

THE FUTURE FLOWS IN THE UPPER ARKANSAS RIVER BASIN:  
AN EXAMINATION OF THE VOLUNTARY FLOW  
MANAGEMENT PROGRAM AMIDST CLIMATE  
AND HYDROLOGIC CHANGE

by

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## ABSTRACT

Colorado's Upper Arkansas River Basin is home to a voluntary and collaborative water management program that aims to optimize river flows for white-water rafting in the summer and fish ecology in the spring and fall. Surprisingly, the program has largely been overlooked by academics even though it has been in place since the early 1990s. This study offers the first close examination of how the basin's Voluntary Flow Management Program (VFMP) currently functions and its prospects for the future. In particular, the study examines the VFMP's resilience to two climate change-related variations to streamflow – earlier spring runoff and more frequent drought – which are expected to test even the most robust collaborative water management programs in the coming years. The research employs a mixed methods approach in order to analyze the VFMP's intertwined social and hydrologic components. In-depth interviews with VFMP stakeholders are coupled with publicly available stream gage and snow telemetry data to provide a multifaceted view of how the program influences the Upper Arkansas streamflow. The analysis reveals that VFMP stakeholders have developed a collaborative management system that is capable of adapting to meet program flow targets in many (but not all) water years. Drawing from these results, the discussion ponders whether these adaptations will be sufficient under increasing hydrologic stress. This study takes place during an important juncture for the VFMP, as a new generation of water managers joins the program and parties undertake a regular 5-year renegotiation of the program's terms in the spring of 2021.

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## LIST OF ABBREVIATIONS

ACM.....	Adaptive Co-management
AHRA.....	Arkansas Headwaters Recreation Area
AF.....	acre-feet
AROA.....	Arkansas River Outfitters Association
CPW.....	Colorado Parks & Wildlife
CSU.....	Colorado Springs Utilities
NRCS.....	Natural Resources Conservation Service
PBWW.....	Pueblo Board of Water Works
Project Water.....	Fryingpan Arkansas Project Water
Reclamation.....	Bureau of Reclamation
SNOTEL.....	snow telemetry
Southeastern.....	Southeastern Water Conservancy District
TU.....	Trout Unlimited
VFMP.....	Voluntary Flow Management Program

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## CHAPTER 1

### INTRODUCTION

As climate change affects hydrology, water managers are being forced to adapt their practices to accommodate unexpected changes in streamflow (Milly, 2008). Especially in the American West, where river systems are experiencing earlier spring runoff and more frequent, intense droughts, water management practices from the past may be less effective in the future (Stewart et al., 2005; Udall and Overpeck, 2017). Major rivers are very crucial because many stakeholders, consumptive and non-consumptive water users, rely on the resource. Therefore, examinations of river management programs may be a critical piece for understanding how water managers can and should react to hydrologic variations due to climate change.

This study focuses on the Voluntary Flow Management Program (VFMP), the only prescribed flow management program on the Upper Basin of the Arkansas River in central Colorado since 1990. The VFMP is a voluntary, multi-stakeholder program to manage flows to improve white-water rafting and aquatic ecology using a collaborative effort between private recreationalists, white-water rafting outfitters, local water conservancy districts, regional NGOs, the State of Colorado, and the Federal Bureau of Reclamation (Reclamation). But as streamflow is altered by climate change, it is unknown whether the VFMP has the capacity to adapt to continue to meet its flow goals.

Examining the VFMP is important because (1) the Upper Arkansas is an important reach of river because of its multitude of uses, and (2) the VFMP has not been studied before. First, the economy of the Arkansas Valley relies on well managed flows of the river. Currently, recreation and tourism generate over \$70.8 million for local communities each year (CPW, 2020). Outside the basin, major municipalities like Colorado Springs, Aurora, and Pueblo rely on the Upper

Arkansas because they own water rights in the valley. Additionally, a programmatic examination of VFMP has never been done, despite its long history of success. Also, the publicly available information about the program is limited and hard to find. Most of the attention, academically, for the Arkansas River is focused on the irrigation issues downstream or the water quality efforts near the headwaters rather than the management of the flows in this vital section (Lin and Garcia, 2012; Gates et al., 2012; Walton-Day and Mills, 2015).

