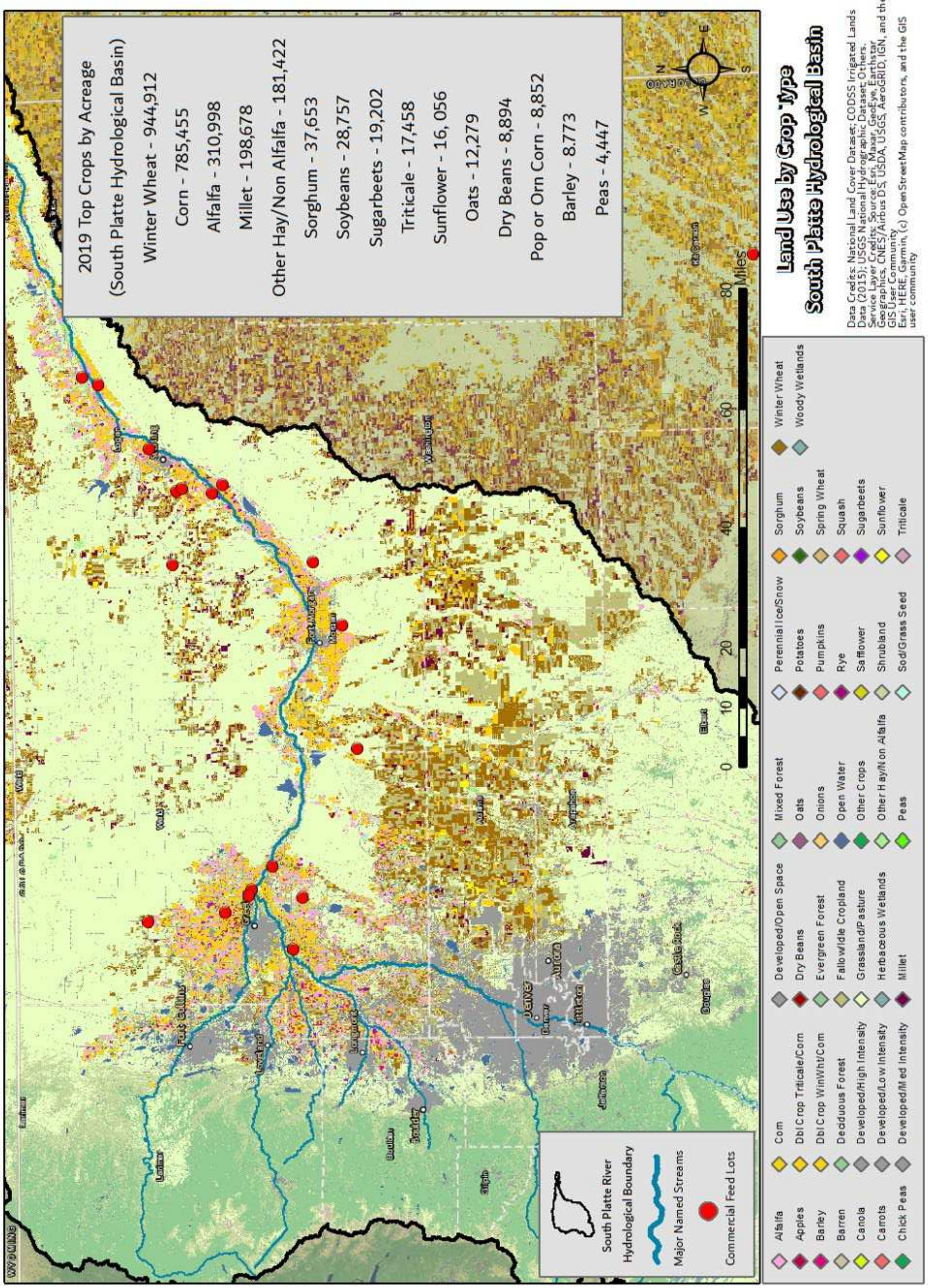

Figure 28 - Human Population and Ecosystem Distribution for the South Platte Basin in Colorado

expected to undergo significant transformations, both due to changes in climate as well as the impacts of continued urban growth along the Front Range unfold over the coming decades. Having almost doubled in population since the 1990s, the region's patterns of urban expansion into agricultural and wildland-urban interface areas are likely to continue into the future, driving both direct conversion of land use types as well as indirect alterations through the acquisition of agricultural waters in lower-basin reaches for use by cities in the Front Range.

Socio-Hydrology

The combination of human-built ecosystems, infrastructure, and impermeable land cover that are found in the human-populated portions of the basin and permeate its headwaters have a variety of impacts on its hydrological dynamics and character, the sum of which have shaped it over the course of under 200 years of Euro-American settlement into what is arguably a state of near-complete human alteration. Put in strictly quantitative terms, within the Colorado portion of the South Platte Basin approximately 1.4 million acre-feet of natural surface flows occur in an average year, with roughly 400,000 acre-feet exiting the state during that same time period at the Nebraska border (Dennehy et al. 1993; SPBIP 2015). Average yearly demand for diversions for human use by agriculture, municipalities, and industry, however, are estimated to currently be over 3.3 million acre-feet, including roughly 700,000 acre-feet for residential, commercial, and industrial use, and 2.6 million acre-feet for agricultural irrigation (CWCB 2019; see Figure 29). How this seemingly paradoxical situation is negotiated each year is far from straight-forward, and a full account of the basin's socio-hydrological operations is well beyond the scope of this document. Here, I focus only briefly on several key factors: its governance through Colorado water law and the water rights administration system and various non-binding authorities; water infrastructure for storage

Demand Type	Total Diversion Demand - South Platte and Metro Basin (Acre-Feet / Year)	
Ag Surface Demand	2186000	66.13%
Ag Ground Demand	403000	12.19%
Indoor Residential	199218	6.03%
Outdoor Residential	145153	4.39%
Indoor Non-Residential	124042	3.75%
Outdoor Non-Residential	112467	3.40%
Non-Revenue Demand (System Loss)	63715	1.93%
Large Industry	52230	1.58%
Thermoelectric	19670	0.60%
Snowmaking	300	0.01%
Total	**3305796***	**100.00%***

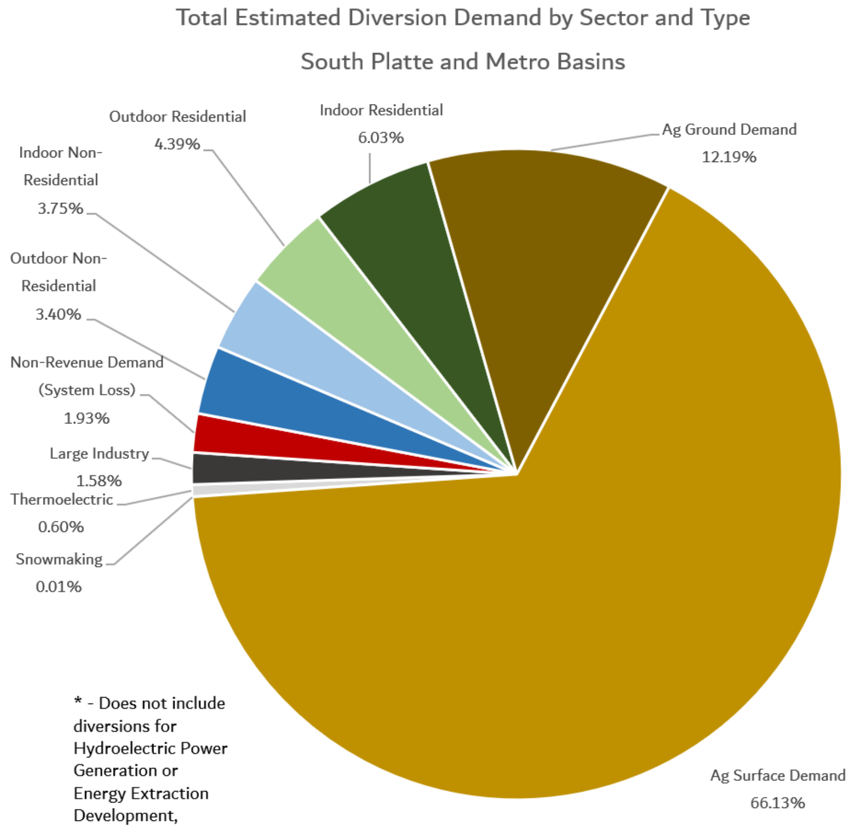

Figure 29 - Diversion Demand by Sector, from the 2019 CWCB Technical Analysis Update for the Colorado Water Plan.

development patters including imported water and groundwater exploitation; patterns of water reuse and return flows; and water provider entities.

Governance

As with all water-related activity in Colorado, the South Platte Basin is governed by the dictates of Colorado Water Law. Developed at first in an informal fashion in the years following the 1860's mining boom in the Colorado Rockies and codified into law just three years after the state's formation in 1876, it is built around four main pillars: 1) the waters of the state are for the beneficial use of the people of the state, and cannot, in themselves, be owned; 2) the state shall make no laws or regulations that prohibit the utilization of waters that are not otherwise appropriated; 3) means of appropriating water shall have right-of-way, be it through public, private, or other lands; and 4) in cases of water scarcity, priority for the beneficial use of water use shall be given to those who can demonstrate that their appropriation of those waters took place earlier than others, i.e., that those "first in time", are therefore "first in right." At the core of this system is the concept of the "water right," which consists of three key elements: a "diversion" or other manipulation of water – i.e., both a type of physical manipulation of water and the amount of water so manipulated; a "beneficial use," for that water (such as crop irrigation, mining, industry, consumption, etc.); and a date of first diversion and use, which is used to determine its priority relative to other water uses. Developed as a result of the region's intense inter-annual and intra-annual precipitation and surface water variability and the insufficiency of the "riparian doctrine" that developed in the much more mesic Eastern U.S. (see Jones and Cech 2010), this system of prior appropriation and water rights allocation has thus served as a means of both controlling naturally emerging conflicts over scarce water resources (if by no means ameliorating them entirely) and as a mechanism through which historical patterns of water use are maintained, altered, transformed and, increasingly, valued as marketable commodities.

The water rights system is administered in the Colorado South Platte through Division 1 of the Colorado Water Court, which includes the Colorado portion of the South Platte River Basin and the plains headwaters of the Republican River Basin, to its southeast (See Figure 30). Determinations regarding the technical specifics and systemic impacts of specific water rights are further administered through the State of Colorado Division of Water Resources and the State Engineer, who, along with any potentially impacted or protesting parties, have significant sway over the proceedings that take place within water court to adjudicate water rights allocations and determine their position within the priority rankings of the prior appropriation system. The key functionality of these systems of governance lies in the ability of senior water rights holders – i.e.,

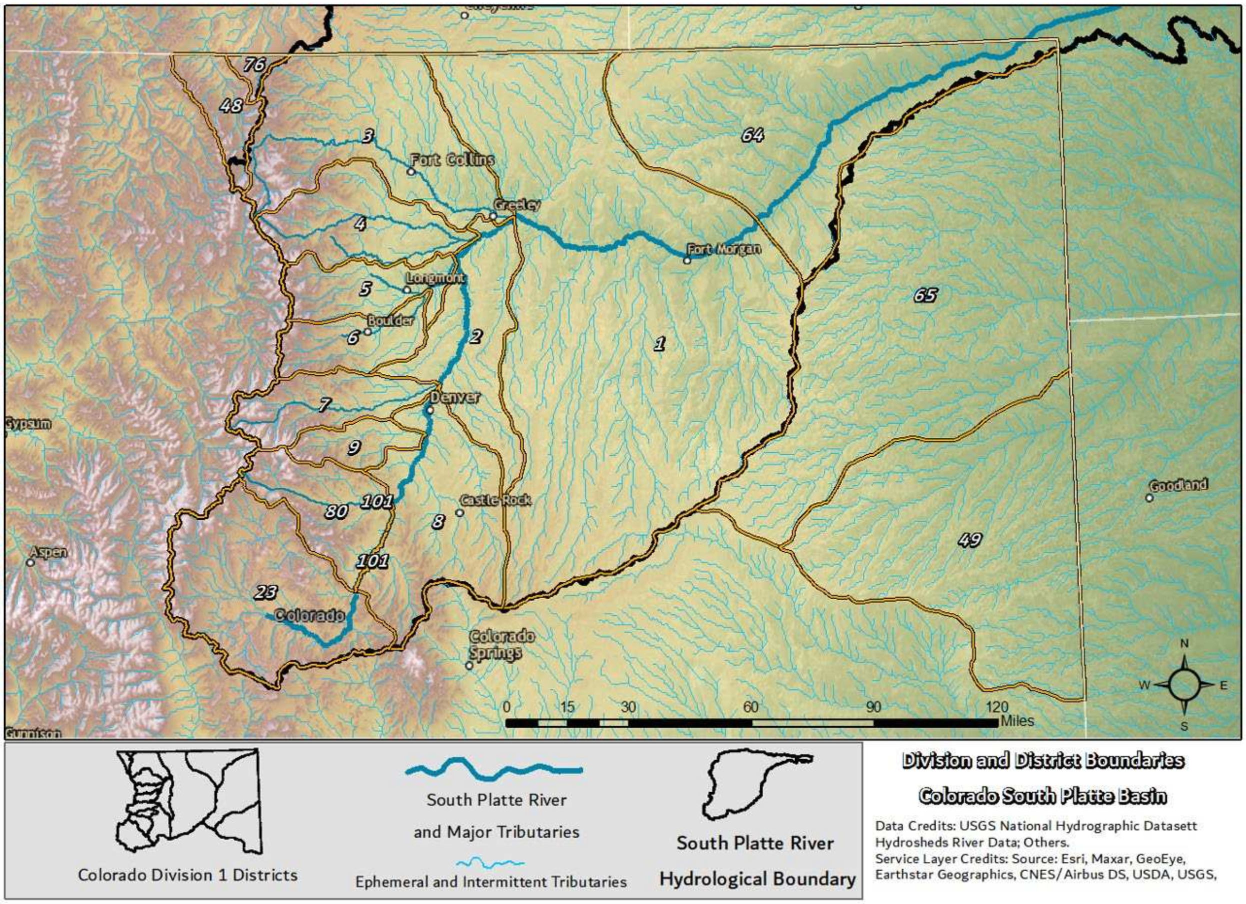

Figure 30 - State Engineer's Office Division and District Boundaries for the South Platte and Republican River Basins in Colorado.

those with a higher priority in the prior appropriation system – to curtail, via the Office of the State Engineer, the diversion activities of junior water rights holders in periods of limited water supply. Referred to as "placing a call" on the river, this allows senior users to defend their ability to divert water when other water users might impinge upon the surface flows required for their specific activities. As illustrated in Figure 31, this process can become quite complicated, as the interconnected nature and over-appropriated status of the basin can lead to numerous counter-intuitive interactions between its roughly 45,000 active water rights (See Figure 31).

In addition to state-level governance systems, activities within the basin are also subject to various Federal regulations pertaining to water quality, water treatment, pollution monitoring, and water use, as well as – due to its multi-basin impacts (discussed below) – the various inter-state water

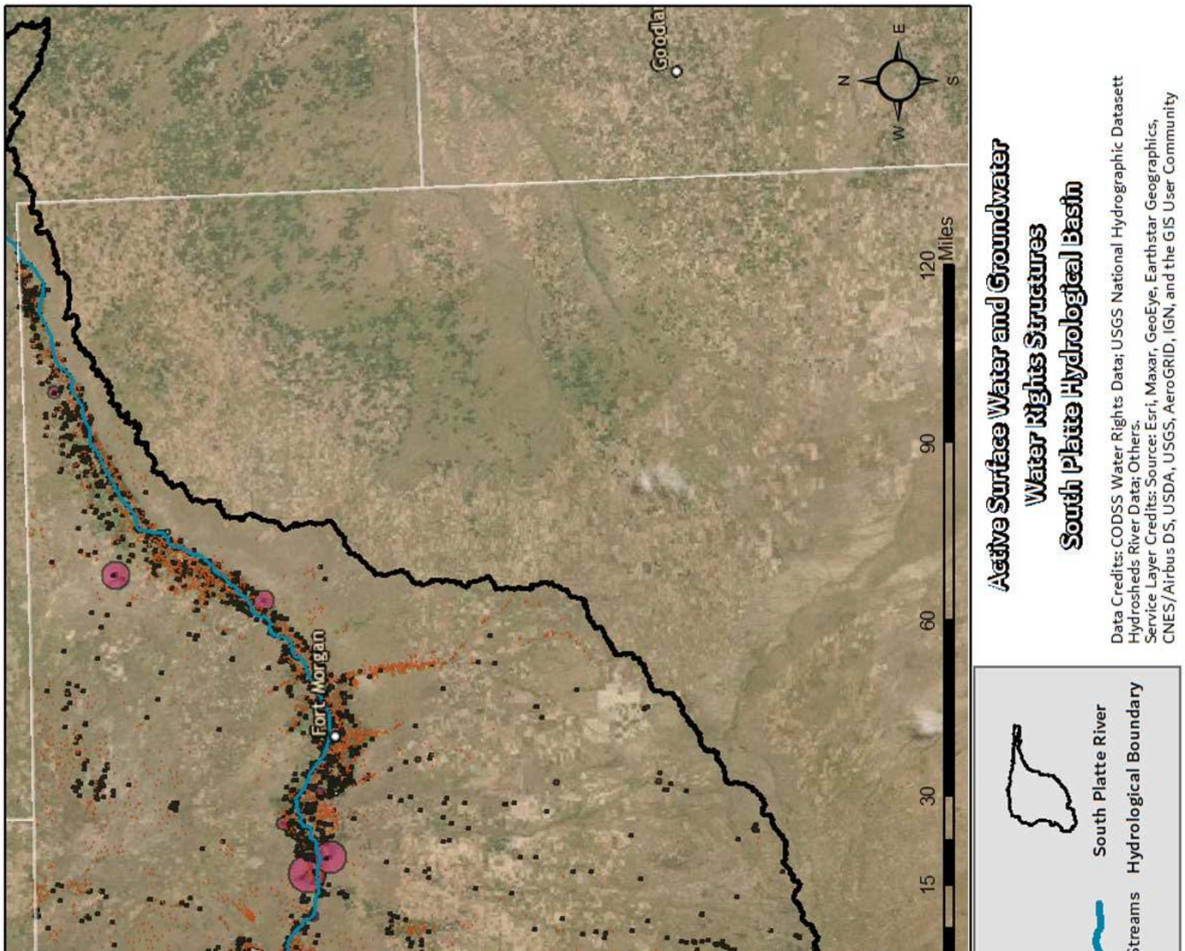

Figure 31 - Active Water Rights Structures by Type as of 2020, based on information from the CODSS Hydrobase Dataset. Water rights structures include dams, canals, ditches, pipelines, ponds, and other manmade manipulations of surface hydrology.

delivery compacts the State of Colorado has entered into with neighboring states to ensure downstream delivery of waters originating in the Colorado Rocky Mountain Headwaters (see Corbridge 1998; Jones and Cech 2010; Colorado Foundation for Water Education 2015). Further, because significant amounts of the forested land that comprise the basin's high elevation watersheds are comprised of federally-owned and managed lands, national level policies and spending priorities have significant influences on the overall trajectory of the region's ecological function and the dynamics of wildfire processes, both of which can have serious implications for downstream water quality.