Case studies are the preferred research design when research questions are being posed about phenomena in an uncontrolled “real world” context, and especially when the goal is to understand how a system works (Yin, 2014). This research is interdisciplinary, bringing together society and politics with hydrology (Wesselink et al, 2017). A case study of the VFMP would bring light to this interesting and underappreciated program, while also providing the opportunity to consider the program’s resilience to alterations to streamflow that are accompanying climate change. Resilience is defined as the capacity of a system to absorb disturbances (or “shocks”) while retaining essentially the same function (Walker et al., 2004). When examining resilience, one must always clarify the scope of analysis. This means specifying the resilience *of* what system *to* what kind of disturbance (Carpenter et al., 2001). This study focuses on the resilience of the VFMP’s specific seasonal streamflow targets to two hydrologic changes associated with climate change that VFMP stakeholders identified as being particularly concerning: earlier spring runoff and increased frequency of seasonal drought. The analysis examines social dynamics that might enable the VFMP to adapt to change (i.e., its adaptive capacity) as well as streamflow trends in the Upper Arkansas (Walker et al., 2004). The following research objectives guide the study:

- RO1: Evaluate the resilience of the VFMP to alterations to streamflow associated with climate change.
- RO2: Consider whether the VFMP needs to change in the future to maintain or increase its resilience.

The first research objective is addressed primarily in the results section, while the second research objective inspires the discussion.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Relevant Hydrologic Trends

Anthropogenic climate change is already affecting the hydrologic cycle in many ways, some of which are more discernable than others. Because the VFMP is focused on streamflow volumes, this study focuses here on links that hydrologists are drawing between our changing climate and changing streamflow. In addition, because the VFMP faces different challenges from year to year, the compounding affects from yearly trends are most relevant.

Streamflow hydrology in Colorado's alpine Rocky Mountains has always been highly variable from year-to-year, even before anthropogenic climate change began to alter watershed behavior (Lukas et al., 2020; Hill and Smith, 2000). The variability makes it more difficult to isolate climate change signals. In general, larger atmospheric trends like the El Nino-Southern Oscillation and the Atlantic Multi-decadal Oscillation can lead to periods of drought or moisture, depending on cyclical phase (Ellis et al, 2010). Recent studies have shown that the interannual variability of Rocky Mountain snowpack- often as a phase change from snow to rain due to increased temperatures- can have major consequences for managing water, both ecologically and socioeconomically (Marshall et al, 2019; Foster et al, 2016). This variability has direct implications for managing anthropogenic water storage structures and fulfilling water use demands (Clow, 2010; Hoerling et al, 2013).

The clearest signal of climate change so far is the shifted timing of snow melt runoff. Observational data suggests that “the timing of snowmelt and peak runoff has shifted earlier in the spring by 1–4 weeks in most of Colorado's river basins and watersheds over the past 30 years” (Lukas et al., 2018; Stewart et al., 2005). Early 21<sup>st</sup> century studies acknowledged that the

early spring runoff was a legitimate phenomenon in the Rocky Mountains, but were also inconclusive when connecting the runoff timing with stream flow volume (Stewart et al., 2005; Regonda et al, 2005). Within the last decade or so, the runoff data have become more available and more regionally focused. Climate scientists and hydrologists have been able pinpoint a statistical correlation between runoff timing and streamflow, and propose causation such as increased temperatures and dust (Fritze et al, 2011; Painter et al, 2012; Skiles et al, 2012). Increased temperatures, for example, can cause a phase shift from snow to rain instead of snow, resulting in earlier seasonal runoff (Foster et al, 2016). Consequently, reservoir operations will need to be able to adapt to earlier snow melt runoff (Sterle et al, 2020). Specific to the Upper Arkansas Basin, a 29-year USGS study showed a substantial shift in the timing of snowmelt and runoff towards earlier in the year at the Fremont Pass snow telemetry (SNOTEL) site within the Upper Arkansas Basin (Clow, 2010).

Precipitation patterns are less clear, but evidence shows that increased warming and drying trends will directly lead to decreased streamflow. In general, research has shown that annual average temperatures in Colorado have increased by about 2°F over the past 30 years (Brekke et al., 2013; Lukas et al., 2018). Despite that, from the observed data, Colorado has not seen any significant evidence to suggest there has been any long-term trends in annual precipitation since 2000 (Daly et al., 1994; Daley et al., 2008; Lukas et al, 2018). But with increased temperatures, snow dominated regions like the Rocky Mountains will see more frequent low-snowfall years and less frequent high-snowfall years (Lute et al., 2015). Additionally, several studies have suggested that drought-inducing conditions such as increasing temperatures, below average snowpack, and decreasing soil moisture will continue to negatively affect streamflow in semi-arid regions like Colorado. (Udall and Overpeck, 2017; Lute et al,

2015; Tang and Piechota, 2009). While different models have debated the magnitude and timeline, the research consistently projects streamflow runoff to decrease in the American West due to climate change, presenting major challenges to water management (Vano et al., 2012; Miller et al., 2021).

## **2.2 Social Trends and Environmental Management**

The adaptive and collaborative management approach that has developed in the Upper Arkansas River Basin is an excellent example of what the environmental management literature calls Adaptive Co-management. ACM approaches combine the “dynamic learning characteristic of adaptive management with the linkage characteristic of cooperative management and with collaborative management” (Olsson et al, 2004). Learning is a process of stakeholders monitoring and evaluating the underlying hydrologic changes within a social-ecological system. Notably with AMC, the acquisition of ecological knowledge is ongoing and self-organized through a learning-by-doing process where stakeholders interact with the system (Olsson et al, 2004; Plummer et al, 2012). In collaborative setting, stakeholder groups work together voluntarily and, in a consensus, -oriented manner. The management power and responsibility can be shared among multiple institutions, public or private, operating at different levels- local, municipal, regional, national, and even international (Armitage et al, 2009; Olsson et al, 2004).

While the general definition of ACM captures big ideas from two schools of management, the VFMP is an exemplary case study for a few key conditions of successful adaptive co-management: commitment to a collaborative, multi-stakeholder program, and a shared, social learning process where adaptable decisions can be made (Armitage et al, 2009). This case study is relevant to existing ACM literature because it focuses on the networks and

interaction among VFMP stakeholder groups, the process of learning, and use of knowledge to make decisions (Plummer et al, 2012).

Most recently, AMC scholars have called for case studies to examine the ability of AMC programs to adapt to the challenges of climate change (Plummer 2013). The VFMP has been in place for 30 years, long before the formalized ACM scholarship. Yet, no one has formally examined the VFMP for its ability to adapt to climate change challenges. Past AMC case studies covered a wide range of social-ecological systems, both empirically and theoretically (Plummer et al, 2012). The VFMP is also focused on recreation, a unique social-ecological system that has not gathered attention from past AMC case studies. By the end of the 2010, outdoor recreation has become a major factor in Colorado's economic force (Blevins, 2020). The particular emphasis on white-water rafting in this study will also contribute to the legitimacy of recreation in academic scholarship (Porterfield, 2018). Paired with recreation, the VFMP is used to manage fish ecosystems. Fisheries are a common case study in ACM literature because the intersection of biological, social, economic resilience of a system can be impacted by climate change in profound ways (Wilson et al, 2018; Leopold et al, 2019; Plummer et al, 2012). Also, within AMC scholarship, water management programs have also been examined for their institutional flexibility (Peat et al, 2017).

## CHAPTER 3

### METHODS

The Problem Orientation framework for natural resources policy analysis provides an overarching structure for the examination (Clark, 2002). The framework instructs researchers to begin any analysis of a natural resources management system by first ascertaining the goals of its stakeholders, and then comparing those goals against relevant social and ecological trends. According to this framework, a policy problem exists when a discrepancy exists between a program's goals and "actual or anticipated state of affairs" (Clark, 2002, pg. 100). The objectives of this framework are to approach the management of natural resource as a system in flux, highlight the complex social dynamics that affect decision making, and propose alternative solutions.

A mixed methods approach, combining both qualitative and quantitative data, is the fundamental research design (Cresswell and Cresswell, 2017). Qualitative data illuminate how the VFMP functions, as well as the stakeholders' goals and their perceptions of river trends. Quantitative data provide additional context by enabling a more systematic and longer-term examination of hydrologic trends, some of which were highlighted by stakeholders.

For the qualitative component, conducting in-depth interviews with VFMP stakeholders was the most effective way to address the initial tasks of problem orientation: clarifying stakeholders' goals, and analyzing social trends and ecological conditions. Ten interviews were conducted with representatives of the VFMP's major stakeholder groups. Because the VFMP operates locally in a rural setting on a relatively short reach of river, ten interviews were adequate for gathering the full array of perspectives on the management of the Upper Arkansas River. Interviews lasted from 45 minutes to an hour and a half, and on average lasted an hour.

All were conducted over the phone due to the COVID-19 pandemic protocols. When interviewees agreed, the interviews were audio recorded and later transcribed for analysis. All interviewees voluntarily agreed to be put on the record. Because of the intimate nature of the VFMP, full confidentiality is nearly impossible. Therefore, for this study, I believed the best way to reduce risks to interviewees is to encourage them to speak “on the record” from the beginning and to say things that they would be comfortable having published and attributed to them. On occasion, follow-up emails and informal conversations were held outside the interview data for this study. Ultimately, the data being gathered in this interview process were synthesized in order to clarify the goals, values, and decision-making process within the VFMP, rather than highlighting individual personal opinions. The interviews were analyzed by coding with the qualitative data analysis software package NVivo (Miles and Huberman, 1994). Following the Problem Orientation framework, interviews were coded for stakeholders’ stated goals and trends (hydrologic and social). The stakeholder goals and other emerging social patterns were then compared.