The basin also falls under the auspices of the non-regulatory but significantly influential Colorado Water Conservation Board [hereafter CWCB]. Brought into being by state legislation in 1937, the CWCB operates via a governor appointed board of sectoral and water user experts from around the state to protect Colorado water resources, provide funding and other support mechanisms for water development, and serve as a convening mechanism for cross-basin collaboration, information exchange, education, and problem solving. Beginning in 2005 with the passage of the Colorado Waters for the 21st Century Act (CO HB 05-1177), it also oversees the formation and administration of the Metro and South Platte Basin Roundtables, which convene various interest groups from within their respective areas to discuss, research, and collaborate on water issues, as well as providing more focused funding for research, information exchange, and specific implementation projects. Among the most important activities undertaken by the CWCB in recent years is the 2015 publication of the Colorado Water Plan (CWCB 2015), which provides a high level strategic guide for the future development and conservation of the state's water resources, focusing on a variety of key water values. These include ensuring the state's economic productivity, the development of "vibrant and sustainable cities," ensuring "viable and productive agriculture," a "strong and healthy environment," and a robust recreation and tourism sector (CWCB 2015). In following with the Water Plan, the South Platte Basin- and Metro Roundtables collaborated to release the South Platte Basin Implementation Plan in 2015 (SPMBRT 2015), which outlines the region's specific challenges and goals in the furtherance of statewide initiatives, and set in motion an on-going process of water needs assessment, future scenarios for growth and water scarcity, and a variety of other water related factors. Taken together, these documents and the organizations behind them represent the highest level of collaborative decision-making, policy engagement, and project development in the area, and continue to undergo periodic refinement and technical updates.

In addition to these various formal and institutionalized systems of water governance, the Colorado South Platte Basin is also home to extensive networks of informal governance entities in the form of non-governmental organization, non-profit entities, and various other collaborative conservation organizations whose work either directly or indirectly influences water-related activity. In a recent survey by the Center for Collaborative Conservation at Colorado State University, researchers identified at least 55 organizations within the basin, ranging from watershed-level river restoration groups to regional wildlife and forest habitat protection advocacy organizations (Huayhaka and Reid 2019). In some cases, these groups apply direct funding and expertise to on-the-ground projects that directly alter local hydrology, such as through riparian vegetation restoration in flood-damaged stream channels. In other cases, they work to organize and provide funding mechanisms for groups of property owners and concerned citizens within watersheds or drainage areas, amplifying individual assets to accomplish stream protection or other water-related goals. Others work at a higher level, via advocacy, legal proceedings, protests, and other mechanisms to challenge or support state and federal level policies and decision-making.

Infrastructure

Modern water system manipulation began in the Colorado South Platte Basin as early as the 1850's, as miners and the small farming communities that supported them attempted to move water from headwaters creeks and lowland perennial streams to suit their needs, usually in the form of hand-dug ditches, wooden sluice channels, and clay pipelines, with native river flows reaching a state of over-appropriation some time in the 1880s (Jones and Cech 2010; Dennehy et al. 1993; Strange et al. 1999). Since that time, extensive development of additional canals, ditches, pipelines, pumping systems, and reservoirs has been constructed throughout the basins headwaters and lower reaches, leading others to describe the basin and its river systems as "an elaborate plumbing systems more than a natural river." (Ibid.) As shown in Figure 32, nearly every linear segment of the basin's perennial streams are under some form of human alteration and infrastructural interference, with only a small handful of the shortest and most difficult to access streams still in a free-flowing condition. Among the most important of these human manipulations of the basin's hydrology are the 15 "trans-basin diversions" found dotting its western periphery, which transfer water from the historically more abundant headwaters regions off the Colorado, Arkansas, and North Platte River Systems into South Platte Basin tributaries. Taken together, these diversions add an estimated 370,000 or more acre-feet per year to the basin's total surface flows, i.e., nearly the same amount that actually exits the state at the Nebraska border (See Figure 17). These waters are distributed through a variety of different systems, the core of which consists of a number of massive man-made reservoirs located throughout the basin's mountainous headwaters areas. In addition to these trans-basin diversion storage facilities, over seven hundred more reservoirs – ranging in surface area from several square miles to mere detention ponds – can be found across the region, with U.S. Army Corp of Engineers dam data showing an estimated 3 million acre-feet or more of available storage in dam-impounded reservoirs alone (US ACE 2019). Storing waters gathered during the rapid spring

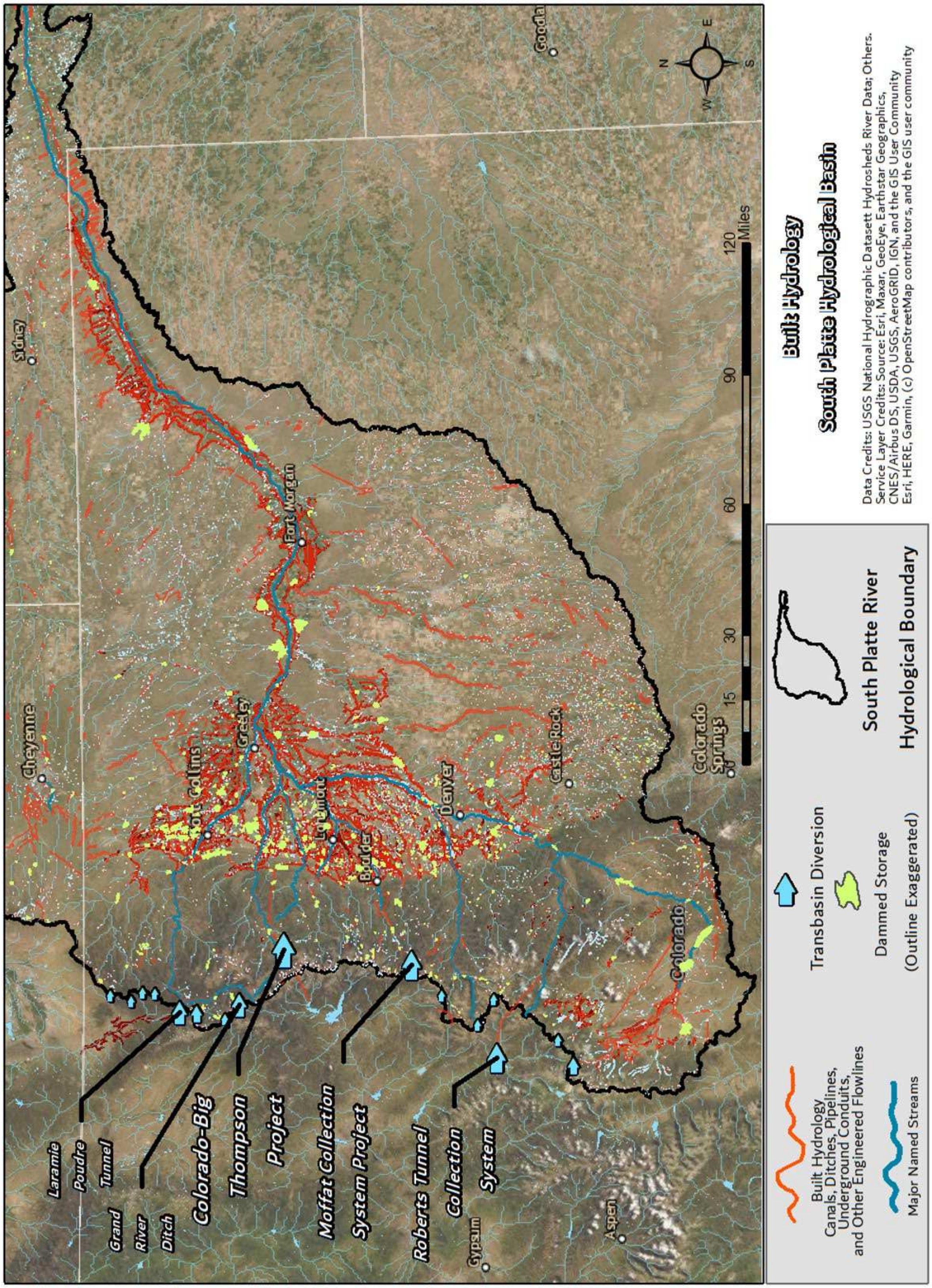

Figure 32 - Built Hydrology of the South Platte Basin in Colorado.

melting of mountain snows and sporadic rain showers, waters gathered in these reservoirs are then distributed via various transmission mechanisms to the treatment facilities, homes, businesses, and – more often than any other case – agricultural fields of the region.

In addition to the extensive network of surface water storage and transmission infrastructure that characterizes the region, groundwater exploitation also plays a critical role in the operation of the basin's economies and land use systems. In addition to the South Platte Alluvial aquifer – a partially renewable groundwater basin varying in depth between 2 and 200 feet that spans most of the river system's footprint, deep rock, non-renewable water resources are also located in the region, primarily beneath the Denver metro area and its various suburbs (See Figure 33). Groundwater is also available, albeit to a significantly lesser degree, in various porous and/or fractured geological formations located throughout the region. According to Colorado Division of Water Resources, there are currently over 30,000 permitted groundwater wells active in the basin, with likely thousands more unpermitted, small scale groundwater wells for small-scale residential use in the mountains and rural areas of the basin operating alongside them. Although specific consumptive use of groundwater in the basin is difficult to parse out given the prevalence of untracked, small-scale wells, among those permitted and monitored by the state over 868,000 acre-feet of water are legally allocated for pumping each year (CDSS Hydrobase 2020). Based on estimates from the Colorado Water Conservation Board (CWCB 2019), roughly half of this groundwater is applied in some form – mainly sprinkler systems – to agricultural fields. The remainder is used both by small rural communities, households, farmsteads, and other isolated points of habitation as well as, more recently, over 250,000 people living in a number of rapidly growing suburban and peri-urban areas, mostly in the southern portion of the Basin and near the various rural towns in the Eastern Plains (Leonard Rice Engineers 2018; See Figure 34).

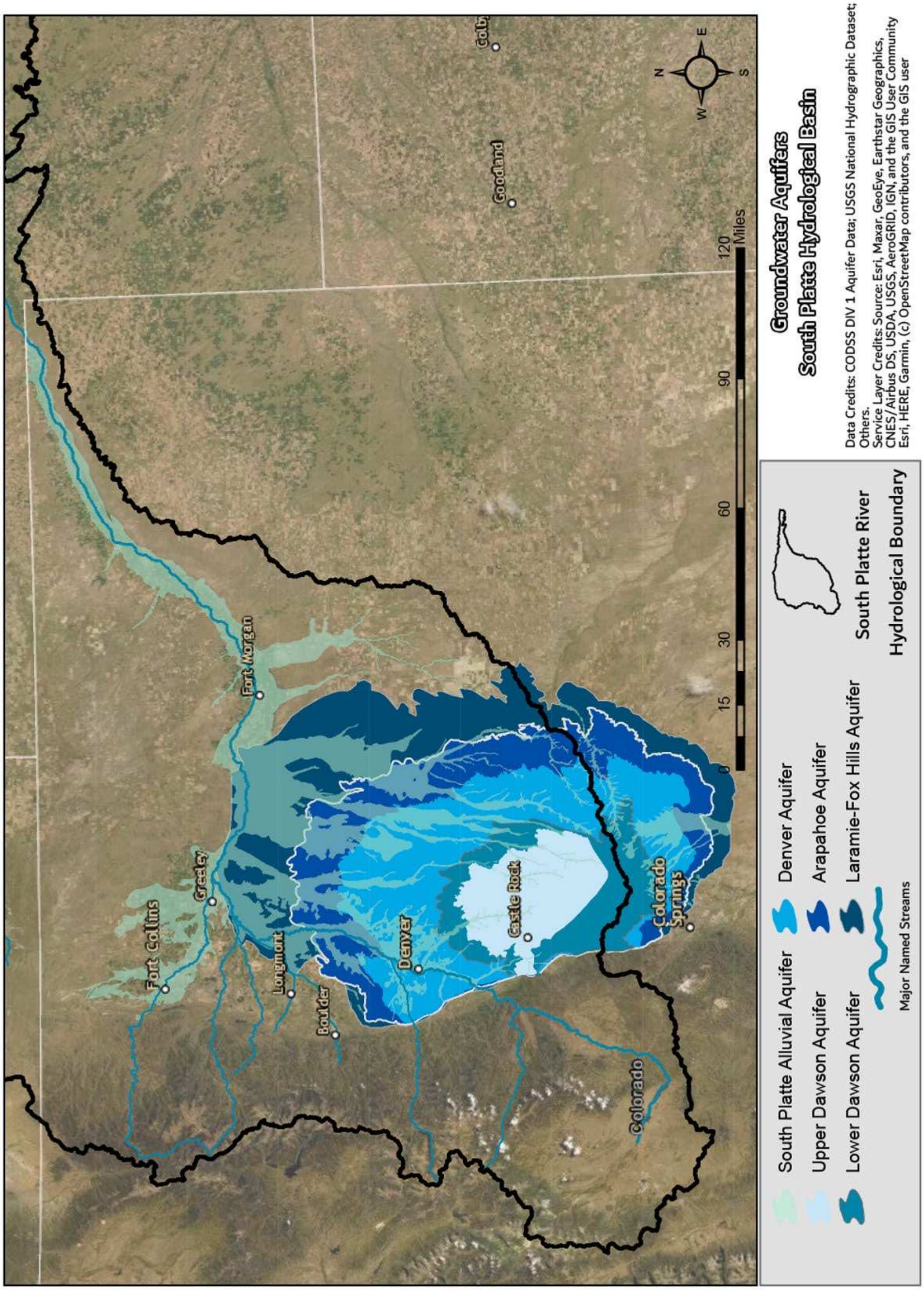

Figure 33 – Major Groundwater Resources in the Colorado South Platte Basin. Note: Groundwater aquifers occur at varying depths, and appear concentric due to their varying size at these depths.

Water Reuse and Return Flows

Part of what makes this complex system work – and how, despite dramatic imbalances between supplies and demand, the vast majority of individuals and business are able to acquire the water they need – is due to the fact that most of the water utilized within the basin is not actually consumed outright. In some cases, such as when residential users turn on their taps to bathe, wash dishes, or eliminate waste, almost all of the water utilized is returned back to the system via treatment facilities and, eventually, transmission back to surface water streams. In agricultural settings, flood irrigation systems also play a similar role, as they often divert nearly double the amount of water actually consumptively used by plants through biomass formation or evapotranspiration. The remainder percolates into soils and bedrock, or returns directly to surface water systems as "tail water," recharging river flows both directly and through slower groundwater transmission processes. Likewise, in many industrial use settings, water utilized for cooling or sanitation are also (at times, perhaps inadequately) treated and returned to the system after they have served their purpose in a given production process. As a result, much of the water that makes its way to the Nebraska border has been utilized in some form by upstream users multiple times. In many cases, this "waste" or "inefficiencies" are actually codified in the legal water diversion rights held by a given user, with a specific rate of return flows following diversion being part of the legally allowable range of water system interference that a given user must adhere to. An important exception to this rule, however, are waters from trans-basin diversions, which can be utilized "to extinction," i.e., can be used and reused as many times as needed by those who hold rights to them, if they have the means to do so. For all other water diversions efforts to improve water use efficiency and eliminate "waste" must always be balanced against the historical patterns of downstream return flows and the consequences those return flows have for downstream water users.

While being an important factor in determining water availability for the wide array of users throughout the basin, these patterns of extensive reuse have several serious implications. At the simplest level, it creates distinct hydrological discontinuity across the river system, as stream reaches below major diversion points near the Front Range cities become almost completely dry, only to then flow freely again as variously treated waters are reintroduced into the system. In agricultural areas, this hydrological disruption results in a distinct shift in peak streamflows, pushing the maximum volumetric flow of the lower reaches of the South Platte towards mid-July as return waters and seepage from irrigation make their way back to the river. This also results in the South Platte system operating in some reaches as what is referred to as a "gaining stream," as cumulative post-use return flows, alluvial recharge, and runoff from pumped groundwater combine to increase river flows at certain times of the year (Waskom 2013; Capesius and Arnold 2012). At the same time, the multiple different successive patterns of water reuse seen across the basin introduce a variety of water contaminants, many of which – such as total dissolved solids (i.e., "salts"), nitrogen, phosphorus, pesticides, herbicides, and other forms of chemical contamination - compound dramatically as the river flows towards Nebraska, bringing with it the accumulated residuum of both urban and agricultural use processes (Litke 1996; Dennehy et al. 1998; Neirbo Hydrogeology 2020). These contamination processes are further exacerbated during periods of extreme low flows, such as occur during droughts, as the total available water for dilution of contaminants is reduced (Sprague 2005). For downstream agricultural users, this bears the risk of soils gradually becoming increasingly unsuited for agricultural production as nutrient and contamination levels increase. Similarly, risks to aquatic and riparian habitat may present detriments both to wildlife and river users, as well as bringing to bear regulatory scrutiny from Federal water quality monitoring and environmental protection programs (see, e.g., Freeman 2010).

Water Providers

Given the complexity of the diversion, provisioning, treatment, and reuse patterns that allow for the South Platte's socio-hydrology to function, it is perhaps unsurprising that its management has become increasingly professionalized and technocratic, with the vast majority of water resources and diversion activity occurring under the auspices of the basin's 278 local, regional, and other water provider entities and its 374+ agricultural irrigation ditch companies (see Figure 34). As a result, while several thousand individual water rights holders (mostly in the agriculture sector) and numerous others living in rural and mountainous areas must maintain and manage their own water provisioning infrastructure, for the overwhelming majority of the people living in the region the practical dimensions of water issues seldom intrude upon daily life, except on those days where their water bill arrives in the mail, or local news coverage on water-related controversies pique their interest, or natural disasters disrupt the otherwise invisible systems that deliver water to them.