Quantitative analysis was done on MatLab and Excel spreadsheets. Streamflow data at the Wellsville gage, the crux of the VFMP, was the data point examined most heavily (DWR, 2021). Figure 3.1 map shows the Wellsville Gage near the bisection of the Upper Arkansas reach. Other streamflow gauges throughout the Upper Basin were also considered and examined. The stream gages’ historical discharge data were analyzed for yearly minima and maxima, variance from season to season, and percentiles of cumulative flow at certain times of the year. Snow-telemetry sites (SNOTEL) were examined for historical snow water equivalence (NRCS, 2021). Information about reservoir storage was also considered to contextualize stream gauge and SNOTEL data (Reclamation, 2021).

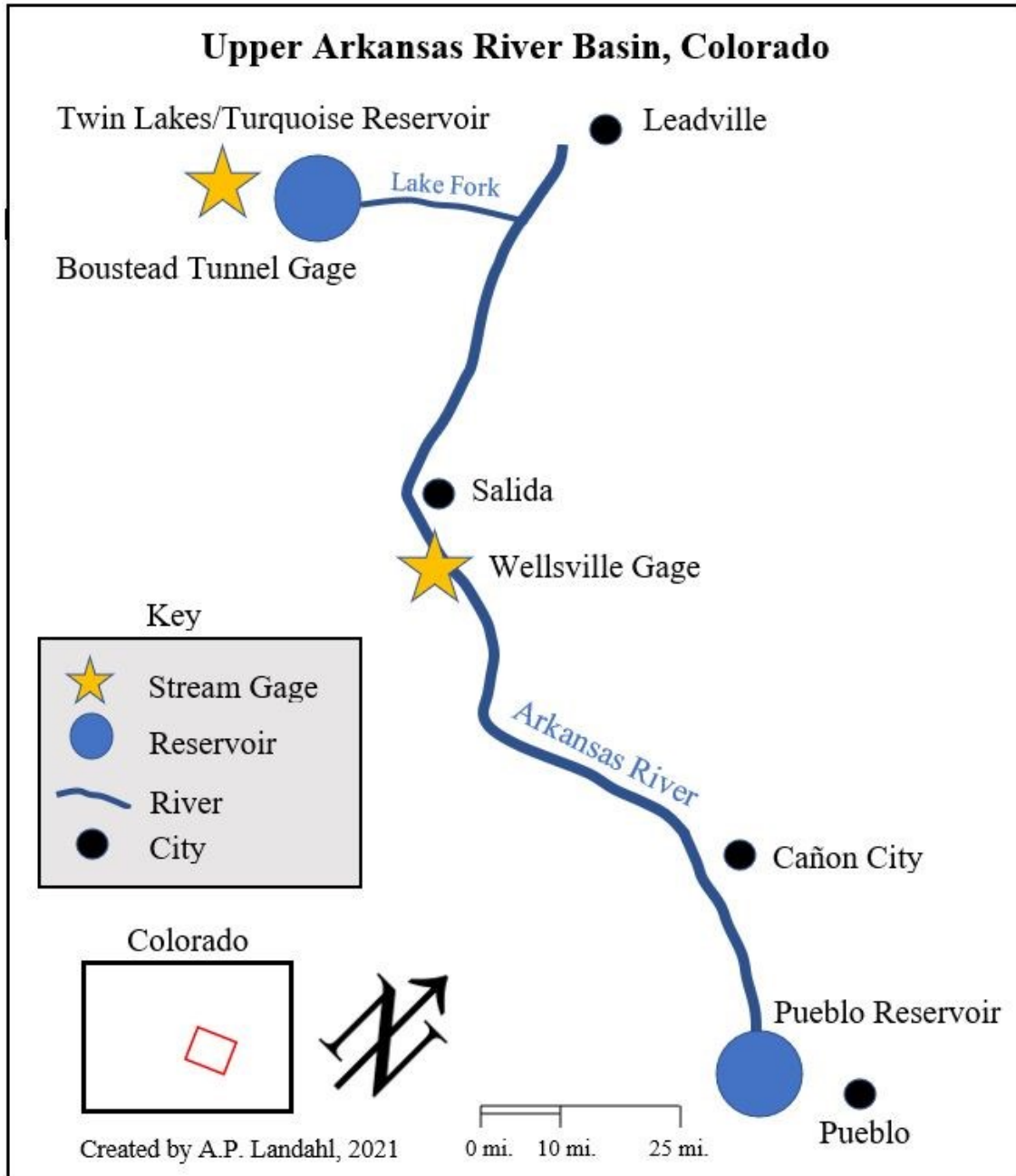


Figure 3.2 Map of the Upper Arkansas River

## CHAPTER 4

### CASE STUDY

#### 4.1 Goals and History of the VFMP

The VFMP operates on a highly recreation-dependent reach of the Upper Arkansas River, which runs from the town of Leadville to the city of Pueblo. The main objective of the program is to benefit both the aquatic life and the recreation industry while fulfilling the needs of the downstream users at the Pueblo Reservoir. White-water rafting and the fishery are the main sources of tourism in the Upper Arkansas Basin. White-water rafting in the basin is one of the most popular spots in the county (Hill and Smith, 2000). The fishery from Leadville to Cañon City was given Gold Medal Status in 2014, mostly notable for brown trout (Atwood, 2019). The official mission and purpose of the VFMP is to maintain “flows at Wellsville, just outside Salida, at 700 cubic feet per second (cfs) from July 1 to August 15 to support rafting” (Woodka, 2016). For the impact on fishing, the incubation flows throughout the winter and spring have different targets depending on the spawning flows in October and November.

The success of both the fishery and white-water rafting was an intentional design of the VFMP. By 1990, a prescribed flow program became necessary to reconcile non-consumptive water uses of white-water recreation and fish ecology with the consumptive water uses from agriculture and municipalities. This need was largely triggered by urban purchases of agricultural water. As the cities of Colorado Springs and Aurora bought more water from farmers on the Lower Arkansas River, Reclamation started to move more water during the winter and less water during the summer. Summer flows for white-water rafting, which had been propped up by irrigation demand during the peak of growing season, declined dramatically. Based on interviews, the rafting industry became uneasy with the sudden hydrologic variability. In an

agreement with the Arkansas Headwaters Recreation Area (AHRA) and Reclamation, 23,000 AF (acre-feet) of water was released between July 13<sup>th</sup> and August 21<sup>st</sup> of 1990 for the purposes of augmenting flows for rafting. In 1991, Trout Unlimited (TU) sued the United States Department of the Interior because these unmitigated flows were disrupting the habitat and health of the trout population. Even though this suit was dismissed, it spurred the genesis of the VFMP.

The hydrology of the basin is a major factor in the VFMP. The Upper Arkansas River Basin is a high altitude, semiarid watershed located in south Central Colorado. For decades, water managers have known that snow melt is the main source for surface water flows on the Arkansas River (Crouch, et al., 1984). The amount of snowpack is directly correlated to the amount of runoff from snowmelt. Because of the variation in temperature and sunlight, the rate of snow runoff can be unpredictable and cause volatile flows throughout the year, and year to year. In fact, the 1990 iteration of the VFMP was instituted mostly to mitigate streamflow during a period of great hydrologic variability. The wettest time on record in the Upper Basin was from 1982 to 1987, immediately followed by an extremely dry spell from 1989 to 1992 (Hill and Smith, 2000).

## **4.2 VFMP Operation**

In addition to the natural runoff, the Fryingpan-Arkansas Project, a trans-mountain diversion, also supplements the Arkansas River with water from the Roaring Fork Basin on the western slope of the Continental Divide. The VFMP manages 10,000 AF of this trans-basin Project water as its main source of flow augmentation for rafting. Snowmelt runoff is collected in catchment basins and transported via the Boustead Tunnel to the Turquoise and Twin Lakes Reservoirs, in Leadville, Colorado, near the headwaters of the Arkansas River. These two facilities are connected via the Mt. Elbert Conduit, and serve as the upper storage facilities in the

basin. Reclamation releases flows from this infrastructure. 152-miles downstream, the Pueblo Dam and Reservoir represents the terminal storage for the VFMP and beginning of the downstream operations. Figure 4.1 shows a comprehensive tea cup diagram of all the water storage facilities and infrastructure in the reach of interest.

In its current iteration, the VFMP is a formal agreement between five signee organizations: Southeastern, Arkansas River Outfitters Association (AROA), Chaffee County, AHRA, and TU. A renegotiation of the terms is renewed every five years. Reclamation plays a major role in the basin as part of the Fryingpan-Arkansas Project. Municipalities, private boaters and anglers are also direct beneficiaries to the program. Figure 4.2 below shows the stakeholders and organizational structure surrounding the VFMP.

Each signee organization has their own role to fulfill. Southeastern is local sponsor of the Fryingpan-Arkansas Project who manages and develops the Project facilities. AROA represents the interests of the white-water rafting industry. TU is tied in from the original lawsuit, formally representing the fish health and ecology. Chaffe County is a local government and is active with legal and economic interests in the program. The AHRA is a branch of Colorado Parks & Wildlife (CPW) specified for protecting the natural resources in this reach of the Upper Arkansas River, and making informed flow recommendations to the VFMP group. In addition, the AHRA yields recommendations from within their own network of water resource managers, fish and wildlife biologists, and the Citizens Task Force.

In general, because the VFMP is voluntary, at its core, it depends on the mutual recognition of good faith planning, support of local economy, and goodwill from other parties. Similar to collaborative management structure distinct to AMC, the flow targets of the VFMP are met in large part by the voluntary participation of Reclamation, Southeastern, and the other

interested parties and municipalities (Olsson et al, 2004). A former AHRA park manager stressed that cooperation is the key to achieving flow targets and goals that benefit all.