For their part, water providers range in size and scope of authority: the various conservancy districts in the region, for example commission, manage, and allocate the resources of major infrastructure and storage facilities, such as the Colorado-Big Thompson trans-basin diversion and storage project, which is overseen by the Northern Water Conservancy District. Special Districts and Water and Sanitation Districts, similarly, are quasi-governmental organizations, usually governed by a board of directors appointed by their constituent communities, whose mandate is to serve the interests and needs of a given community, set of communities, or other area as designated at their foundation. Municipal water providers, in most cases, are controlled directly by the local governments of the cities and towns they serve, with some entering into contracts with larger water management entities, managing their own water infrastructure assets, or some combination thereof. Irrigation ditch companies, as their name suggests, are usually comprised of a group of agricultural irrigation ditch users acting as shareholders and decision-makers in a collaborative effort to

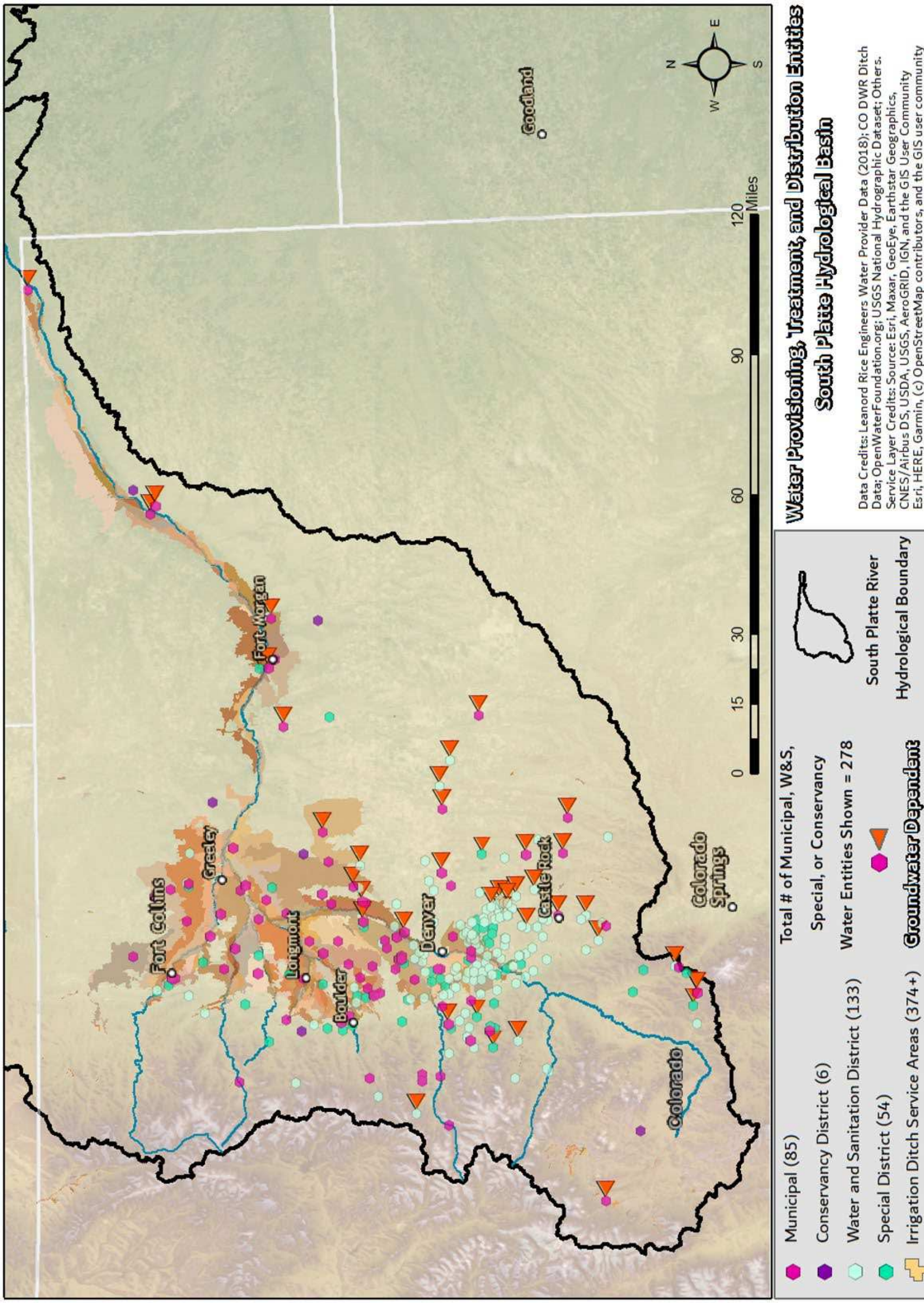

Figure 34 - Water Provider Entities by Type for the Colorado South Platte Basin

construct, maintain, manage, and allocate the collective diversion assets of the company. Many of these ditch companies are small, and serve only a handful of water users. Others are quite large and expansive, with multiple miles of infrastructure. In recent decades, many municipalities, as part of their efforts to secure adequate water resources for future growth and risk mitigation, have themselves become shareholders in ditch companies, as well, as individual shareholders sell off the properties and associated diversion rights to municipal governments or their associated water providers. Additionally, because of the extreme cost, complexity, regulatory, and political challenges associated with major water resource development projects, many of the more recent efforts and major infrastructure development have operated through collaborative mechanisms, often involving multiple water providers and local government entities.

Summary

The South Platte Basin in Colorado is a deeply nuanced and complex region, whose water systems are in a state of extensive human alteration across a diverse range of topographic, climatic, ecological, and social settings. Within it, surface and groundwater resources are used and re-used for a wide variety of purposes but mainly agricultural irrigation for commodity crops, to such a degree that its capacity to accommodate new water uses is extremely limited. It operates through complicated systems of infrastructure and hydrological manipulation that have developed over the last 170 years and a governance system founded in principles of prior appropriation and the reactive management of water scarcity scenarios. At the current point in time, efforts are underway at a variety of levels to encourage collaborative problem solving and decision-making as the basin faces numerous climatological, demographic, and hydrological challenges. However, fundamentally zero-sum dynamics within the system have the potential to significantly disrupt existing livelihood and land use patterns, and challenge the functionality of both its formal and informal governance systems.

Methodology

Primary data for this study were gathered by way of 35 semi-structured interviews conducted in the months between March and October of 2019 at a variety of locations throughout the Colorado South Platte Basin, both in-person and via telephone and video chat. In total, 38 individuals participated in the interview process, as three interview sessions had multiple participants. In all cases, interviews took place at a location of the interviewee's choosing and were prefaced with assurances that their comments would be kept anonymous throughout the research process. This point was underscored with the presentation of a letter of consent outlining the purpose of the study, their rights as participants (including their right to confidentiality and to remove themselves from the study at any time), and means by which participants could contact research personnel and supervisors. Interviews generally lasted roughly one hour and were digitally recorded for later transcription through an outside service.

Secondary data was also gathered from a variety of sources, as many organizations active in the water management system of the South Platte engage in a variety of public facing communications activities. These included brochures, newsletters, municipal master plans, and official documents related to the Colorado Water Conservation Board and Colorado Water Plan. In the analyses presented below, these documents served to provide critical context, especially as related to the official stances of decision-making bodies and the types of priorities and groups already considered within high level water management discussions. In addition, participant observation was undertaken at several water-related events during the data collection period, including public events convened by major organizations related to water decision-making collaboration, business-oriented conferenced focused on water, fund-raising events for river- and water-related organizations, and informal conversations with representatives of water-related groups at various public events. Further, when possible, meetings of the South Platte Basin Roundtable, Colorado Water Conservation Board, and

Statewide Water Availability Taskforce were attended and/or viewed (via on-line video recordings) to establish context and to provide continued monitoring of on-going developments in the region following data collection. Several informal conversations with high level water experts and researchers associated with Colorado State University and the Colorado Water Institute were also conducted to further ground research findings and ensure the applicability of the research process to existing sites of confusion known to affect the governance system.

Sampling for this study took a purposive approach, in which information was sought from those who were deemed via background research to have a high likelihood of deep connections with water-related decision-making and the various value systems that interact with it. Initially this was shaped primarily by a desire to gain sufficient coverage across the sectors of interest to existing governance frameworks related to water – i.e., agriculture, urban water managers, industrial or commercial water users, water sector experts, representatives from water-related recreational businesses, and actors involved in water-related environmental protection and advocacy – as significant background research had identified these groups as being central to existing discourse on water-related issues. This initial approach was further augmented through early recommendations from the Colorado Water Institute, whose efforts to engender collaborative decision-making in the water sector was noted early in the research process, and who had already gathered substantial contact information for individuals that were both engaged in water decision-making in some way and who were already attempting to bridge cultural and institutional gaps within the regional water system. From this, specific examinations of real estate development concerns, agricultural ditch managers (as opposed to farmers, more generally), key rural community officials, and representatives from different types of environmentally-oriented organizations were included in the sampling approach. Further interviewees were identified via fieldwork (especially attendance at water-related public events and forums), interviewee referrals, and monitoring of water related news from the around the region. In each case, the criteria for inclusion were based upon a desire to reflect both the overall geographic scope of the basin, a range of value orientations with regard to water resources (e.g., for the profit of industry and economic growth vs. the conservation of natural systems), and the range of power (i.e., powerful, institutionally legitimized actors vs. marginal advocates and activists) known to characterize the system as a whole. Ultimately, interview participants ranged widely in terms of their position within the water governance and advocacy networks of the basin, sectoral expertise, and their pathways to involvement with the water decision-making world (see Table 1). These included both professionals directly engaged in water-related livelihoods or technical work as well as those who came to be involved in water-related discussions as an indirect result of their employment or volitional engagement with water-related decision-making processes.

Transcripts from interviews were analyzed using a thematic coding approach focused on two main dimensions of interest: First, when and in what ways is water valued by the interviewee, i.e., what referents are relied upon to imbue water with either a positive or negative value? Second, what concepts relating to the water systems and the actors within it (be they moral, ideological, scientific, or otherwise) are utilized to explain or demonstrate these valuations? Put more simply, how is water valued by respondents and major actors within the socio-hydrological system, in terms of its capacities to effect certain environmental, lifestyle, or livelihood conditions? Further, how are those values inflected or altered by their relative position within the water system and their understanding of other actors with which they interact?

In practical terms this was accomplished in three phases: First, using MaxQDA 2020 (a qualitative data analysis program) transcripts were compiled into a database, and reviewed for errors and generalized themes across all transcripts. Second, each individual interview was coded in terms

Table 1 - Interviewee Identity Codes. Several interviewees had more than one identity or role within the water system, either professionally or vocationally.

Identity Code	Interviewees w/ Code
Agricultural Cooperative Manager	1
Agricultural Irrigation Ditch Company Manager	2
Agricultural Researcher	4
Brewing Industry Representative	1
City Manager	1
Conservancy District Manager	1
Conservation Organization Representative	1
CWCB Board Member (Urban)	1
CWCB Water Supply Expert	1
Ecologist	1
Energy-Water-Food Nexus Researcher	1
Environmental Advocate	2
Exurban City Manager	1
Exurban City Water Planning Specialist	1
Fishing Guide	1
Food/Tourism Business Owner	2
Industrial-Scale Commodity Farmer	1
Industrial-Scale Vegetable Farmer	1
Member of Community Affected by Disaster	1
Real Estate Developer	1
Rural Community Councilmember	1
Small-scale Farmer	1
Small-scale Rancher	2
Special District Manager	2
State Forest Service Watershed Section Specialist	1
Urban Natural Areas Director	1
Water Consultant	1
Water Lawyer	1
Water Outreach and Collaboration Specialist	1
Water Rights Valuation Specialist	1
Water Supplier (Municipal)	1
Water Supply Engineer	1
Watershed Coalition Director	1
Watershed Restoration Organization Director	1

of the interviewee's key identities (insofar as they could be derived from the interview sessions) in terms of their role or roles within the socio-hydrological system. Finally, each transcript was coded for specific segments as they related to:

A) What "water *is*", i.e., its value in various dimensions of interviewee's lives or the systems that they ascribe values to, e.g., as a financially valuable asset, as a component in a way of life, a physical input in a valued system, or as a vector of harm;
B) the domains or referents of these values (i.e., the context in which these values are realized, such as in agricultural systems and the communities that depend on them, or in natural systems and the recreational and tourism livelihoods that depend on them, etc.);
C) challenges related to holding and actualizing these values (i.e., acquiring and using water in a desired fashion; impacts from reduced availability of water on natural systems, etc.);
D) Understandings of what "*water systems are",* in terms of how interviewees understood the structure and function of socio-hydrological systems they interacted with, their purpose, and their views of how these systems might be altered or changed to better reflect the values they perceived of as important.

Based on initial reviews of the interview contents and notes taken during the interview process, these codes were centered around two main themes ("Water is…" and "Water Systems Are…"), into which the individual codes (corresponding, e.g., to a particular form of system understanding, or a commonly noted challenge in acquiring water for a specific process) were populated as the in-depth examination of the documents proceeded. This process resulted in a total of 1,619 code applications across 92 individual codes, with most thematically rich text segments being associated with multiple codes. These codes were, throughout the process of coding, successively condensed into 8 key thematic groupings (with four pertaining to each major theme). The result of this process is a database of quotes and exchanges relating to the full code set and the intersections between codes found within the comments of interviewees, referenced to both the specific topical or content themes of a given segment as well as their categorization within the condensed analysis framework.

For the purposes of clarity and salience, these findings are presented here in a condensed form. Specifically, I examine four key dimensions of water valuations and conceptualization across six "viewpoints" or livelihood and water-use perspectives across the basin. Detailed in the following section, this matrix of values and viewpoints does not attempt to provide a comprehensive assessment of the people and cultural complexes interacting with water resources in the Colorado South Platte, but rather attempts to bring an additional level of clarity and sophistication to existing domains of discussion regarding water related issues.

Results

This section is structured around two main parts: 1) An examination of the role of identity and social roles in participants' interactions with the water system, and 2) a review of the key themes corresponding to the topics, examples, and mental models utilized by participants to talk about water and the array of value systems they found pertinent to its management. Specifically, I examine valuations and conceptualizations of water across four levels of valuation: water as a *commodity*, as an *input* in productive or valued systems, as a valued component in a cultural value system or way of life (i.e., as an *artifact, symbol, or totem*), and as a *hazard* or vector of harm. To illustrate how these dimensions of value intersect with the livelihoods and positions of those in the basin, I further explore them as they relate to six major categories of viewpoint or perspective within the system. These are:

- Farming, Ranching and Alternative Agricultural Systems – which includes the spectrum of farming operations in the basin, including large-scale industrially operated commodity farms, cattle ranches, sheep farms, vegetable farms, and the wide variety of smaller farms operating at the urban interface around and between Front Range cities or in greenhouse operations, among others;
- Municipal Governments and Water Providers – i.e., both cities as governmental entities and the water providers they manage or are affiliated with;
- Industrial Users – including both "traditional" industries in manufacturing and oil and gas extraction, as well as the wide variety of food processing, beer brewing, and related firms;
- Residential, Commercial, and Other Non-Industrial Consumers – i.e., users of water for personal consumption or other domestic uses as well as those utilizing municipal water systems in offices, restaurants, and other businesses where basic water infrastructure are required;
- River and Environmental Recreation Businesses – especially angling guides, rafting guides, and tourism-dependent businesses located in and around the upper watersheds of the basin; and
- Environmental Protection, Restoration, and Advocacy Groups – which also represent a broad and diverse spectrum of actors ranging from international advocacy and conservation organizations to watershed restoration and management groups organized by local land owners. This group also includes regional organizations that operate primarily for the purposes of watershed restoration, education, and wildlife habitat protection, as well as those organizations whose primary function is to engage in public-facing activism for environmental causes related to rivers.

Though by no means exhaustive these viewpoints are critical to understanding the water landscape of the South Platte. More importantly, as I will discuss below, these categories are seldom exclusive, with many who operate from one or another viewpoint often engaging with others, with all the complication and at-times, dissonance that that entails.

Identities of Water Actors: Layers and Contradictions

Participants in this study represented what was ultimately a highly narrow cross-section of the broad range of individuals, institutional actors, organizations, industries, environmental advocates, and consumers that interact with the South Platte Basin's water systems in Colorado. Overwhelmingly white (one participant was Japanese American), male (seven participants were female), and advanced in years (most participants were approximately fifty years or older), this study's sample is far from representative of the ethnic diversity and youthfulness found when examining the population of the region as a whole. However, as several participants in the study pointed out themselves, this homogeneity is precisely the sort commonly encountered when engaging with the various multi-stakeholder collaborative water governance mechanisms found within the region, and especially representative in terms of the agricultural water rights holders who continue to account for the overwhelming majority of the region's water use. As one high-level actor within the CWCB's technical advisory network whose work brings him into contact with a wide array of decision-making contexts across the state pointed out, it has only been in the past several years that the CWCB itself has reached gender parity (with a majority of chairs held by women as of the time of this writing), leaving the vast majority of water-related conversations he encounters to be dominated by "white male voices." As he noted, in reference to his aspirational goals for the long-term evolution of the CWCB:

> I don't see a lot of diversity all the time at some of the conversations we have, and I feel like bringing in more Latino community, getting smarter about how we engage a range of folks. We certainly have tribal interests represented, but there's not a lot of African American perspective or any others. […]
>
> I think that we need to be reaching more women and more faces of color in these conversations, because one of the things you're bringing up is we can only have these conversations because we're hearing each other's perspectives. What's also true is that we can't ever understand a perspective of the ones we don't know. In my opinion, there's nothing but good that's going to come with having more faces in the room.

The implicit message being, that, from his vantage point, the evolution of the region's water governance systems – despite ambitions towards inclusivity – has largely failed to keep pace with the change occurring within the communities that system serves. That is, in a basin where roughly 16 percent of the population is not white and approximately 21 percent is of Hispanic ethnicity (with some counties, i.e. Weld, Morgan, Denver, and Adams having 30% or more Hispanic populations), zero members of the South Platte Basin Roundtable could say the same (Headwaters Economics 2020). Similarly, although almost 40% of the citizens of the basin's counties rent rather than own homes, the majority of programs focused on water conservation and education focus almost exclusively on home- and/or building owners, with few policies or programs available to those living in rented facilities often operated in an absentee fashion by landlords.

Despite the superficial homogeneity of this study's sample – and, generally, the broader networks of governance that it draws from – several factors nevertheless emerged as the study proceeded that highlight the complexities of how interviewees interacted with the water system, particularly in the context of their roles within organizations, businesses, and other entities involved in water resource issues and the values and ideals they hold as individuals and community members. In some cases, this came in the form of actors simply acknowledging the need for compromise between ones personally held values and the needs of collaborative decision-making and working in multi-stakeholder settings where, by design, potentially widely differing views are brought into play. For others, working in the context of natural resource systems, environmental advocacy, or on large infrastructure projects, there was the recognition that, while they viewed what they were doing as critically important, it may not be valued or understood by those it is meant to serve – or, as one participant put it – ever fully realized on a time scale that they could personally appreciate, i.e.,:

> It's not a do something and reap the rewards right away sort of thing. Most of the rewards from the work we're doing now, won't be seen for... we got to be thinking 50, 100 years down the road. When we're all retired and gone.

Similarly, professionals in the water supply and management sector consistently noted that, while they performed what they viewed as a critical public service function, most of those they serve have little to no real understanding of the complexity of the systems involved, nor the enormity of the task that delivering consistent water supplies represented. As one interviewee working as a water provider in the Metro Basin put it, "I spend hours trying to figure out how to educate people in my service area about how incredibly lucky they are to have this incredible clean water supply [in a semi-arid region with limited surface water]. And still you get people whose only response is: '*I don't drink the tap water. Why do we need to get rid of our sod?*'" As a result, for many of those who have spent significant portions of their lives endeavoring to improve and maintain water systems – and to learn about the wide array of factors that go into such work – a distinct feeling of alienation from the communities whose water needs they serve was a common frustration.

This feeling of disconnect or alienation from larger processes at play in the region was not limited to water providers and natural resource management professionals, however, as various stakeholders across a range of levels of power and value orientations to the water "world" also expressed frustrations regarding misunderstandings between groups or a deeper dissonance brought about when comparing what they themselves saw as valuable or desirable and what was actually taking place as a result of the function of the organizations they served. In some cases, this emerged as a simple matter of their role within an organization whose priorities and dictates they ultimately had no control over. For example, for one manager of a water provider for two special districts, his priorities as an individual with deeply held environmental values were secondary to the priorities of the boards of directors of the organizations by which he was employed, which, while currently willing to embrace efforts to put resources into ecologically sound and environmentally beneficial projects, were ultimately driven by the need to attract residents and deliver water for whatever uses their constituents required. This disconnect between growth and use imperatives and the individual values of interviewees was also echoed by those working in higher-level decision making capacities. Here, interviewees noted that much of their work involved finding ways to maximize revenues and promote economic and housing growth even if, in their case, this meant the erosion of the agricultural and natural resource systems they valued as individuals. As one rural city council member and former mayor related after detailing work to transfer agricultural water to a new residential development that would bring hundreds of new homes to his community:

> Well I mean if it was up to me, everyone would slow down growth. […] And I say that as a hypocrite as the developers drying up a farm and bringing us the water so we can grow but I mean [...] I think you lose your sense of being the bigger you get.