Essentially, the VFMP has two layers of voluntary actions. First, Reclamation and Southeastern have a yearly agreement to provide up to 10,000 AF of water of Project water for the VFMP augmentation, “if and when” the water is available. Southeastern, the is administrative body that owns, distributes and monitors Project water- contrasted to Reclamation, who operates the physical releases from the upper storage facility. Southeastern works together with the other VFMP stakeholders to make decisions about the flows, and then relay the requests to Reclamation.

Second, the municipalities of Pueblo, Pueblo West, Colorado Springs, and Aurora have the rights to some water in the Upper Arkansas River. They participate in the VFMP by strategically moving their water during times that supplement the summer flows and do not harm the winter flows. In the most common scenario, Pueblo and Pueblo West have water in the upper reservoirs and need to move it down to Pueblo Reservoir through a physical water transfer. Contrarily, Colorado Springs and Aurora have water downstream in Pueblo that they need to transfer upstream to reach their pumping infrastructure. The Division Manager of Water Resources from Pueblo Board of Water Works (PBWW) clarified how these exchanges are made in accordance with the VFMP. He explained when the VFMP needs more flows for rafting, they want Pueblo and Pueblo West to release their water from the upper reservoirs. When the VFMP needs lower flows for the fishery, they want Colorado Springs and Aurora to operate exchanges to reduce flows. Even though the direction of the exchanges is opposite, the municipalities work together for the greater benefit of the program. For example, if an exchange or release would harm the target flow, municipalities can do a legal paper trade. The PBWW manager explained

that the cities can “just swap” with an account transfer at both reservoirs so no physical water is actually moved in the process. These exchanges are certainly non-trivial. PBWW typically contributes from 5000 to 12,000 AF over the summer.