As I hope to show in the sections that follow, this conflict between the imperative for water use maximization, population growth, and economic expansion, and the simultaneous desire to preserve existing ways of life runs far deeper than the cognitive dissonance of a few high-power stakeholders. However, what it underscores is a critical factor in understanding the ways in which individual actors navigate multiple identities when they engage with water allocation decisions and the ways of life and enterprise that flow from them. That is, for anyone who engages seriously with water resource systems, their identities become split – as individual consumers, they, much like the customers or community members they work for or hope to engage, need to access clean, reliable sources of water to meet their daily needs. As economic actors, they must utilize these resources further still to bring about the fruits of whatever enterprise they might be involved in. As professionals within organizations, they must set aside their personal values to enact the mandates of the individuals or communities who pay them. Likewise, should they work toward the goals of environmental sustainability, environmental protection, or other outwardly-directed goals, they must come to terms with the fact that, in a resource limited basin where water resources are already over allocated, then unless novel mechanisms for mutually beneficial use are devised their efforts will necessarily result to undermine the livelihoods of those who rely upon existing water distribution patterns. (And moreover – the more attractive the region's natural amenities, the more likely it is that others will be drawn to the region). In other words, no one who engages with complex socio-ecological systems does so in a fully coherent or consonant manner, as the multiple layers of their identities – social, community, professional, moral, and otherwise – inevitably all come into play.

Water Values: As Asset; as Input; as Lifeblood; as Risk

For participants in this study, questions about the value of water in their lives and in the context of their professional or advocacy work were met with a range of responses, spanning issues of financial burden, infrastructural practicalities, intellectual fascination, spiritual solace, and a host of nuanced value expressions in between. Here, I focus on four distinct levels of valuation and conceptualization that emerged from these conversations, with the aim to capture water's complex, and at times conflicted, role within the lives and professions of those living in a water scarce system. These are: water as an abstract asset or commodity, water as an input in physical systems, water as a component of a way of life – be it as a symbol, a culturally valued presence, or a totem of a moral system – and finally, water as a vector of burden or harm, that is, as a hazard. As we will see, however, these categories of valuation and understanding do not always occur discretely, as the complexities and dynamic character of water often lend it to taking on a variety of roles, both practical and symbolic, within participants' lives.

Water as Asset and Commodity: Paper Water, Digital Water, and Water Rights

As enshrined in Colorado Water Law, the natural surface and groundwater resources of the state cannot, themselves, be owned, as they are seen to belong inherently to the public, i.e., the people of the state. Rather, the legally recognized right to divert, extract, or otherwise manipulate water for a specific use or set of uses – known as a "water right" – defines the extent to which one can be said to possess a given amount of physical water, with the legally recognized "beneficial use" of that water comprising the basis, measure, and extent of that right (see CFWE 2015; 6-7). These water rights, which are adjudicated through the water court and apportioned according to the prior appropriation system, were historically tied to specific enterprises, pieces of real estate, or infrastructure. However, as this system evolved throughout the 20th century, it became necessary to establish an increasingly complex system for transferring, changing, exchanging, leasing, and banking these water rights in a manner that separated them from the original use case and situation. Because of this, and because of the over-appropriated status of the basin's natural surface and groundwater resources – individuals or entities hoping to engage in some form of water use or manipulation must engage in the process of navigating the water market, wherein water rights owned by a wide variety of previous users can be sold and transformed while maintaining their position in the priority system. As a result, these "paper rights" can be some of the most valuable and sought-after commodities in the state, and due to ever rising demand from cities, especially in the South Platte Basin.

In other words, there exists a sort of de facto cross-cultural valuation of water in the region, one that is largely de-coupled from the feelings, attitudes, and behaviors of the individuals and groups that populate it. Brought about by the abstraction of water use authorization enshrined by state law and spurred forward by narratives of limited supplies propagated by governments and media outlets, this value complex approaches water as a profoundly scarce and difficult to acquire resource, whose regulations are frustrating to navigate, and whose utilization involves a variety of economically costly processes. Put more simply, whatever values people and organizations may place on water and its various articulations with human and natural systems, they must first confront the fact that it is a highly prized and virtualized commodity, one whose acquisition and control is increasingly outside of the capacities of all but the most powerful, fortunate, and/or wealthy actors. To adapt an adage, while in nature water follows the path of least resistance, in Colorado it follows the path of highest profitability, often flowing quite literally uphill, if its path is towards money.

For some, this represents a much needed boon, as a great number of those who hold valuable senior water rights across the region – generally those that have been inherited through family farms or associated with properties purchased before the population boom that proceeded from the 1970's onward – may enjoy the possession of an asset whose value seems only to increase. This is especially true for those farmers who, for one reason or another (some of which will be discussed in subsequent sections) have seen the depreciation of their land holdings, declines in the profitability of their farming operations, or who might lack a next generation of heirs to whom farm assets might be entrusted. For these farmers, their paper water rights, if sold to municipalities or developers, can represent a sort of emergency retirement plan, with even relatively small farms having access to water resources necessary to supply dozens if not hundreds of homes. Put another way, water that, applied to farmlands, yields little to no profit, can be, if converted and sold, represent a potential windfall.

Accordingly, the industry surrounding the navigation, litigation, purchase, transfer and valuation of water rights is one of the more reliable and lucrative in the region, with one water sector expert noting that "the only thing more valuable than water in Colorado is knowing how to value water." With water prices ranging between $20,000 and nearly $60,000 per acre foot as the basin's cities and exurban communities attempt to grow and reserve water for planned future use (Smith 2019), utilizing the expertise necessary to accurately price water for sale bears with it serious consequences. This is especially true given that, while all water is, to some degree, highly valuable, certain water resources, such as those derived from trans-basin diversions (which are rather straightforward to manipulate to novel uses within existing infrastructure) or in- basin water rights conveniently located with regard to existing municipal diversion or storage structures can be particularly attractive. Similarly, former irrigation waters affected by different land-use legacies (such as salination or industrial pollution) or other contextual impediments (e.g., no ready access to infrastructure related to new uses) can prove much more costly for municipal or other users than upon first inspection.

Perhaps for this same reason, a number of research projects and NGO efforts are currently underway to analyze the potential for expanding what are known as "water banking" systems, currently limited to water rights associated with reservoir storage that can be apportioned in a more flexible manner than traditional, permanent water rights transfers. In this view, water resources once tied to specific uses and diversion points would become increasingly abstracted or "digitized" within market-driven systems (with one respondent characterizing these schemes as "Bit-Water," a reference to the cryptocurrency Bitcoin). Proponents of these systems argue that this would allow for legally stored water resources to be re-allocated based on changing demands and willingness to pay while simultaneously allowing water rights holders to maintain control over their assets over the long term. As one interviewee, working for a for-profit organization attempting to bank water assets in the upper Colorado basin (where significant trans-basin diversion for the South Platte originate), these could open more water resources to pro-environmental and river recreation purposes, which are often limited legally or financially from gaining access to water rights through existing transfer mechanisms. However, without appropriate regulatory mechanisms, these waters could, theoretically, be just as open to market forces currently diverting both instream flows and agricultural waters to urban development purposes.

A similar sentiment was voiced concerning other, already established methods of temporarily or partially transferring water from valuable water rights to other uses, particularly those known as "alternative transfer mechanisms" or ATMs. Under these arrangements, a water rights holder (usually a farmer) can enter into an agreement to either partially or conditionally transfer portions of their allocated diversions to another use (usually a municipal water supply), while retaining the option to continue to divert that water for its original purpose. Advanced as part of both the Colorado Water Plan and the South Platte Implementation Plan, ATMs were meant to slow the permanent drying of irrigated agricultural lands by giving farmers a means to profit off of water rights during years where crop prices, labor costs, or regional drought might make farm activity non-viable. However, several interviewees involved in both sides of ATMs had noted that such

Table 2 - Water as a Commodity by Viewpoint

Viewpoint	Water as Commodity or Asset
Farming, Ranching, and Alternative Agricultural Systems	• Surface water, groundwater, or other diversion right in irrigation system. • Transferrable asset; "Retirement Fund." • Underlying asset in acquisition of credit. • Presence of infrastructure for water management systems can increase or decrease the value of agricultural properties depending on its condition and functionality. • Urban, peri-urban, and networked (co-op) farmers may face additional costs associated with flexibly moving water rights and/or purchasing water from urban systems. • Costs are a limiting factor in the expansion of existing operations or development of new operations, making prospects bleak for new farmers without heavy investment or taking on debt.
Municipal Governments and Water Providers	• Surface water, groundwater, or other diversion right in irrigation, consumptive use, and sewage treatment system. • Underlying asset in growth management and master planning processes. Possession of surplus water rights can allow cities to attract, manage, dictate terms of, or restrict development in line with community goals.
Industrial Users	• Surface water, groundwater, or other diversion right in process, maintenance, energy generation, or production system. • Underlying asset in business plan and credit acquisition. • As an input, costs associated with water acquisition, treatment, and delivery affect the asset value of operational properties and profitability of operations in specific sites.
Residential, Commercial, and Other Non-Industrial Consumers	• Purchased commodity through local service systems. • Foundational component of private property valuation. E.g., properties must have access to water utilities; proximity to water-related amenities can increase property value or attractiveness of businesses location. • Price driver for new housing or land development. For developers, water resources may be required prior to construction in communities without "cash-in-lieu" systems. Generally, represent a significant portion of costs associated with developments.

River Recreation Businesses (esp. Angling and Rafting Guides)	• Angling Guides:
	  o Operations may involve privately-owned property or access points proximal to surface waters. Most rely upon publicly owned lands.
	  o Diversion or storage right for fisheries.
	• Rafting Guides:
	  o Operations may involve privately-owned property or access points proximal to surface waters. Most reply on public access points and lands.
	  o Diversion, storage, or other form of water right or agreement associated with maintaining adequate flows amenable to recreation.

Environmental Protection, Restoration, and Advocacy	• In-stream Flow Right associated with ecological river function (CWCB, State of CO Only). • Diversion right associated with conservation easement schemes on formerly irrigated land.

mechanisms only rarely functioned as intended. Rather, several characterized it merely as "buy and dry with extra steps," noting that, on the one hand, cities and large water providers required both control and predictability in water resources, meaning that contingent ATMs had less value than water rights purchased outright. Similarly, several farmers noted that, while they were able, due to both expansive operations and ample water rights, to take advantage of such programs in years where commodity or specialty crop prices discouraged normal operations on portions of their land, they did little for the more vulnerable farm operations most likely to be bought out and removed from the irrigation system. That is, because these farms often lacked the financial and capital buffers needed to respond flexibly in down years, entering into a complex ATM was less viable than simply getting out of the farming game altogether. Similarly, cities hoping to act as the recipient of an ATM would likely only do so if buttressing already sufficient water supplies, as the uncertainty associated with such a transfer would present a potential risk that water would not be available when it was needed. A more preferential – and increasingly common – arrangement, then was for cities water providers and special districts to simply buy up water rights in excess of their current needs, and then lease those back to farmers, thereby retaining the ability to completely utilize said waters when future municipal use demands materialized. As a result, although many farmers at the urban fringe continue to operate – and may yet for some time – the ultimate drying up and or land use conversion of those farms is effectively "baked in" as cities continue to pursue growth and expansion.

How they will do so, however, will depend heavily upon policies and decisions relating to water, as many communities require all developers and prospective home builders to ensure that water resources sufficient to provide for future residents are in hand prior to permitting and construction. As a result, the cost of housing – already steep and climbing over the last decade – will likely continue to rise beyond the capacity of most of the region's residents to pay for it. For smaller cities undergoing rapid growth pressure whose water resource portfolios are meagre, this may mean requiring housing, industrial, and other real estate developers to bring their own water rights, thereby detracting from their suitability for operations concerned mainly with their bottom line. Conversely, for those larger municipalities whose water rights portfolios are relatively flush, it means having the capacity to negotiate from a strong position with prospective industrial, residential, office, and other sorts of developments looking for a new home.

Valuing water as a commodity or abstract asset has less centrality for those engaged in environmental work and the various sorts of recreational businesses that rely upon functioning environments. However, these viewpoints must also contend with the economic realities of the region's water system, even if only from a position of resistance as they attempt to keep unallocated or historically flowing waters out of the diversion systems of future development. For large conservation organizations, water rights may also present a highly valued addendum to properties or tracts of land sought for conservation, as artificially irrigated landscapes can often have surprising habitat values. Likewise – although not a water right, in and of itself - fishing and rafting guides may seek out properties adjacent to particularly suitable river stretches and entry points so as to ensure easy access to desired fishing and rafting spots as the region's public stream access points become increasingly crowded. Along these same lines, the Colorado Water Conservation Board's Instream Flow Program – which seeks to maintain environmentally and ecologically necessary river flows in critical stream sections – must also work within the language of economics, as its ability to acquire and utilize water rights often comes with both acquisition and litigation costs.

Granted, this is only an extremely brief, and ultimately, superficial summary of the ways in which value systems of commodification and legalistic abstraction intersect with water. What it should impress, however, is that any conversation about water resources – whether in terms of their use, purpose, or potential to cause harm – is ultimately inseparable from the legal and economic instruments that have evolved in the state and region to overcome the challenges presented by its scarcity and the threat of conflict looming behind it. At the same time, however, it presents its own sort of battlefield, with its own winners and losers; one that, as many interviewees noted, may not be ready to constrain the new forms of scarcity and conflict that increasing demands and uncertainty bring with them. More importantly, if water can be said to have a price, its value is derived from the potential profitability and productivity associated with its actual use.

It is to those aspects – and the cultural values that underly them – that I now turn.

Water as Input; Water as Totem; Water as a Part of a Way of Life

In the early days of Euro-American settlement in the territory that would become Colorado, the diversion of water from the region's native streams and acquirers generally occurred solely for the purposes of mining, the irrigation of agricultural fields, for direct human consumption and bathing, or for the watering of livestock. Today, these same uses, (albeit in some cases dramatically transformed from their historical counterparts), now occur alongside dozens of officially recognized "beneficial uses" of water within the basin, ranging from craft beer brewing and golf course irrigation to the artificial maintenance of natural river flows, recreational releases for rafting, and a variety of industrial and chemical production processes. Owing to technical advances in water treatment and reuse, a given molecule of water may be used and reused numerous times before exiting the basin, either as streamflows to Nebraska, to the atmosphere, or in the form of finished products. For the vast majority of individuals living in the Colorado portion of the South Platte Basin, as well as the state as a whole, most of this practical complexity is generally beyond the space of their daily concerns, as water delivery to homes, retail businesses, and office spaces is both hidden from view and so reliable as to pass out of mind. For the 600+ different water provider entities in the basin – ranging from municipal water utilities to multi-city special districts, agricultural ditch companies, augmentation companies, and regional water conservancy districts – and thousands of

Table 3 - Water as an Input in Physical Systems

Viewpoint	Water as Input into Physical Systems
Farming, Ranching, and Alternative Agricultural Systems	• Core component of plant biomass formation, plant reproductive activity, yields. • Control, consistency, and timing are critical to usefulness. Must align with plant phenological needs and capacity of infrastructure and machinery. • Ideally, farmers and ranchers will have the ability to flexibly apply and transfer water to where it is needed in response to natural precipitation amounts and farm/ranch system water needs. • Urban farmers may rely upon urban water systems that require non-standard irrigation infrastructure within farming systems. Costs may also be higher. Urban water users may also face additional restrictions during droughts. • Farmers operating in urban or peri-urban settings may also face increased regulation relating to agricultural runoff and increased contamination from urban runoff.
Municipal Governments and Water Providers	• Core component of development schemes and ability to attract and control development. • Critical input within valued amenities (parks, etc.), and service infrastructure. • Reliability, safety, and quality are critical to its delivery for municipal users. • Source waters must be of such quality that treatment is financially affordable and technologically possible.
Industrial Users	• Core component for profit generation through production processes and externalization of byproducts • Generally needs to be constantly available as pertains to specific processes; must have suitable chemical and other quality dimensions. • Temperature can be a critical determinant of water input value for many processes, such as thermoelectric power generation and cooling.
Residential, Commercial, and Other Non-Industrial Consumers	• Essential input for maintenance of human, animal, landscape, and infrastructure function. • Critical for waste management as a mechanism for pollutant dilution, sewage treatment, and waste transmission. • Critical for culturally valued landscape maintenance; amenity function (e.g., golf courses, water parks, parks, ponds, etc.) • Absence of contaminants critical for consumption. On-demand reliability is expected in homes, offices, businesses.
River Recreation Businesses (esp. Angling and Rafting Guides)	• Angling Guides: o Ecosystem service in the form of habitat for desired fish and associated species. o Temperature, salinity, pH, and other chemical aspects are critical for ecosystem function. o Flow regimes and related habitat formation processes are also critical for maintaining native fish populations. o Critical habitat for prey species and other related components of fish foodwebs. • Rafting Guides: o Natural or Built Ecosystem service in the form of varied stream beds with a range of flow patterns and characteristics suitable for the range of desired activities (beginner, advanced, expert, etc.) o Consistency year-to-year and within specific places are critical to business success.
Environmental Protection, Restoration, and Advocacy	• Essential component of healthy, functioning ecosystems, including both consumptive uses by animals and plants and as habitat for critical species across all trophic levels. • Variability in flow regimes shapes habitat formation, succession processes, and promotes habitat mosaic formation critical to biodiversity. • Provides regulating services essential to human health; cultural services essential to well-being.

individual diverters, however, the physical manipulation and transformation of water is a constant concern whose challenges only mount as the complexity and technical sophistication of water use systems of the region continue to grow.

At the same time, however, water users and providers must also deal with an evolving moral landscape pertaining to water, its purpose, and the subjectively defined "rightness" of its various use cases. Indeed, if there was one theme that resonated most consistently throughout the course of this study, it was that discussions relating to the practical dimensions of water as an input in specific systems were often inextricable from the diverse moral lenses that water users found turned towards them, and that they, in turn, relied upon to frame the meaning of their water related activities.

For water providers in municipal settings delivering water for domestic, business, and industrial uses, the task laid before them has historically been rather straightforward, if at times technically challenging: First, divert or extract water from areas where it is readily available, treat this water to a degree that it is safe enough for its specified uses, and transmit that water to the various places that customers desire it. Once it has been used, treat this water again according to the pertinent water quality regulations, and send it back into the streams, rivers, and other systems that will convey it out of their service area. As their service area grows in population or size, they then simply add new infrastructure, facilities, and water resources as needed, maintaining and improving existing systems along the way. Should they do all of this is a manner that ensures high levels of supply consistency, adequate quality, and confers a feeling of control over water needs to customers, they could well expect to retire comfortably, resting assured in their execution of a job well done.

In agricultural systems, the picture is somewhat more complex, if the ultimate message is the same: here, the need for control, consistency, and predictability are all paramount, just as they are for municipal providers. However, the purpose – the production of plant biomass – brings with it additional considerations, as the irrigation of crops must be carefully timed throughout the year as pertains to specific crop types and their individual growth patterns. For most crops, this involves large diversions during the months of late May and June, as seeds germinate and plants undergo their initial growth periods, followed by supplemental irrigation throughout the remainder of the summer as temperatures rise and plant evaporative demand peaks. For those in long-established agricultural systems, this involves the operation of irrigation ditches, canals, and the controlled flooding of fields, with a growing portion also utilizing center-pivot sprinkler irrigation, often supplied by groundwater wells. In addition, an extremely small but growing number may use either surface drip lines or below ground "precision" irrigation techniques that deliver exact amounts of water to the rooting zone of crops, which can often lead to yields comparable to other irrigation methods at a fraction of water diversion – albeit with additional infrastructure costs involved.

In each case, however, consideration must be taken to ensure that the water used for agricultural irrigation is of adequate quality, particularly in areas where aggregate contamination from upstream diverters has introduced copious amounts of dissolved solids (salts), pesticide and herbicide runoff, unwanted nitrogen from fertilizer and animal feeding runoff, or other contaminants associated with urban impermeable surface runoff or contamination from oil and gas extraction sites. These concerns are especially acute for those who divert water for animal consumption, as water contamination in stock ponds can lead to a variety of health issues for livestock. For farmers operating in alternative arrangements, such as cooperatives, rental farmers, or small-scale organic farmers operating in urban areas, the same considerations for quality and control also apply. However, because these types of farmers often lack senior water rights and might depend upon leased water or water from municipal supplies, working to manage costs associated with water falls alongside the more practical concerns of getting sufficient quantities of adequate quality water to crops when required.

Table 4 - Water as a Symbol, Totem, or as Part of a Way of Life

Viewpoint	Water as Cultural Artifact, Symbol, or Totem
Farming, Ranching, and Alternative Agricultural Systems	• Water rights and associated properties are symbols of land use legacies and connections to places, landscapes, and traditional ways of life. • Water infrastructure can be associated with long-term place connections and legacies of socio-hydrological manipulation reaching back generations. • Independence and self-reliance associated with farming and ranching are often reliant upon water management practices; mastery of water challenges often cited as core component in narratives of independence. • Alterative Agricultural Systems are often rooted in value systems related to local resilience, improving local food security, addressing social injustices relating to quality food access, environmental sustainability, personal independence, and the valuation of food system knowledge as a component of personal growth.
Municipal Governments and Water Providers	• The ability to provide stable, clean, high quality water in a reliable manner is essential to cities hoping to attract residents, businesses, and industry. • Amenities maintained through irrigation and other water use provide a sense of pride, and are seen as improving quality of life and overall community health and well-being. • Successful water management maintains stability and minimizes the impacts of climatic variability and weather extremes; i.e., resilience and sustainability • Control of water resources suitable to current and future needs provides a sense of being able to control one's own destiny; plan according to community values; meet demands for development.
Industrial Users	• Efforts to minimize environmental or other downstream impacts from water use can be platforms for public relations campaigns. • Many industrial users also engage in significant water-related advocacy and public outreach (esp. beer brewers) to ensure input quality and maintain a positive public image. • Sustainability and other green initiatives can serve as recruiting, retention, and marketing boosters while also reducing certain long-term costs associated with doing business.
Residential, Commercial, and Other Non-Industrial Consumers	• Access to clean, reliable, affordable water is seen as a precursor to expected minimum standards of living; poor water quality is subjectively defined, however, and varies substantially based on class. Many expend additional resources to retreat or filter water for consumption even in areas with properly treated water. • Signs of water contamination carry a visceral charge; cause stress above and beyond direct health impacts. • Outdoor consumption of water serves as a public-facing status and value orientation indicator, in terms of both using water extensively and minimizing its use, respectively.
River Recreation Businesses (esp. Angling and Rafting Guides)	• Can serve as an attractor to tourists and regional customers while serving as a point of community pride. • Angling Guides: • Fishing experiences serve as rites of passage, annual traditions within families, personal escapes from daily or professional stress, and sites of spiritual cultivation. • Successful fishing conditions and the ability to guide others to them are the foundation of successful guide business practice. • Experiences in and attachment to valued fishing locations provide connections to communities and networks within them. • Rafting Guides: • Rafting experiences can serve for group bonding, personal achievement, or as a means of exercise. • Successfully navigating and guiding others in a safe and reliable manner is essential to rafting guide operations, making river knowledge critical to gaining repeat business and referrals.
Environmental Protection, Restoration, and Advocacy	• Protection of remaining natural water courses and associated ecosystem processes are viewed as a moral and practical good. • Sacrifice of functional environmental systems, water channels, water variability, wildlife, etc. are viewed as unjustifiable regardless of short term benefit. • Restoration of human-altered, degraded, or otherwise impaired ecosystems are seen as virtuous pursuits with multiple tangible and cultural benefits both near- and long-term. • Experiences and interactions with ecosystems are seen as a source of personal, spiritual, or moral cultivation. Preservation of these systems is seen as core of a positive legacy for humanity.

Put more plainly, for users and providers in the municipal, industrial, domestic, and agricultural realm, the practical dimensions of water management ultimately boil down to being able to control water, and to ensure that it is available in an on-demand fashion regardless of what natural precipitation and local streamflows dictate. On the other hand, for those operating from the viewpoint of river recreation-based livelihoods – and to a great degree, that of environmental protection, restoration, and advocacy – the practical side of water is focused on ensuring that water is *not controlled*, but left to its own devices so as to carve out the diverse aquatic systems critical to ecological function and processes of stream transformation. For angling guides and fishing enthusiasts, this means ensuring that streamflows are able to be maintained in ways that allow for fish migration, spawning, and growth, all of which require a diversity of streambed types and un-fettered waterways that extend across climatic zones. For rafting guides and rafters, this means ensuring that flows are available in across a diversity of streambed configurations, ranging from the calm, relatively deep flats to the shallower and more exhilarating rapids that enthusiasts desire. For those involved in environmentally related work, be it advocacy or restoration, the need for natural flow regimes – which often include channel migration, periods of extreme flows that scour and reshape the river, and that, over time, create the gradient of in stream and near stream habitats critical to wildlife – is paramount, often putting their goals at odds with those who seek to channel the river and tame its variability for the purposes of downstream human populations and their desired ends.

It is in no small part due to this conflict between natural river phenomena and the need for water resource control that the once purely technical profession of water management has become infused with a variety of moral and at times contradictory systems of value that significantly complicate the achievement of its seemingly straightforward goals. Although early patterns of water development were, of course, deeply rooted in national narratives of Manifest Destiny and the virtue of productive industry, the ubiquity of these points of view lent a sort of innate legitimacy to water infrastructure development projects that has since fallen out of favor. For municipal providers, this change has come in the form of an ever-growing need for water departments and providers to communicate effectively about water conservation practices, ranging from changes to in-home fixtures and behaviors to outdoor landscaping choices. For agricultural ditch company and irrigation company managers, it means working alongside their shareholders to maintain agricultural flows in the face of dramatic upstream changes in surface and groundwater hydrology, ever-shifting regulatory regimes, aging infrastructure, and the vast array of transfer instruments continually threatening to undermine the connectivity of their irrigation networks. In both cases, they must also navigate a water resource system wherein collaboration between diverse stakeholders, perspectives, interests, and knowledge levels introduce significant new challenges to those steeped in single-field specializations. At the same time, the availability of readily transferrable water rights decreases, and the costs associated with infrastructure maintenance and development grows, making urban growth a matter of rural desanguination, and agricultural expansion nearly impossible. As a result, water managers in all settings increasingly find themselves required to develop new ways to solve resource problems in a manner that serves multiple needs precisely as once tried and true methods of water resource problem solving seem poised to become obsolete.

Pre-eminent among these challenges is that, owing to the increasing concern over the impact of large river diversion and storage projects on natural environmental systems, new dams and other storage infrastructure have become both more costly to initiate and politically intractable, leaving many large infrastructure projects languishing in a seemingly interminable process of environmental review, legal challenges, and cost overruns. The most notable example of this trend is the Norther Integrated Supply Project, known as NISP, which if built, will involve the storage of an additional 215,000 acre feet of water per year (yielding up to an additional 40,000 new acre-feet of storage for the region) in a pair of newly constructed reservoirs outside of Fort Collins and Greeley. Initiated in 1988, the project is not likely to see its first storage activity until well after 2028, a full forty years after its conception. Throughout this process, it has seen both significant challenges from environmental groups, and, via lobbying by local anti-growth and pro-environmental organizations of various city councils, the exit of several of its original beneficiaries and partners. Though it now appears to be on the way towards initial construction, critical opposition from local landowners, conservation organizations, and others continue to inject significant uncertainty into both its prospective timeline, and, for some, whether it will be completed at all.

For proponents of the project and others like it, their efforts are underscored by a general understanding that population and economic growth are – if not necessarily uniformly *good*, then, at least, essential to the region's economic well-being and, given recent trends, inevitable. As a result, new supplies of reliable water resources are required, and if there are environmental or social costs associated with securing such resources, they are outweighed by the benefits of control, consistency, reliability and overall increased supply that will come with the project's completion. Likewise, for the various communities and water providers signatory to the project, their mandate to pursue expanding revenues for services through growth and the expansion of their tax base – all of which require additional water supplies – are largely seen as inherent to their ability to function, even if the unintended costs of rapid growth have the potential to reduce the quality of their community members' lives due to increased traffic or other strains on physical and social infrastructure. As a result, supporting additional storage projects becomes a matter of, on the one hand, survival, and on the other, one of maintaining their capacity to control their own development futures, as it is through the possession of water supplies in excess of current needs that a community can attract and support local economic growth. This is especially true for the numerous smaller exurban communities (usually former farming or rail depot towns that are now transforming into commuteror “bedroom” communities) that have been unable to build significant excess water supply portfolios, and that now find themselves beholden to their larger neighbors for water treatment resources and facing untenable costs for accessing agricultural water transfers. Though many in these communities are themselves wary of uncontrolled population growth, the need for critical commercial and service facilities necessitates finding some way to bring water resources into their communities at a cost they can afford within their constrained budgets. As one city manager working in a small exurban city with a limited water portfolio put it rather starkly:

> […]When cities have that water that they bought 20 years ago for $5,000 an acre foot and now water costs 35,000 an acre foot or more, and cities can say, "We'll help you out. We'll sell to you for 20 or 25,000. They get the development and they make good profit off their investment that they made 20 years ago. So [our town] does not have the portfolio with enough water to facilitate that growth in the future. […] We don’t have a grocery store, we don’t have healthcare facilities. We have a downtown, but don’t have the restaurants we want. Those are the things we desire. Right now, we don’t have the critical mass yet to support them. So there is some strategic growth that we’d like to have happen in terms of residential growth, to create the community that we think will then attract commercial development. But the water is going to be a governor on that.

Among agricultural water rights holders and residents of rural communities reliant upon agricultural economies, projects like NISP are seen as an answer to another need: namely, the reduction of pressure on agricultural water rights holders to permanently dry up irrigated land following transfers of diversion rights to municipal water providers. Though nearly all of those involved in agriculture that were interviewed for this study noted that, perhaps ambivalently, that municipal demand for water had granted many older farmers possession of an extremely lucrative asset, they also noted that the costs to the surrounding community and related economies of cashing in that asset often outstripped whatever benefits they might bring to an individual family. For some, it means the removal of families with long-term ties to the land, with one rural town councilmember noting that after significant water purchases in their area in the early 2000s, local school attendance dropped to levels comparable to the 1980s. As a result, local businesses, seed suppliers, implement dealers, restaurants, and other services lost both a client base and a critical part of the community fabric central to their way of life. A water lawyer and advocate of alternative transfer mechanisms, reflecting on this dilemma, put it this way, noting that, when water rights are bought outright:

> There's effects on rural communities […] while maybe you could replace those jobs, and have a sort of net zero effect, economically, but it wouldn't be the same. And I think that that's not just nostalgia talking. I think that's a matter of valuing some of the mix of what Colorado is. That's part of who we are.

Other critics of NISP and other large infrastructure and storage projects, however, reject both the practical and in part, moral principles underlying such work. On the practical side, many critics would argue that the additional water provided by NISP is only required if one takes for granted population growth projections and projections of increased per capita water demand that are out of line with observed trends, which have shown both slower than expected population growth and significant decreases in per capita water use. Further, they argue, increased innovation in terms of personal, business, industrial, and agricultural water conservation practices could support growth while simultaneously maintaining existing levels of water diversion from streams. That is to say, in practical and empirical terms, these critics argue that the justification for projects like NISP is fundamentally incorrect, relying on incomplete information, unsupported projections, and a failure to account for the flexibility and ingenuity of the various water user communities implicated in existing water scarcity problems (for more information on this line of argumentation, see:

(Western Resource Advocates 2012)). In their view, new infrastructure on the scale of NISP are not required if cities and their citizens are willing to make reductions in their demands, and likewise, agricultural communities are able to engage with novel processes for water transfers and urban-rural collaboration to ensure that future ag-to-city transfers can occur without destroying or destabilizing rural economies.

Similarly, many observers of the changes occurring in rural communities – as well as those who readily acknowledge the negative consequences of status quo buy and dry activities – note that a far greater array of factors above and beyond urban demand for water are at play when it comes to why farmers have historically chosen to allow water transfers to occur. As noted above, one of the most significant reasons is simply that farming at the scale of a family-run operation of the sort most often held up as the symbol of rural community structure is no longer economically or logistically possible, even when water is in ample supply. Faced with increasing competition from global supply chains as well as national trends toward farm consolidation and corporate organization, family farms are simply unable to compete against market actors with access to significant advantages of scale and capital resources. Likewise, due to increases in the costs of equipment, implements, inputs, and industry-wide shortages of labor, the historically low profit margins of independent farming operations are generally unable to keep up with the capital costs needed to respond to market dynamics in an agile manner. Because of this, simply reducing the pressure on farms to sell water rights to cities would likely do little more than reduce the value – if temporarily – of what might be the most valuable transferable asset a farming family possesses.

Though not themselves critics of NISP or other large projects, several water providers also noted that, if the effort of large projects is to reduce rate of acquisition of agricultural water rights by cities, then the simple truth is that such efforts would seem too little, too late. As mentioned previously, in many areas where cities directly adjoin agricultural lands, much of the surrounding irrigation water diversions are in fact already owned by cities, with operations on farms taking place through leases of city-owned agricultural water back to farms. As such, the drying up of said lands is "baked in", so to speak, unless future population growth is of such a character as to not require additional water use (i.e., through dramatic decreases in per capita water use in the future). Moreover, because many of the most valuable soils for agriculture already fall within many of the region's growing cities' planned growth boundaries, these farms face not only drying up, but complete replacement within the land use matrix.

Further, while those in the agricultural sector interviewed for this study were generally opposed to relinquishing local control or other measures to curtail growth, they themselves noted that, far more than any other factor, urban population growth and development represented the single greatest pressure on their ability to continue operations in the manner they had done so in the past. For some, this was mainly due to the economic pull away from agriculture that urban water demands represented – i.e., the classical scenario of buying and drying – continued to be far too enticing for many farmers, thereby threatening the integrity of the agricultural system as a whole. In other cases, it was due to the lack of a next generation to whom to pass on operations, either through a lack of offspring or the fact that their children had moved on to more stable, higher paying jobs in nearby cities. On the other hand, many farmers noted that, as farmers themselves aged, these same high costs of water made it virtually impossible for new farmers to enter the system, Instead, if farmlands remained active following a given family's retirement, it was often due to consolidation into a larger corporate entity's holdings.

Beyond these arguments, however, is an additional layer of concern at what is perceived of as the failure of NISP and similar projects to account for the intangible cultural and ecological values associated with a free flowing river (of which the Cache de la Poudre, the main stream impacted by NISP, is one of the few remaining in the state). In this view, efforts to encourage further development and population growth either ignore or contradict the needs of living ecological systems to maintain function and to experience the intra-annual variation necessary to that function. As one conservation organization director and resident of the area potentially impacted by construction of the main NISP reservoir put it:

> There's a pretense that we can have all the people we want […] Now they're talking about taking this whole valley here and flooding it. Pardon me, but flooding it with what? [..] And then, what happens downstream? We are completely losing track of the fact that downstream life exists, that these streams are in effect living organisms that keep the planet working and the wildlife in place, the livestock growers going, and so on.

Others responding to the suggestion that continuations of status quo ante growth patterns are required for the continued well-being of the region reject it more flatly, noting that unless the character of that growth falls in line with stringent principles of sustainability – largely absent, in their view, from existing growth models and land use patterns – then any growth at all would only be a further entrenchment of what they view as a environmentally deleterious and undesirable way of life. As one long-term grassroots environmental activist put it in response to efforts by developers at the periphery of Fort Collins to acquire access to city water resources to build several hundred homes along the I-25 corridor, the presumption of the need for growth is shortsighted given the global processes of environmental degradation already unfolding:

> I agree it's a good project that the city really wants. What I don't agree with is that we can have the level of growth they are planning and I don't believe it's inevitable we should continue to do business as usual […] What I am currently expecting is that we are on the verge of environmental and (therefore) societal collapse. That may seem radical, but it's really been rolling out for a long time […] how long is it going to take before we need to take radical action, before we can't go back? We're in big trouble NOW. Many things are happening worldwide which are moving us toward the cliff environmentally. Given this reality, creating more densely populated cities is not a priority, in my opinion.

Another sustainability advocate with experience working on various steering committees and development boards put cast their objections less as a matter of priorities than as a question of who actually benefits from growth, noting that it is seldom those who actually already live in an area, (and whom might be better served by investments aimed toward existing service and affordability issues):

> I challenge notions that "growth is inevitable". That is, while of course, continued global population growth will continue to induce some growth here, there are in fact government policies which tend to drive growth beyond "natural" factors such as births over deaths or the natural consequences of displacements (refugees), etc. I'm referring to the policies that are often considered as "economic development", which is driven primarily by a lobby that includes land and water speculators, developers, builders, real estate businesses, and some others who benefit from continual growth. They promote [growth] successfully to many officials, under the guise of "job creation" which is in reality almost never really intended to provide jobs for the existing population, but instead, to draw in more families as potential consumers for real estate and water. This is why the local economic development organizations are almost always made up and driven largely by the above vested interests; and their real goals are about increasing

> demand for their commodities: land, water, houses, apartments, etc. They universally promote subsidies for such "job creation"; and unfortunately, less-sophisticated members of local governments very quickly become believers in what essentially is a variant of "trickle down" theory. That is also why, for example, there is rarely if ever any follow-up accounting for numbers of people employed in an enterprise who were already resident at the time the subsidies are given.

Interestingly, criticisms toward the need for growth were far from limited to those involved in environmental activism and advocacy. Rather, nearly all of those interviewed in this study – even those who, presumably, benefitted directly from economic development and increased foot traffic – held at best ambivalent views of the region's recent growth, noting that alongside whatever cultural and economic benefits that it might bring, the consequences for the region's infrastructure and valued natural systems threatened the undermine the very attractiveness that brings so many people to the state in the first place. As one special district water provider, who himself came to Colorado via a love of kayaking, noted, growth without planning presented almost a dereliction of duty, both on his own part and that of the various communities he serves:

> My board's primary concern is making sure that we're providing reliable, safe, secure, dependable drinking water for our existing customers. While also doing a good job planning for the future and making sure that we don't have our heads in the sand and I mean, growth is going to occur, people will continue to move here, so our mission as an organization is to be ready to serve water. So part of what we do too is plan for the future. [..] We have to plan for additional water use in the future, to do otherwise is irresponsible. It doesn't really matter if you want them to move here or not, or whether water's cheap or expensive, they will continue to move here. So you've got to be ready for that and part of that is to make sure that we've got enough water supply and facilities to get it wheeled around and transported and delivered. If a person would take a no-growth

> attitude and just say, try and prevent growth, it's going to occur anyway, all that's going to happen is you're going to be less prepared for it and you're going to run into an emergency situation later.