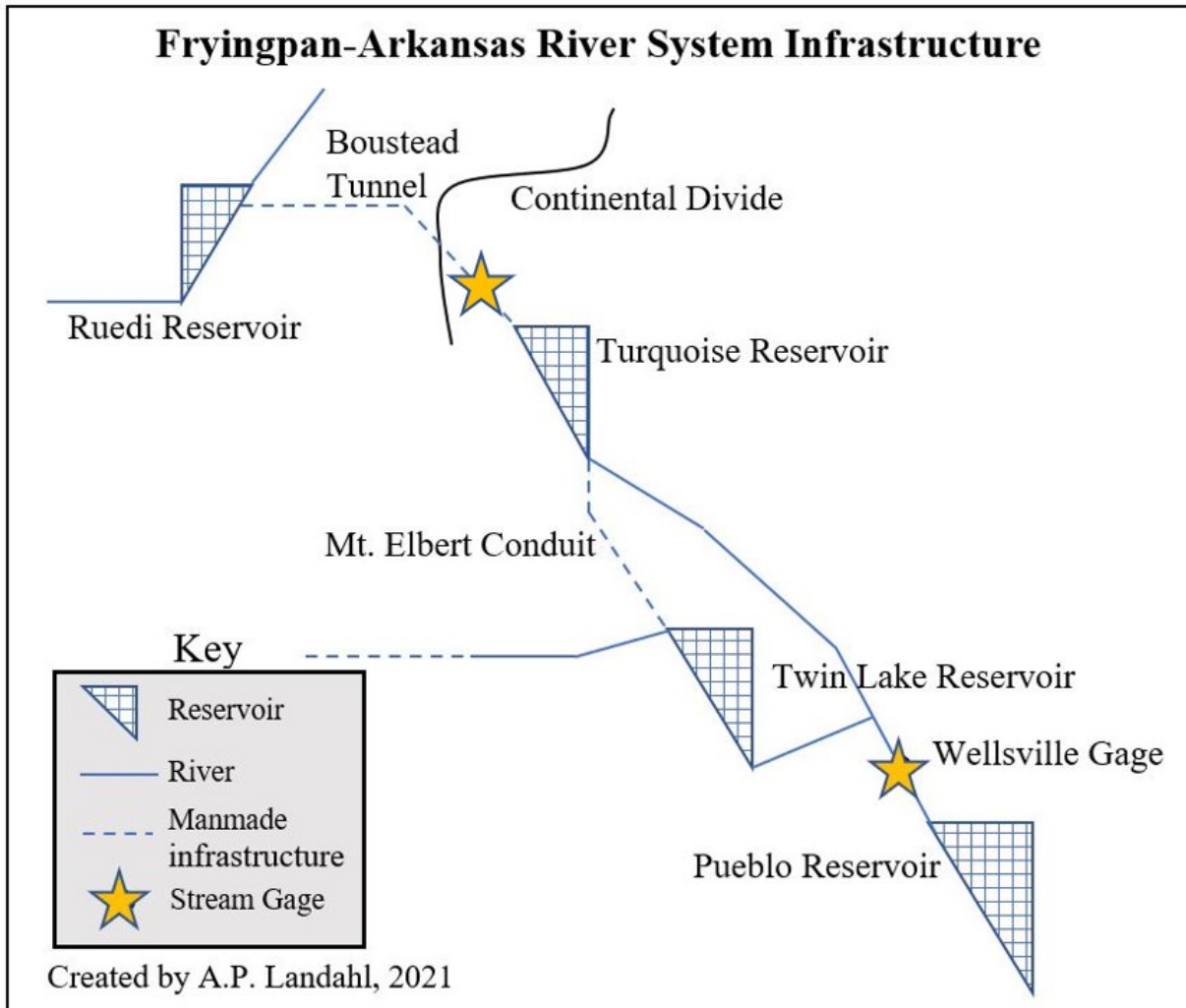


Figure 4.1 Tea Cup Diagram of the Upper Arkansas River

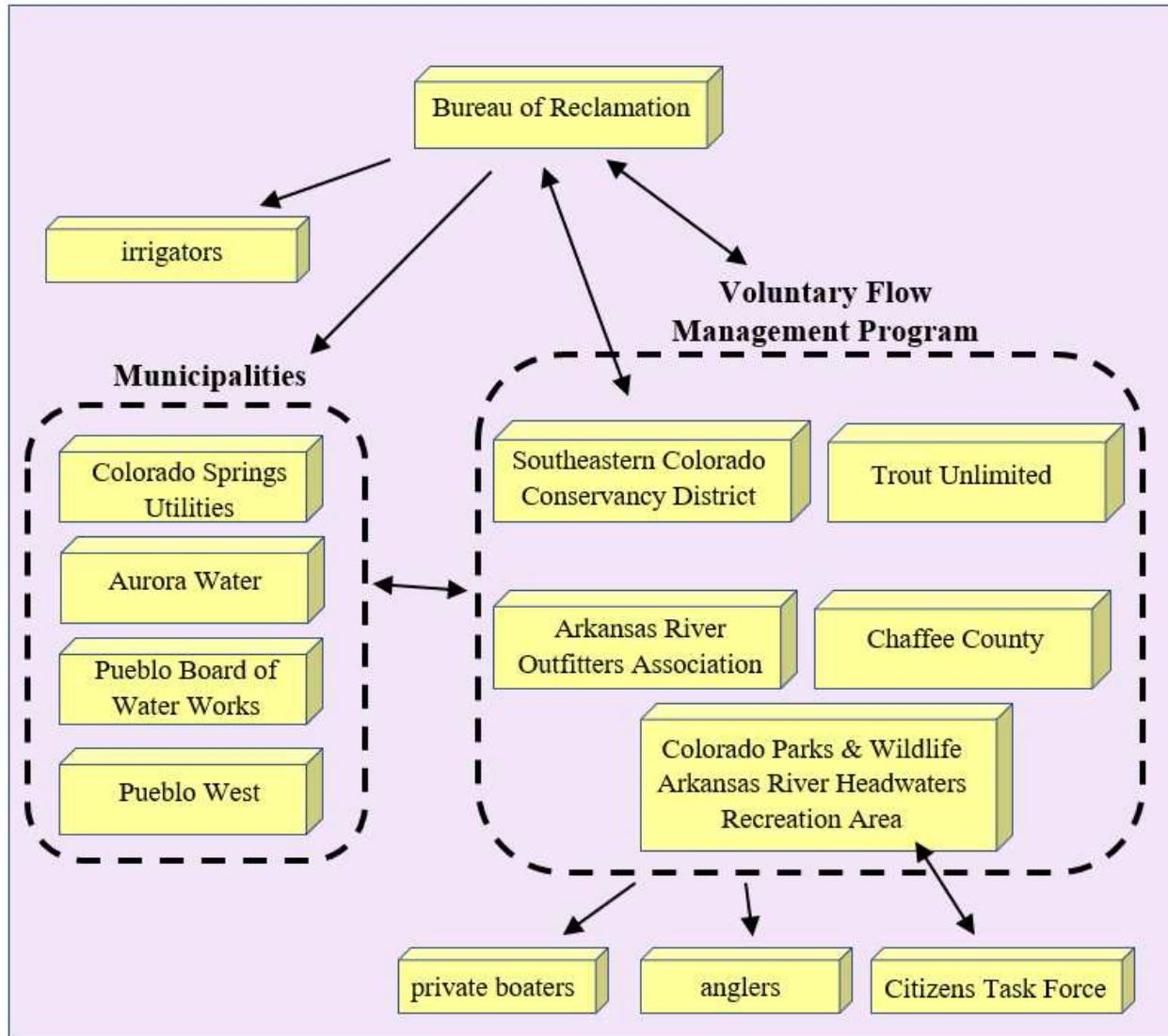


Figure 4.2 VFMP Flow Chart. A two headed arrow represents a two-way relationship. The one headed arrow represents a one-way relationship. For example, both the private irrigators and the municipalities are direct benefactors of the Fryingpan-Arkansas Project Water and facilities (managed and operated by the Bureau of Reclamation) but do not communicate back to Reclamation with requests or recommendations. Similarly, the private boaters and anglers have a one-way relationship with the AHRA, unlike the formal relationship with the Citizens Task Force. The Bureau of Reclamation and Southeastern have a separate agreement that ensures 10,000 acre-feet of Frying Pan Arkansas Project Water will be made available for the VFMP.

## CHAPTER 5

### RESULTS

#### 5.1 Early Spring Runoff

Earlier spring runoff can affect the way Reclamation manages the upper storage system. Past practices can no longer be used to predict future hydrologic as runoff becomes less predictable; therefore, common practices may need to be adjusted. A water operations specialist for Reclamation confirmed this idea. “We have moved forward about two weeks on when we have opened our collection system when runoff starts... What we were using as a rule of thumb 20 years ago doesn't seem to be working quite as well now.” Now, Reclamation has to anticipate an earlier start date to open their catchment basins to collect runoff.

Beyond the import operation, the unpredictable timing of spring runoff also threatens the availability and efficient use of the 10,000 AF of Project water. As the start of snow runoff moves earlier in May, because the collection system has to open sooner, Reclamation has to vacate space in the upper reservoir system earlier. “We like to have our upper reservoirs fairly low going into spring runoff,” said PBWW’s Division Manager. “It used to be a lot of that water would fill those upper reservoirs in late-June and then we start moving it down in July for the flow program. Well now, we're getting it in early June and holding it for a whole month or more before we start releasing it down to Pueblo.” For water managers, this is not an impossible challenge to overcome, but they must be flexible and extra attentive to maximize the benefit of the flows.

The earlier shift in runoff can have negative effects on the development of trout fry. When the snow melts sooner, flows will be higher in early May, a time when low flow is critically important to the success fry spawning. A CPW biologist who monitored the trout