As such, his organization, rather than advocating for any specific growth restrictions, instead takes the approach of utilized tiered rate structures to effectively incentivize greater residential and commercial building density – the bigger the lot for a given water customer, the higher per connection and per unit fee they will pay. Similarly, another water provider, while acknowledging that growth is an essential part of the systems in place in the region, she also felt that the time was rapidly approaching where the rgion needed to begin thinking differently about how to control it, noting that a heavy handed approach was as likely to do harm as allowing the status quo to continue:

> I haven't seen a growth control mechanism that I think works well. You look at an Aspen or Boulder, city of Boulder, not necessarily Boulder County, city of Boulder or city of Athens that have adopted strict growth control measures. You end up with horrific income inequality. You end up with your workers having to drive hours to get there or living in substandard houses. When your school teachers cannot even imagine affording to live where it is they teach.[…] I mean, good God.

Instead, she, like her colleague above, advocated for a comprehensive program of demand management, novel mechanisms for incentivizing agricultural water efficiency, and dedication to the protection of open spaces and regional natural assets. As she went on:

> From an ecology perspective, one organism that grows rampant without any control isn't going to be healthy, but I just don't see a good way to control growth that doesn't have even more negative impacts. […] That's why I think the demand management model may actually be a model that we can use in many other situations to improve stream flows and improve environment, improve habitat for the aquatic environment. I think there's things

> we can do. I'm also a big proponent for instead of sitting around and looking at our rivers and wring our hands and saying, "Oh my God, there's not enough water for the fish." How do we fix the stream because most of them have been messed up by our development? How do we fix the streams so that they work better with the water that they've got? So that we're protecting the fish.

That is to say, rather than prohibit and constrain growth, she would argue that making clear, determined strides toward defining and enacting the type of growth you want is what is necessary. Determining what exactly that looks like, however, remains a persistent challenge without the ready ability to understand how different alternatives might play out at various scales – and whether or not said alternatives would be deemed acceptable by the people whose lives they might affect.

But while some may be opposed to growth – and some, merely dubious of its untethered procession - others working in the region hope to develop alternative pathways forward that look past the megastructure-focused strategies of the 20th century while simultaneously fostering a new type of development across the urban-to-rural spectrum of land use. For these actors, new kinds of livelihood- and water-related projects that take a more holistic view of the systems involved could provide an answer to both the region's water supply issues and provide mechanisms for eliding the seemingly zero-sum competition currently underscoring much of the transformation underway within the region's water balance. In a sense, these hybridized forms of land use and development present ways of eliding the sacrifice of one type of land and water use for another by incorporating both into a new form of cultural-environmental operation. However, they are not without challenges, be it in terms of the practical matters of repurposing landscapes and water, or the difficulty of creating new cultural formations within existing networks of value and behavior.

For example, one ecologist, researcher, and advocate of the Cache de la Poudre argued that while he and the organization he is a part of is generally against large dam projects, when considering issues related to flooding, siltation, and invasive plant species – as well as the loss of valued spaces for fishing, rafting, and other forms of river recreation – a more nature based approach could open up new ways of benefiting both humans and the living river system:

> [One] of the most significant experiences I've had my life are standing on the banks and the Blackstone river in the Northwest territories. For one of the first times in my life, seeing, just being completely absorbed in a system that was free of alterations. There were no dams, there were no diversions, there were no mines upstream, nothing else. It was just ecosystem process at work. It was so amazing. It was so beautiful. And that just had a big influence on me.
>
> And of course we can't recreate that, but we can restore the Poudre in the South Platte in Colorado, back to some point where those processes take hold more than they are now, and influence the system in ways that can have so many benefits beyond just satisfying my own personal needs; that can have co-benefits for a lot of places.

As part of this effort, he and others in the environmental advocacy community have worked alongside Fort Collins city staff to develop a novel concept for river restoration and development in the city, one that incorporates recreational facilities and riverbed restoration in the form of the Poudre Whitewater Park, located near the city's downtown area. As a result, this project has channeled funds to address long-standing flood risk issues in the area while simultaneously protecting river function and increasing the attractiveness of the area for the town's many tourism-dependent businesses. Perhaps more importantly, it has established a model for future ecologically sound "recreational diversions" within the state's water law system, serving as a tangible example for the area's other growing cities – many of which are increasingly looking for financially viable ways of simultaneously improving river recreational values and mitigating flood risk, and restoring function to silt-locked and otherwise degraded streambeds.

The desire to resolve the tension between a value system and way of life that venerates the intrinsic, natural qualities of river systems with the needs of human populations was echoed by the experiences of another participant in the study, whose livelihood was based in fishing guide work near Estes Park. Though it was, of course, a fundamentally economic activity dependent upon tourist traffic, he experienced his work on and with the river as an almost spiritual vocation, in which the river served as a gateway to something larger and more meaningful than the more mundane dimensions of his life. As he put it:

> The three biggest things I think a river can provide for everybody, both fishing guides and the community in general are, one: stability. Two, it's almost like a church. I don't know if you've ever sat there, and you just understand what it does for the soul. Then three, […] escape. […] I thought at first it was that I just liked catching fish, but I've come to realize that's not why I'm fishing. I'm fishing for greater reasons than I can understand, and I think the biggest one is that I am trying to understand and really get connected with what created us in the first place.

As a result, he voiced deep concern, both about continued demand for diversions from streams for continued growth and for agricultural purposes. Nevertheless, he noted that it was possible to find ways to build dams and other diversion structures while accommodating fish migration, such as through fish ladders or side streams, which provide passageways for fish to move upstream past impediments during spawning season. That is to say, if carefully planned in ways that center ecological needs, even large infrastructure projects might be acceptable – even if, truly, he might prefer the river be let alone.

Leveraging the common interests found at the confluence of pro-environmental value systems, recreational economies, a desire for nature-based amenities, and the practical concerns of river restoration and flood risk mitigation, projects like the Poudre Whitewater Park thus point towards a space of fruitful compromise with significant potential for accommodating the needs of both human and natural systems. And they are far from unique: throughout the basin, multiple projects are underway or are already complete that attempt to address multiple levels of concern relating to hydrological dynamics such as flood risk and stormwater management while also delivering recreational and environmental benefits. Examples of this include the High Line Canal Conservancy's on-going work to integrate ecologically functional vegetated floodplain management techniques into the on-going maintenance plan of the High Line Canal, which stretches across 67 miles of the Denver Metropolitan area and historically served agricultural and municipal water supplies in the region. Currently subject to overflows during intense storms, the proposed project would convert the canal into a complex network of flood control greenways and recreational areas, which would simultaneously provide improved animal movement corridors and water delivery capacity. Similar projects can also be found in Loveland, Longmont, and Greeley, operating through watershed level planning processes, county coordination, and collaborations with the Army Corp of Engineers, all of which seem to point to the easy synergy of naturally-designed flood mitigation, recreational amenities, and environmental improvement.

The effort to integrate the needs of communities and natural systems – and to do so in ways that mitigate the risks faced by both – goes beyond the stormwater and infrastructure challenges of large cities. As detailed in other research in the region, the last several decades have seen a marked proliferation in the formation of collaborative conservation organizations of varied types aimed at working across organizational and community boundaries to address wildlife, streamflow, or other environmental issues in a cooperative, locally-driven manner (Huayhuaca and Reid, 2019). Operating at diverse levels (i.e., watershed-, basin-, region-, and statewide scales), these organizations engage in a wide range of activities centered around maintaining collaborative networks, knowledge generation and dissemination, community engagement through outreach and education, project planning, and on-the-ground restoration (ibid.).

In practical terms, this most often involves the going to those with a direct interest in river function, such as private land owners in the wildland urban interface, federal lands agencies, municipalities, downstream farmers and ranchers, or water utilities, and developing or finding ways to bring them together to identify shared problems that can be resolved through restoration of river function, watershed management, or other manipulations of surface hydrology. As part of this, they rely upon three key forms of expertise: first, they must be sensitive to and knowledgeable about the various value orientations and desires of the various community actors and organizations they work with. Second, they must be able to develop and implement solutions based in sound ecological and hydrological science, and, in the case of organizations involved in on-the-ground work, the practical skills of river and watershed management. Third, and perhaps most importantly, they must be able to overcome any existing conflicts and misunderstandings in a manner that communicates a clear and desirable vision for the future state of the system in question – in essence, creating cultural networks of valuation and behavior that translate into the long-term maintenance of new forms of living with, using, and maintain rivers.

This works best, it seems, in areas where existing cultural value systems already align in many ways with the needs of ecosystem or stream restoration. For example, in mountain communities with homes near headwaters streams, people may already place significant value on the functioning of river systems, fishing opportunities, wildlife habitat, and various other stream health-related aspects of where they live. Similarly, in cities, desires to minimize flood risk and maximize recreational and environmental amenities also lend themselves well to river-related restoration and conservation projects, given that funding can be secured and the oft-considerable process of gaining community support can be accomplished. As those involved in conservation or restoration work noted, however, these processes all rely fundamentally upon a foundation of trust, both in the participants and experts involved as well as the viability of the proposed intervention or solution to meet the needs of the various interested parties. Where this trust is absent, it must be built; where it is hard won because of property rights implications, feelings of unfairness, or general doubt about the viability of what is being proposed, it is unlikely that work will go forward without considerable efforts by all parties involved.

It is perhaps for this reason that efforts to hybridize environmental protection and agricultural systems in the same manner seen with mountain communities and cities have not been as widespread. Although many conservation organizations are indeed working with farmers and ranchers on issues of landscape conservation, these programs generally take the form of traditional conservation easements, which remove portions of land from agricultural or ranching use for wildlife habitat purposes. Perhaps more visible, then, have been efforts to split the difference between agricultural and urban land uses, either through the accommodation of agricultural operations within city limits (such as in the case of small scale greenhouses in the marijuana industry, community-supported agriculture operations, and numerous small, direct-sales farms), leased-water operations at the urban fringe, agricultural protection measures (such as those undertaken in Weld County that restrict zoning changes or nuisance complaints from impinging upon certain agricultural activity), or, as has been proposed in Fort Collins, building new developments with working farmland at its core. The latter case, dubbed Montava, is currently under preliminary development review, but would involve a mixed use development of over 3,900 living units as well as roughly forty acres of professionally farmed land, built over a former barley field once utilized for beer production. Due to salination issues related to the underlying water rights associated with these lands, however, work is underway – with some protest from local environmental groups opposed to the additional population growth and infrastructure strain – to transfer either treated or non-potable City of Fort Collins water to the site, as well as to acquire potable water for the development's prospective future residents (Marmaduke 2019; Ferrier 2020). At the time of this writing, it remains unclear whether this will go forward as planned. However, what it signifies is one of the few instances in the region where substantial agricultural production has been incorporated into what would otherwise be a simple land use conversion from farmland to housing. More importantly, it speaks to the deep tension, yet to be resolved, between the region's high valuation of local agricultural production, its ambivalent dependence upon continued growth, and the challenge of finding affordable water for innovative practices.

Attempting to summarize, then: what emerges from the interviews conducted in this study and observation of the water-related discourse of the region is a complex picture, one in which the value systems centered upon diverse – and sometimes, coextensive – viewpoints find themselves suspended within networks of historical water and land use, powerful economic imperatives for growth, and deep uncertainty surrounding what it means to live a fulfilled life within a system defined by both natural and socially-created limits on water availability. At the intersections of these diverse value systems, practical concerns related to water delivery, water quality, and the aggregate effects of water reuse provide some degree of empirical framing for the path forward, albeit only to the degree that they limit the viability of certain solutions and preference the maintenance of tried-and-true methods – even if, as is the case in rural communities, those very solutions face insults from broader contextual factors. Compromise – or, rather, innovation – is also highly evident, occurring most prominently where multiple distinct value systems can converge upon a particular site and thereby marshal the financial and social capitals necessary to endure the long process of water project planning and development. Put in a more formulaic manner, water related projects are generally unlikely to proceed from imagination into reality without significant buy in from multiple actors within web of actors surrounding water resources, even when substantial practical or economic gains might lay in wait. At the same time, however, even those projects that promise to meet the ideals and cultural demands of a wide variety of diverse groups may also fail to coalesce as finalized constructions, if practical matters of water distribution are not accounted for, both hydrologically and economically. That is, for a given socio-hydrological formation to come to life, so to speak, it must be animated by systems that answer to the multiple levels of value that it impinges upon, which, in the case of the South Platte, seems to represent an increasingly tight design space, particularly given that it must then go on to live in a world where natural variability and extreme events are increasingly commonplace. As the next section will explore, this vulnerability has different meanings, depending on the specific purpose or purposes of the system in question, as water, along with its benefits, also brings with it distinct risks, be it in its overabundance, its scarcity, or in its ability to connect distant actors and their actions in a complex system.

Water as Hazard and as a Vector of Harm

For participants in this study, water was mainly discussed in terms of what it could provide – i.e., the various benefits, both tangible and intangible, of its use, and of securing access to water supplies adequate to current and future needs. When conversations shifted towards water-related risks such as drought, flooding, and pollution, initial responses often tended to focus on the relatively benign conditions occurring at the time, as 2019 proved to be a relatively comfortable year for the basin in terms of both overall precipitation, winter snowpack, and its altogether quiescent wildfire season. Some, having only come to the region in the last several years, had not been present for the intense droughts of 2002-2004 and 2012-2013, and had not seen the worst of the area's 2013 floods. For those that had – or whose prior work had brought them face to face with the risks inherent in water systems – the risks of water use and management elicited a variety of responses, both in terms of the damages the region's hydrological hazards represented to them and the surprising opportunities they bring with them. In this section, I will go over the general outlines of three particular types of hazard scenario: droughts, floods, and pollution, as well as their inflections along the lines of the varied perspectives encountered in this study.

Drought

What it means to not have enough water is always relative to the nature of the needs in question. As a region, the South Platte Basin in Colorado has been subject to a number of major hydrological droughts over the last century, with some of the worst coming in the last two decades, as precipitation in the form of snow and rain both have generally fallen well below historical averages in combination with steadily increasing average and extreme high temperatures. Owing in no small part to the basin's extensively developed water management infrastructure, these droughts have not resulted in the sort of absolute water scarcity that might impinge upon human health directly. However, for ecosystems, agricultural operations, water providers, recreational businesses, and other large water users, it has prompted an array of responses.

In agriculture, drought can manifest both locally and through the networked connections of the water rights system, as senior rights holders place calls on junior diverters due to insufficient flows. In both cases, available water for irrigation is reduced, generally at the same time as supplementary natural precipitation is also limited, and high temperatures drive upward plant evaporative demand. Similarly livestock operations – most of which rely upon groundwater for stock

Table 5 - Drought Impacts and Responses

Viewpoint	Drought Impacts and Responses
Farming, Ranching, and Alternative Agricultural Systems	• Can result in reduced soil water availability, reduced availability or feasibility of diversions, and reduced function of plants. • Reduced livestock condition, health, protein uptake, and overall ranch productivity. • Dynamically increases buy-and-dry phenomena, through increased risk aversion from cities, increased demand for ag water, and increased financial stress on farms • May result in negative impacts to farmer and farmer worker health, both mental and physical.
Municipal Governments and Water Providers	• Junior water rights holders may face curtailment • Reservoir levels may fall; in extreme cases, threatening viability of infrastructure or hydroelectric generation capacity • May require curtailment of certain water uses, e.g. landscape irrigation • Can drive wildfire and post-wildfire runoff contamination w/ implications for treatment • Can increase feeling of scarcity; drive up cost of water rights acquisition due to induced competition • Increases opportunities for demand management and xeriscaping conversion.
Industrial Users	• May increase cost of water, increase treatment needs, or interrupt supplies. • May result in disruptions to process water due to high temperatures or low flows. • May result in increased concerns relating to return water contamination due to reduced dilution capacity as a result of low flows.
Residential, Commercial, and Other Non-Industrial Consumers	• May result in outdoor irrigation bans or restrictions that lead to degradation of certain landscape systems. • Increased risks from wildfire, dust, poor air quality, and other similar secondary hazards, as well as post-wildfire flash-flooding. • In communities with junior rights, may halt or otherwise impair development projects meant to increase community service provisioning.
River Recreation Businesses (esp. Angling and Rafting Guides)	• Low river flows associated with drought can preclude many river recreation activities. • High water temperatures correlated with drought episodes can increase fish mortality and result in voluntary or mandatory closures of areas with heat-sensitive fish populations. • Wildfire activity can reduce visitation and inhibit recreational activity access. • Post-wildfire runoff can result in fish die-off and contamination of critical fish habitat for spawning.
Environmental Protection, Restoration, and Advocacy	• Can be important periods for messaging on the need for water conservation and watershed restoration due to increased salience of water scarcity. • Post-wildfire recovery periods can serve as a important time for coalition building and collaboration on forest-to-watershed restoration projects. • Negative impacts to communities following wildfires and other drought impacts can hinder participation in programs; reduce community capital for involvement in projects.

tanks and other sources of animal water consumptive use – also face a multiple bind scenario, as both water demand from livestock and feed costs both rise, often just as livestock prices fall as operators reduce their herd sizes through sell-offs. What emerges, in both scenarios, is thus an increasingly precarious situation, in which both pressure from yearly operating costs and debts have the potential to combine to drive operators out of the industry – potentially selling off water rights – or to find themselves suffering from insults to their mental and physical health due to increased workloads, increased exposure to high temperatures, and increased stress. In order to get through, irrigators may reduce irrigation globally across their fields, leave portions of their lands in fallow, convert to less thirsty crop types, or purchase water (often at high cost) from other water rights holders. For those operators who are able to weather the drought, however, it can mean an opportunity to expand operations into lands that have exited the industry, with the potential to increase operational resilience over the long term through strategies of land distribution and the expansion of water rights portfolios.

Water scarcity can also impose itself upon agriculture through changes in water governance, such as has been seen following the Empire Lodge case in the early 2000s, which resulting in alterations to the ways in which groundwater wells were managed and their extractions from the alluvial aquifer were augmented. As a result, hundreds of wells in the region were forced to shut down following a failure to acquire and adjudicate sufficient augmentation supplies (usually acquired through surface diversions and stored in augmentation ponds), resulting in substantial dry-up of agricultural and ranching lands. Water scarcity is also felt via the increasingly high cost of water, meaning that those attempting to enter agriculture must bring substantial capital to the table to do so, even if they are able to identify suitable lands and infrastructure. It is perhaps for this reason that although population and, thereby, food demand are likely to grow – and, if trends continue, residents are going to continue wishing that said food was locally grown – there is no expectation that agricultural operations will expand in the future, save perhaps through innovative, extremely water-efficient models within urban areas.

Indeed, if there is one major impact to the availability of water during drought periods that goes beyond natural decreases in precipitation, it is the ways in which municipal and industrial users – specifically, water providers – have responded to major drought episodes. Although buffered substantially compared to land-based livelihoods, cities looking to ensure constant reliability and surplus water supplies responded to the droughts in the early part of the century through both efforts to reduce population per capita demand at the same time as they sought out as many convertible water rights as they could acquire. Although not all cities were able to take this latter route, due mainly to the high costs associated with doing so, the former, demand management, has become a widespread strategy in the region. This includes both efforts to reduce indoor water use through the installation (at time mandatory and/or subsidized) of low-flow fixtures, toilets, and similar devices. Many of the area's larger water providers have also undertaken significant campaigns to promote xeriscaping, i.e., landscaping with native drought resistant plants, as a means of reducing the roughly 50% of their water demand that stems from outdoor irrigation. As a result, water providers and urban decision-makers involved in this study often saw drought periods as a critical time for communication and outreach to their citizens/customers. In some cases, this also involved the imposition of outdoor water use restrictions of varying types. Increasing the cost of delivered water, either generally or through tiered rate structures that scale upwards as total water use follows suit, were also strategies discussed. In areas reliant upon groundwater resources, and thus inured from normal drought cycles but faced with a sort of absolute scarcity due to the non-renewable nature of these water supplies had also led to raises in water prices as a strategy to mitigate over-use, the execution of which often required extensive outreach and communication with customers wondering why their rates were so high compared to the region as a whole.

Cities and industry may also be impacted during drought through the environmental conditions they induce in upland watersheds, especially in cases where high temperatures and dry conditions result in wildfire. In addition to direct damages from the fires themselves, accumulations of ash, debris, and the resultingly barren slopes that follow from intense wildfire can result in heightened contamination of normally pristine water sources. This can result in increased pre-use treatment costs, damage to existing treatment infrastructure, or, in the cases of specialized industries where water quality concerns are acute, the need to acquire alternative water supplies. This is especially evident in the food processing industry, where water often comprises a significant amount of the final product, e.g., in beer brewing. Drought conditions can also influence water temperatures – which in turn drive up its holding capacity for various contaminants and dissolved solids – further rendering them less suitable for both consumptive and non-consumptive use, such as in the cooling of thermoelectric turbines or manufacturing equipment. Similarly, low surface water flows associated with drought can also have impacts on how industrial and municipal systems deal with contaminants, as in many cases these systems rely upon the dilution provided by stream water to maintain contaminant levels below certain thresholds. When contaminant introduction rates stay the same, but water levels are reduced, the toxicity and other impacts associated with different contamination sources become more acutely felt, both by the biological systems in question, and thereby, the risk of regulatory scrutiny from state and federal environmental protection agencies.

River recreation businesses and the outdoor tourism industry as a whole can also face severe negative impacts during drought episodes, both directly and as a result of associated wildfire conditions. Although winter runoff is usually sufficient for early season rafting even in drought years, as river levels fall the suitability of upper watershed streams for river activity rapidly falls off. On the other hand, if temperatures rise too quickly in the early spring, and runoff becomes too intense, conditions may be plentiful but too dangerous for the sort of guided rafting activity that forms the core of most rafting businesses. For fishing guides, low streams levels and attendant high water temperatures can create grim conditions for fish populations, prompting both reduced activity overall and, in some cases, voluntary closures of traditional fishing areas. In both cases, wildfires can compound the effects of drought, both through the fear they induce in potential visitors as well as the potential for the creation of unsafe river conditions. Ash and particulate infiltration following wildfires can cause significant fish die-offs and otherwise impair habitat in the periods following drought, further stressing systems as they might otherwise be on the rebound.

It is in no small part because of these environmental insults and the often highly visible impacts of wildfires that drought periods represent a time of significant opportunity for environmental advocacy efforts and for efforts to restore human-altered watersheds and river segments. In some cases, restoration and advocacy groups can provide essential services to communities impacted by wildfires, and new organizations may emerge from community efforts to restore forest conditions, bring about new management regimes, or to restore specific segments of forest-river interface areas. At the same time, however, environmental advocacy groups must also contend with the increased salience of regional water scarcity that comes along with drought episodes, which can often lead to greater support within the general population and within high water use sectors for the expansion of large scale water storage or redirection projects, most of which are generally regarded as having negative environmental impacts.

Flooding and Extreme Precipitation Events

The South Platte Basin's highly variable climate brings with it the periodic risk of extreme precipitation events, be they in the form of intense blizzards, sudden, powerful rainstorms, or, more rarely, long-duration intense rainfall episodes caused by the interaction of multiple continental-scale weather phenomena. Further, because floods, as a hazardous phenomenon, require both excess quantities of water and valued assets within its path – i.e., are to a certain degree, socially constructed – and are often further influenced by the region's extensively managed and infrastructurally-

Table 6 - Flood Impacts and Responses

Viewpoint	Flood Impacts and Responses
Farming, Ranching, and Alternative Agricultural Systems	• Damage to homes, crops, field preparation, soils, irrigation equipment, ditches, fences, wells, etc. • In moderate cases, can complicate planting, harvest, and other seasonally-timed work. • May introduce contaminants from sewage, industrial, or other upstream actors. • Livestock loss and/or increased livestock disease • Risk to life and property
Municipal Governments and Water Providers	• Damage to homes, businesses, infrastructure, public facilities, parks, and other value locations. • Damage to stream beds, shorelines, and other recreational areas. • Damage to roads and other transportation infrastructure. • Damage to treatment facilities; both direct and through overwhelming treatment burden • Contamination of water supplies
Industrial Users	• Damage to facilities and infrastructure. • Damage to transportation networks; supply chain interruption. • Contamination of process water or component water sources. • Disruption of the lives of employees, from commuting challenges to loss of life.
Residential, Commercial, and Other Non-Industrial Consumers	• Risks to lives, property, and disruption of critical services. • Loss of property value or changes in flood zone designation following extreme flood events. In some cases, entire neighborhoods may be destroyed and re-zoned. • Parks, riverbanks, and other outdoor amenities may be damaged or dramatically altered.
River Recreation Businesses (esp. Angling and Rafting Guides)	• Periodic high flows and riverbed restructuring can be critical to fish habitat formation and ecosystem health. • Extreme flood events can result in river closures, damage to river access locations, and introduction of pollutants and debris into streams, hindering both angling and rafting activity. • Extreme high flows can make activity more hazardous than expected.
Environmental Protection, Restoration, and Advocacy	• Functioning ecosystems require periodic high flow periods and associated hydrological effects (scouring, river bed movement). • May represent opportunities for coalition building and collaboration for streambed restoration in the post-flood period. • May reduce capital capacity of residents, volunteers, and donors in extreme cases.

manipulated river channels, legacies of land use and water management can play a central role in determining the salience and severity of a given flood episode to a great degree. That said, as with drought, the impacts of resulting floods can take on different characteristics depending upon the type of system impacted. Likewise, in addition to their obvious negative impacts on lives, property, and the orderly expectations placed upon water systems, they can present significant opportunities for improved resilience and change, given the right circumstances.

For those who concern themselves primarily with the wellbeing of the basin's river ecosystems, for example, periodic extreme flow scenarios are actually a critically important factor in natural stream evolution, carving out fresh pathways for water flows and creating a diversity of aquatic habitat along a given reach that can be critical for various forms of aquatic species' lifecycles. At the same time, periodic shocks to streambank plant life and disturbance of bank configuration present opportunities for natural secession processes to occur. In areas that have been intensively developed, and which are often overtaken by invasive phreatophytes, the post-flood period can also be an important phase for awareness raising and coalition building around streambank restoration, as ecologically functional streambeds often have the capacity to mitigate damage to nearby property and homes. Post-flood recovery periods can also be opportune times to advocate for the replacement of grey infrastructure – i.e., concrete or other human-made stream control infrastructure – in favor of green infrastructure, such as artificial wetlands and riparian zones, which have the dual benefit of reducing the risk of flood-related losses and provide important wildlife habitat services. However, as is the case for all those living or working nearby flood-prone areas, the risk of contamination from sewage, chemical storage sites, or man-made debris can seriously degrade existing river habitat areas. Further, if floods are particularly destructive for surrounding communities, residents and governments may be too cash- and energy deprived to engage with restoration or other environmentally focused work.

Along these same lines, river recreation businesses require, to a certain degree, that natural periods of high flows and river-bed disturbance take place, as it is through the heterogeneity created by natural stream evolution processes that their livelihoods have a substrate upon which to build. Both in rafting and in fishing, a diversity of stream characteristics is important for the overall conduct of work. However, extreme high flows can cause damage to critical infrastructure – such as boat ramps, jetties, or river access roads, and may also create on-river conditions that are far too dangerous for normal activity. In more severe, regional flooding events – such as the 2013 flood – access to specific stream reaches may be closed for years due to road damage and the significant challenges of high elevation, stream-adjacent roadway repair.

For those who live near rivers and within flood zones, the experience of flood events is generally experienced as a negative phenomena, at best a nuisance, and worst, an existential threat. In many areas of the basin, peri-urban and exurban communities stretch towards the small handful of mountain towns in tight ribbons around natural streambeds, as proximity to rivers bears substantial aesthetic benefits. Likewise, because most of the roadways into and out of the mountains follow along streams, these areas were simply those where ground was flat enough or accessible enough for construction to occur. As a result, during major flood episodes homes and property can find themselves both under threat of the flood itself and at risk of being systemic devalued as county governments decide to limit reconstruction in these areas, or flood insurance rates climb so high as to make rebuilding credit unattainable. Within more densely developed urban areas, immediate risks to lives and homes have been severe in some cases, and have brought with them similar condemnations and re-zoning in the recovery phase that aim to preclude the possibility of future flood events from destroying homes or placing lives at risk. In some cases, this has come in the form of flood mitigation zones that serve as parks or naturalized areas. In others, where resources are scarce or resistance to re-zoning is strong, redevelopment into floodplains takes a "hardening," rather than retreat approach, with berms or levees put in place in an attempt to stave off future flood waters.

For municipal governments and water providers, flood events also represent both a serious risk as well as a chance for renewal, with capital reserves and forward-thinking planning often determining if the former can transition to the latter. As floods occur, introduced debris and surface contamination from areas adjacent to rivers can seriously strain or damage water treatment and sewage infrastructure, interrupt water service, or result in secondary flooding within homes and businesses. As a result, extensive capital outlays may be required to recover, likely during a time when transportation and other infrastructure are also in need of repair. Though in the past federal and state-level assistance programs have been able to cover some of this need, application and accounting processes associated with such funds are often taxing in and of themselves, which can position well-resourced cities more favorably in terms of receiving aid in a timely manner. However, if funds, expertise, and plans are in place, post-flood episodes can yield systems more capable of ignoring or rebounding from extreme high flow periods, either through the improvement of existing infrastructure or the adoption of green flood mitigation measures such as those described above.

Industrial water users also face a similar combination of risks to on-site facilities, staff, and property, but also face risks associated with networked connections to both critical supply lines and the need for regular delivery of process water. Given that many rely upon municipal water systems, or diversions that can be impacted by numerous types of upstream users, flood damage to infrastructure or contamination of input water can represent costly setbacks. This is especially acute, as with post-wildfire contamination, for the region's beer brewing sector, which often has stringent input water requirements. In addition to various logistic concerns, industrial water users might also face disruptions in the lives and health of their employees, as well as transportation-related hindrances for workers. Just the same, post-flood recovery periods can be an opportunity for positive image building, either through philanthropic giving, direct aid in the response phase, or support for recovery organizations over the long term.

In industries where hazardous chemicals are involved, floods can also represent a serious liability, both to processes and to public image. This has been especially true for the oil and gas industry in the region, which often operates via widely dispersed networks of above ground product and waste storage facilities, many of which are well within flood plains. As occurred following the 2013 floods, these facilities can be completely destroyed under relatively minimal flooding conditions, causing infrastructure to become unmoored, contaminants to leak into surrounding waterways, and thereby, provide significant fuel for the various activist groups working to limit or ban such activities.

For irrigation companies serving agricultural areas, floods can also present a serious risk, as many operate aging infrastructure that is easily overwhelmed, clogged with debris, or damaged by flood waters, prompting the need for rapid repairs in order to maintain diversions for users and to maintain propriety within the water rights system. Farmers may also be directly impacted, particularly if flood strike late in the growing season, as contamination from upstream sewage, surface contaminants, and other pollutants can both damage crops and render them unfit for sale. However, during the recovery phase, irrigation companies may be able to gain access to funds necessary for the updating of infrastructure, with the potential for improving delivery efficiency and safety. Ranches adjacent to waterways or within larger floodplains – particularly in areas east of the South Platte confluence past Greeley – may experience significant direct impacts from flooding, as stock ponds and other water sources become fouled, cattle are exposed to contaminants, and moist soil conditions lend themselves to the development of livestock disease. Much as with other industrial operations, post-flood contamination of surrounding waters via influx of cattle and other livestock waste is also a concern and may cause damage to nearby agricultural soils.

Pollution

In addition to the discussion of wildfire, flood, or drought driven contamination processes described above, several other important dimensions of the pollutant risk profile in the region emerged, both through discussions and through secondary research. Due to the extensive nature of human alteration in the basin, as well as the intensive patterns of water reuse across a variety of systems, potential avenues for water contamination bring with them a number of challenges, both to water treatment facilities and the overall wellbeing of the humans, animals, and plant communities that comprise its socio-ecology. Though a full accounting for the complex interconnectivity that link together water contaminants in the region is well beyond both my expertise and the scope of this document, several key issues come to the fore.

First among these is that in both conversations with water managers, in public settings surrounding water, and in informal conversations about water that took place during this research, the salience of potential water contamination was present in nearly every location. Most notable in this mix was the concern, held by a significant number of those involved in environmental advocacy or conservation work, that the booming oil and gas industry – now, due to economic factors related to COVID-19 and continued transition away from historical demand for oil and gas – represents an existential threat to groundwater and surface supplies, as well as to the overall health of communities through factors related to air pollution, noise pollution, dust production, and the long-term legacies of the several thousand small fracking facilities found throughout the region. This narrative was present in local media coverage, in academic settings, and could be heard in nearly every public

Table 7 - Pollution Impacts and Responses

Viewpoint	Pollution Impacts and Responses
Farming, Ranching, and Alternative Agricultural Systems	• Can result in irrigation water quality degrading beyond usability • If farm is the source of pollution, can result in increased regulatory burden
Municipal Governments and Water Providers	• Development must be managed to minimize pollution burdens on treatment facilities and infrastructure. • Risks to public image, trust of citizens, and trust of businesses from perceived or actual water pollution can be grave. • Pollutant knowledge, monitoring, and mitigation must be continuously developed.
Industrial Users	• Low flows may hinder effort to utilize dilution as means of externalizing by-products. • Pollutants in input water can preclude their use in many processes, prompting need to purchase, haul, or otherwise replace supplies. • Pollutant releases in excess of acceptable amounts can impact profitability of operations; harm public image; increase long-term regulatory burdens.
Residential, Commercial, and Other Non-Industrial Consumers	• Contamination of household water can prompt excessive costs of in-home treatment or relocation; home abandonment. • Perceptions of water supply contamination can reduce property values. • Improper waste and land management can lead to visible contamination from garbage as well as other forms of contamination from surface runoff or human waste.
River Recreation Businesses (esp. Angling and Rafting Guides)	• River contamination from agricultural, industrial, natural, or other sources can create unsafe conditions for recreation and negatively impact the attractiveness of rivers to visitors. • May also result in aquatic habitat impairment, resulting in declining wildlife health and fish die-offs. • Over-use of recreational areas and poor waste management can lead to unsightly conditions and direct contamination of water from human waste, garbage, and other materials.
Environmental Protection, Restoration, and Advocacy	• Contamination of aquatic ecosystems and watersheds from industrial, municipal, or other sources can undo previous restoration work, or prohibit future work. • Few organizations are capable of industrial clean up; costs are higher where pollution legacies are present. However, may also serve as a focusing point for collaboration and coalition building. • Salience of water quality and the visceral reaction prompted by water contamination is seen as a viable communication avenue for groups focused on industrial regulation, esp. re: Oil and gas extraction.

venue related to water. Though industry representatives and overall communications strategies often voiced the safety of oil and gas extraction practices, and the inherent obviation of potential groundwater contamination concerns due to the nature of how drilling activities occur, these were held by many to be largely public relations fodder. As such, though the particulars of water contamination by oil and gas process water ponds, surface tanks, and drilling activities continue to face both scientific and cultural scrutiny, it is likely to continue to be a flashpoint in water contamination discussions for some time to come. This is especially true given the seeming fact that many oil and gas wells are currently being actively abandoned, leaving an uncertain – and for many, unsettling – land use legacy across significant portions of the basin.

The high standard of quality to which residents and other water users held water providers was also possible to observe casually in a variety of settings, as the region's generally extremely high water quality standards were nevertheless not sufficient for many households. Whether due to local infrastructure issues or merely personal tastes, secondary filtration systems are a common sight in many homes, particularly those within Front Range cities. In areas where small scale groundwater was the main source of drinking water, resident concerns about taste and potential mineral contaminants were also a surprisingly common topic of discussion, particularly in homes where small-scale gardening or other minor agricultural production was a part of the household culture. How widespread these deep concerns about water quality truly are is a matter to be left to a more systematic study. However, what they potentially underscore is the serious task put before municipal water providers when it comes to ensuring water quality of the highest standard. On the other hand, for those in the agricultural and industrial sectors, concerns about water contamination from point and non-point source pollutants within the general population also have the potential to continue to shape their place within the region's rapidly changing communities. In addition to concerns about regulation at the federal level – perhaps, for the moment, largely abated due to executive largesse surrounding such issues – state level mandates surrounding water quality continue to evolve, and seem to have a substantial degree of support from residents of the area.

What this points to, then, is a need for continued development of water quality monitoring systems, both in terms of the technical apparatus necessary for detecting different pollutants as well as the need for further cultural development within the broader population regarding pollutant risks and their dynamics within the basin as a whole.

Discussion

Throughout the process of this research, what has been perhaps most evident when addressing the values and concepts that are set in motion when engaging in conversations about water resources in the Colorado South Platte Basin is that they are not, in fact, about the South Platte Basin itself. Though the South Platte portion of Division 1 of the State Engineer's Office is a widely recognized category, and likewise, the hydrologic basin that comprises the physical drainage area of the South Platte River and its tributaries is, at least in the abstract, a recognized term, it does not hold any deeper meaning to those who live within it, and does not exist as any sort of identifying marker of who they are, or where they are from. Granted, those who enjoy fishing in the streams east of Kersey and the South Platte River confluence, or who live along the Upper South Platte's headwaters reaches in Park County may associate fond memories with the name, it is, at best, a feature of the places it passes through. In mountain communities, where life is often tightly woven alongside the banks of the river system's tributaries, community identity and, increasingly, collaborative action are indeed tied closely to streams, but these areas are the exception to the general rule. Rather, for most within the basin, identity is bound mainly to the communities in which they live or live nearby, a characteristic particularly prominent in those who, having only just come to the area in the last several years, may not even know the names of the rivers upon which they rely each day.

This is not to say that knowledge about water – be it as an asset, as a physical thing, as a lodestone of emotion and identity, or as the substrate of a vast network of interdependent living things – is not deep within the minds of many of its residents. Whether it is the particulars of a given shallow groundwater well's problematic iron content, the history of the region's expansive legacy of water infrastructure development, or the specific contours of a given stretch of headwaters stream, conversations of the sort engaged in over the course of this project could amount, on their own, to whole case studies in human-hydrological connection and meaning making. Though what I have presented here is, in a sense, "an inch deep and a mile wide" in comparison, what nevertheless rings through throughout all of it has been that, despite the individual depth of a given actor's relationship with water, the system as a whole is at best understood in the most superficial manner. As one early participant put it (in not quite so many words, but nevertheless in a way that would influence many of the conversations to come): the basin as a whole has no unified identity, and for that, it cannot develop a common vision of itself as an interconnected system. That is to say, if the Colorado South Platte Basin is to be thought of as a 'thing', or rather, as a unified socio-hydro-ecological system, it must be thought of as something whose existence comes about in an emergent fashion, with its various communities, counties, and innumerable iterations of organization in between operating in a self-motivated fashion – at times heedless of what is around, and at others, highly self-conscious – to produce the ends and outcomes that they individually desire. If it is unified at all, either through the Colorado Water Conservation Board, the South Platte Basin Roundtable, the Office of the State Engineer, the State of Colorado, the minimalist-yet-convoluted system of Water Law, or merely the dictates of global capitalism, its unity seems to emerge only for the sake of no alternative system having arisen. That its fundamental characteristics of climate, topography, ecology, and hydrology have yet to emerge as a unifying web of meaning despite quite literally tying together the entirety of its well-being is a testament both to the vastness and complexity of these systems, and the narrowness through which most of us find ourselves carrying out or experience of them.

It is perhaps unsurprising, then, that among the most common replies to questions about what the scientific and scholarly community could do to assist water decision-making community in their work was develop some means to bring the complexity of the basin's water systems into clearer relief; that is, to help people within the region to understand the systems they are a part of, and to see them for all their complexity. As this project has hopefully demonstrated, however, such a task would likely require a degree of interdisciplinary expertise, sensitivity, and depth of knowledge that as yet has no match in either the water management literature, the broader literature on socio-ecological system dynamics, or the extensive work being undertaken by a phalanx of consultants and technical experts working within the South Platte Basin itself. Though this project has attempted to lay some of the foundation that might be required for such work, where it goes from here will be a question as much of the assumptions behind what "knowing the basin as a system" means as it is one of which methods and aspects need to be emphasized in order to do so. More importantly, given the dramatic processes of change taking place across the basin, the questions of "what the basin is" might be less important than one of "what do we want the basin to be?"

What the literature on human-water interactions puts forth are, roughly speaking, two distinct paths forward for these questions: on one side, the socio-hydrological approach would advocate for what might be termed a top-down approach – one in which the physical and technical dimensions of the basin and its numerous systems are laid out for learners in a programmatic fashion, and the interactions between human decision-making and water supply and quality outcomes are tied together in a systematic and generalizable way (e.g., Sivapalan et al. 2012; Di

Baldasare et al. 2013). To this end, the extensive work undertaken at the state level by the Department of Natural Resources and the Colorado Decision Support System, along with various other spatial and statistical datasets (such as those relied upon in the Study Context section, above) would form at least part of the basis of a historical analysis of the region, its people, and the various high-level policy levers that could be brought to bear upon the co-evolutionary processes of climatic, hydrologic, and social change that will determine its future. Indeed, significant work in this vein already seems underway, most notably within the scenario planning-based model utilized within the CWCB's work to update statewide supply shortage analyses within the South Platte Basin Implementation Plan. This work, based on significant community outreach and iteration, revolves around five distinct future scenarios, each of which is quantitatively expressed in terms of water supply and demand, varied potential impacts climate change, diverse population growth trajectories, and a mix of economic dynamics related to agricultural and industrial development trends (CWCB 2019). Similarly, the Future Avoided Costs Explorer, developed by various state agencies and consultants at Lynker Technologies, attempts to quantify the benefits and risks associated with various adaptation or mitigation measures under various climate change scenarios on a sector by sector and asset by asset basis (Lynker 2020).

Baked into these approaches, however, is the assumption that what is lacking in terms of the basin's future function and capacity to adapt is mainly a matter of information, i.e., that if decision makers, however defined, are presented with the facts regarding their options, the costs of each, and the potential outcomes that might be achieved, then they will be able to make the best decisions possible to achieve the outcomes they desire. Unfortunately, as this study has attempted to explore to some degree, many of those involved in even the highest levels of decision-making within the water system do not act on fiat – for most actors within the system, power begins and ends with the utilization of a given portfolio of water rights, and by extension, the economic power related to them. Being, such as they are, products of a nominally apolitical, non-binding state authority, and therefore bound to a careful balancing act between a state whose political divisions (and diverse relationships with empirical reality) can at time appear vast, this is perhaps not surprising that these types of top-down decision support tools fall short in this regard. However, what they gain in palatability and neutrality they lose in veracity, especially as the balance of both economic and cultural power shift ever more toward the state's growing Front Range cities. Though the CWCB's work, does, in fact, take for granted that agricultural lands will continue to be dried up for expansion within urban areas, it does so in a way that assumes the processes behind this transition are themselves inevitable, and will not be subject to change as climate change and other social processes play out over the coming decades. At the simplest level, it ignores the growing desire among many basin residents for food system that promote local networks of production, land use sustainability, and connections with food producers, the sum of which, if properly channeled, could lead to novel agricultural-to-urban conversion dynamics, be it through urban farming, municipal partnerships with existing farmlands, or yet to be realized arrangements between agricultural production areas and the cities they might, one day, work to feed.

Put more simply, it ignores the radical possibilities inherent in areas undergoing cultural change, and in which major decisions about infrastructure, water supply, and the processes of water governance are themselves undergoing significant transformations. As an alternative, hydro-social theorists and other social scientists examining water systems might argue that a more bottom-up approach is merited, one in which an analysis of the systems of power operating within the water system are placed at the foreground (Morrison et al. 2017, 2019; Donahue 1997; Johnston 2011; Boelens et al. 2016). In such a view, rather than seeing the basin and its varied populations, water supply networks, and infrastructure projects as a sort of self-driving machine, researchers focus would instead turn to the cultural and social forces that operate it. In the case of the Colorado South

Platte, this would have to recognize both the tremendous power of economic forces (to borrow from Morrison and colleagues, the "practical power" of wealthy and profitable industries) as well as the highly influential "framing power" to shift minds, behaviors, and shape policy wielded by actors in the environmental advocacy and community organizing sphere. Thus while top down approaches seek knowledge of the basin in terms of asking "what is, physically, hydrologically, or technologically, the South Platte Basin?" this work would ask "What do the actors who animate the South Platte Basin actually want?" The Colorado Water Plan, for its part, attempts to answer this sort of a question, putting forth the various aspirational goals of Colorado's Water Values in a vaguely defined and, arguably, somewhat hollow way. Digging deeper on what things like "vibrant, sustainable cities," "productive agriculture," and robust environments and recreational industries actually mean, relative to the desires of its citizens, then, would be the next step in this sort of a pursuit. However, in order for this type of effort to be effective, it would have to find ways to move beyond the usual cast of characters encountered in water decision-making systems. As part of this project, efforts to elicit what these types of actors might want for the future of the basin elicited a range of responses, with some merely wishing for a slowing to growth and the rapid processes of change that effected their work, and others voicing a more straightforward desire to see their particular point of view take dominance over discussions. For others, thinking about the future beyond the next 1-5 years was simply not part of the job description, with more immediate problems and concerns taking necessary precedent over speculation on what the basin as a whole might one day be. That is to say, because most – if not all – of those involved in water decision-making are themselves subordinate to higher powers of economics, political will, or hierarchies of governance beyond their control, efforts to understand the desires driving change within the basin must go beyond those who manage its most essential resources.

Indeed, if there was one aspect that stood out most prominently in the conversations about water that took place during this research, it was that the future, if it was thought about at all, was seldom spoken about in any clear or vivid terms. Even among environmental advocates and those working on somewhat radical efforts to reshape the ways in which diverse actors come together and deal with water issues, discussions about the future were most often framed in the negative – i.e., in terms of what an individual did not want – be that in terms of the destruction of what remains of the region's natural ecology, the erosion of agricultural communities, or the long-feared but as yet largely avoided outright conflict seen lurking behind a failure to address the negative impacts of zero-sum competition over water that currently characterizes the region. Although, in adjacent spaces, efforts to formally engage with creative planning for potential future scenarios was underway – including within the CWCB's own efforts to implement the Colorado Water Plan – very few highly visible spaces for collaboratively imagining what the residents of the region might want water use dynamics to enable were encountered. Granted, several cities in the region have recently undertaken efforts to engage their constituents in programs to collaboratively imagine the future development trajectories of their communities, such as in the case of Fort Collins's "Our Climate Future" program (see: https://www.fcgov.com/climateaction/our-climate-future) and several highly engaged efforts at incorporating extensive community input in master planning processes. However, within the water world itself, much of this future-oriented work remains largely "top-down," being driven primarily by experts, technicians, and engineers proffering various tools and quantitative analyses to evaluate a limited subset of often vague future scenarios. Those these may yet prove highly valuable in putting quantitative weight to the largely uncertain contours of the future currently being brought about by the continuation of status quo activity in the region, they do little to allow space for the active imagination of alternative arrangements capable of disentangling the various wicked challenges the combined threats of climate change, socially-constructed water scarcity, and cultural division that characterize the region today.

But as this research and the experiences of water sector leaders working to solve water supply challenges show, no one approach alone will be sufficient to elevating the region's understanding of itself, be it as a network of cultural complexes, or as a co-extensive system of natural, constructed, and non-living systems undergoing iterative processes of change. To bring to the two together, approaches that find ways to integrate both top down knowledge relating to the biophysical and structural features of the system as well as the bottom up, cultural, social, and micro-economic aspects are required, as it is through the meeting of the two that the socio-ecology and socio-hydrology of the region exist, as such. Here, agent-based modeling points toward the potential for platforms for engagement and education that synthesize across these diverse knowledge domains. As outlined in previous sections, agent-based models developed within participatory contexts have demonstrated significant promise in their ability to render complex, interconnected systems in a manner accessible to a broad variety of stakeholders (e.g, Miller et al. 2010; Cosgrove et al. 2015). Building upon these and similar efforts, ABMs scaled across the various levels of meaningful geography within the South Platte could be realized in quite vivid ways, as significant effort has already been put in place to provide systematically rigorous and legally-cogent information about its biophysical features and water systems to the public and research communities. At the same time, cultural value systems could be brought into the modeling framework through a mix of approaches, including expanded iterations of studies such as this, basin-scale survey instruments, reviews of other value-related survey research, and investigations of emerging technological changes occurring around the region. Indeed, though it represented only a small portion of the discussions in this study, many of the most intriguing avenues for future development in the region came out of approaches to land and water use that attempted to hybridize diverse, normally discrete system functions. In addition to conservation efforts that doubled as recreational areas and flood mitigation systems and systems incorporating agricultural production into urbanized spaces, discussions on the intermingling of diversified energy production systems and protected agropastoralism also entered the fray. In terms of a modeling framework, this would require the ability to iterate across versions so as to incorporate new types of agent functionality and associated interactions with other units, as well as mechanisms for participants to imagine such novel hybrids as part of the process.

Taking this approach further, given the need for broadening existing patterns of engagement – and the solicitation of totally new types of participants in basin-scale planning – recent research in sustainability education and collective action for climate change action points toward the utility of not only interactively simulating the basin, but the full-scale gamification of such a process, such as can be seen in modern expressions of the city simulation video game genre. As argued by Trott and colleages (2020), the integration of "top-down" scientific knowledge and "bottom-up" dimensions of cultural values need not only take the path in which experts in the social and physical sciences conspire together to describe a system and its trajectory from the outside. Rather, through the utilization of participatory education processes and the integration of creative arts approaches, this integration can bring into otherwise cloistered academic spaces the voices, concerns, ideals, and ambitions of those normally excluded from such spaces. Envisioning sustainability action as a collaborative process that emerges from the conjunction of experts and local knowledge leaders discovering both "what is?" a given system, and, through creative expression, answering, with the help of their communities, "what if?" – i.e., What if we wanted a region where cities could offer affordable housing to the full range of economic actors within its valued systems? What if we were to support agricultural community continuity through subsidies or direct sales contracts between farmers and nearby cities? What if we wanted to build a region capable of shielding itself and those who come to it from the worst ravages of oncoming change?

Answering such questions would require not only a robust and empirically grounded platform for modeling, but also the intractability necessary to allow individual users to think creatively within the model space – to build, in essence, the basins that they would like to live in, and help guide those systems as they evolved into a future of dynamic environmental and cultural change. Though merely speculative at this time, it would seem that the tools necessary for it are readily available, if scattered in disparate locations, waiting for the will to bring them together in a useable form. Future research will have to explore the genuine feasibility of such an approach, but research like this, at the very least, points toward its possibility.

Conclusion

What the future of Colorado will look like remains an open question, even if it is clear that the cities of the Front Range and the South Platte Basin will determine much of its direction forward, and that decisions made about water will be central to its story. Given the multiple challenges currently faced by the citizens and non-human systems of the region, it is likely that the future will bring with it significant need for change, particularly in the face of a warmer, more variable, and increasingly intense climate. After all, in addition to the risks faced locally, the South Platte and its citizens must also contend with a world of increasing instability, migration, food system instability, and perhaps fundamentally novel processes of change, all of which will inevitably make their echoes felt in what is an increasingly cosmopolitan and dynamic economic system.

This research has attempted to shed some light – albeit at-times mottled and admittedly, dim – on what sort of characters will be taking this uncertain and unpredictable path, and what conflicts and common causes they might find as they do so. At the same time, it represents an effort to compile and synthesize knowledge about the basin from both a bird's eye view – or satellite view, as the case may be – and an on-the-ground look at the feelings, ideas, and values that bring life to its patterns of human-environment and human-hydrological interactions and systems. In this, it provides a basis for future publications that could serve as a much needed update to the relatively sparse and often aged literature on the region (e.g., Dennehy et al. 1993), as well as the start of new educational products for current and future water leaders in the region hoping to come to grips with the intricacies, complexity, and vastness of the basin's water system operation. At the same time, it attempts to provide a glimpse – albeit from a single moment in time, and from a limited transect of the basin's many communities and points of view – at the ways in which different critical actors within the water decision-making world approach water resource issues, and the outcomes they hope to achieve, and the reasons for cleaving to those pursuits. And although significant work has and will continue to attempt to come to grips with the cultural dynamics of the region – both as a part of state-led efforts to plan for the basin's future and by concerned groups hoping to gain an edge in the highly competitive water politics landscape, this work represents a significant contribution to what is a surprisingly meagre literature on a cluster of communities and governments whose decisions could well shape the fate of much of the southwestern United States in the decades to come.

This project began with the hope that, through the application of anthropological methods and a holistic approach to the complex adaptive socio-ecological systems that make up the South Platte Basin, that a foundation could be laid for aiding those who live within the region to better know themselves, their neighbors, and the coextensive network of living and non-living systems of which they are a part. As it stands, it does not quite achieve that goal, remaining as it is perhaps too ponderous, too generalized, too specific, and too circuitously written to inspire a higher order of understanding in all but the most pernicious of students of the region. Future work, both in the public domain and in continued research on the potential of new forms of simulation tools for collective learning, will have to take place in order for the pursuit of my original goal to move forward. Nevertheless, it is hoped that readers encountering this document will find themselves, if not more clear in their understanding of the basin, at least more curious as to the complexities of the systems at play, and perhaps, more capable of apprehending the reality of what it means to live as an individual, as a citizen, and as a creature of water in the semi-arid Western United States.

Several key recommendations nevertheless stand out:

1. **As the process to update the Colorado Water Plan and basin implementation plans continues, a systematic effort to engage stakeholders on a one-on-one, in-depth basis in the manner piloted here should be undertaken**. Throughout this project, among the

more common reactions to the interview process was an expression of gratitude – a surprising outcome, given that the time and experience of those interviewed often fetched a high price in other venues. Moreover, given that this effort was accomplished by one individual with no direct funding, more serious and institutionally supported efforts may yield still more valuable insights into the micro- and meso-scale operations of the basin's diverse livelihood and value systems. People want to be heard, and existing mechanisms for public engagement only accomplish this to a certain degree. By rooting future work by the CWCB and Basin Roundtables in the on-the-ground experience of a diverse array of system actors, future water demands, land and water use change dynamics, and programs to manage both can be set on a more culturally and empirically valid footing.

2. **Mechanisms to incorporate innovative, hybridized, and other experimental approaches to land and water use conversion into scenario planning analyses must be pursued, and innovation in this domain must be encouraged by the CWCB and other interested parties.** Current efforts by the CWCB to address water supply conflicts continue to operate in a zero-sum mindset, often overlooking opportunities to find paths forward that meet multiple societal and business needs through novel approaches to land and water use. In many cases, the past – and the approaches to business, farm, development, and recreation industry operations – is taken as the model for how the future will play out, but increasing challenges from climate change and other factors may subvert this long-held assumption. Working through existing venues, such as the variety of conferences and institutions currently working on water issues in the region, water leaders should keep a clear eye out for approaches to land and water use that meet multiple value system goals, and take seriously the changes to both model projections and water management that may need to occur to accommodate their potential.

3. **The lack of a basin-scale identity and subsequent absence of basin-scale visions represent a challenge that must be met with interventions that allow for creativity and imagination that are rooted in facts, and that acknowledge the social construction of water scarcity in the region.** With few exceptions, the cultural systems encountered in this research operate across spatial domains far smaller than the sum of networked socio-hydrological phenomena that shape them, leaving blind spots in the mental landscapes of many of the key actors working to shape the region's future. Through integration of "top-down" educational programs that more thoroughly and vividly portray the system as a whole with "bottom-up" avenues for creativity and communal imagination of desired futures, paths forward can be more clearly delineated and followed. Such work would need to be tailored to the diverse audiences encountered in the region, as well as the diverse ways of engaging with the future enlisted therein, and may have to overcome a certain degree of atrophy in the imaginative faculties of actors who are often perforce focused solely on the current fiscal period.
4. **The ingredients for high validity agent-based modeling frameworks are available (if scattered) and should be pursued for the purposes of continued social learning.** Agent-based simulations and models have the potential to bring to life in a vivid and interactive way many of the extant datasets and information repositories on water systems and their human interlocutors across both the basin and the state as a whole. Future research within NREL and affiliated partners at the Colorado Water Institute should examine ways in which these relatively dry datasets can be compiled and put to meaningful use for public-education oriented tools. The integration of climate change scenarios, population growth scenarios, risk scenarios, and other important and potentially non-linear system phenomena

could be incorporated into existing work by the SPBRT and CWCB to address future water system needs through such work.

5. **Spaces for the active analytical and creative engagement with the future are limited,** both by institutional factors within organizations and due to widely diverse modes of engagement with the future – and what people think it ought to and will look like – that characterize the region. Nevertheless, without some tangible vision of what the Basin is meant to achieve – be it for economic profit, ecological functionality, or both – it seems largely unlikely that a purposeful and meaningful willingness to sacrifice current desires will emerge across the system's diverse array of interested actors. Looking forward, lessons learned by smaller-scale efforts within cities and counties to collaboratively plan for the future should be adopted at the basin scale.

Though these efforts alone are not all that is likely needed, given the findings above they seem to provide a path forward for those hoping to help the basin and its people come to understand what they are, and to gain agency over their development in the future.

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