population on the Upper Arkansas River for nearly 25 years said “The most critical period of brown trout is when those fry are coming out of the gravel.... They need essentially zero velocity, or very low velocity water, or they're getting blown away.... They start emerging in mid-April and they are emergent by the beginning of May and into the first couple weeks of May.... So, if you move runoff up a couple weeks up to the first of May, you're going to have impact on fry production- no doubt about it.” High flows during late April, early May will produce smaller, less healthy fish population.

The important challenge is to find a balance to vacate space in upper storage system for new imports, without disrupting the vulnerable low flows for fish health in April and May. Moving the water earlier in the year and holding water for longer at Twin Lakes/Turquoise Reservoirs could lead to a lull in flows during late May and June, affecting the rafting experience. At the same time, vacating the water too early could present problems downstream if the Pueblo Reservoir is at a capacity. If the lower storage system has room to take on these flows, it allows for a little bit of buffering because creative exchanges can be made throughout the summer. But if Pueblo is full, water has to spill, being lost to the system entirely. Also, the system can lose over 100 AF of water from evapotranspiration held in the hot, low elevation Pueblo compared to the cool, high elevation Leadville storage facilities. All of these factors are subtle but important to optimal management of the Upper Arkansas Basin and the VFMP.

The Ivanhoe SNOTEL site can be a key data point for analyzing runoff timing relevant to the VFMP. This site observes high elevation snow in the Roaring Fork Valley, the area where the Fryingpan-Arkansas Project captures runoff for imports into Turquoise Reservoir. An analysis of the 27 years of available data at that site (1991-2018) did not reveal a clear trend in the timing of spring runoff, potentially because the timeseries is short and the runoff data are highly

variable. Rather than drawing conclusions about average spring runoff timing then, the figures below (Figure 5.1 and 5.2) isolate four years from roughly the last decade that stand out as having especially early runoff compared to the historic average. The goal of highlighting these early runoff years is not to make a statement about changes to average runoff timing, but rather to show what an “early runoff year” looks like in more detail.

Reclamation has a schedule for opening the catchment basins, so, undoubtedly, they must consider the volume, rate, and timing of these spring runoff imports when balancing the VFMP’s upper storage system. The gage at the Boustead Tunnel has recorded the discharge of imported Project water coming into Turquoise Lakes consistently since 1971. High elevation snowmelt that naturally runs off to the Roaring Fork Valley and Ruedi Reservoir on the western side of the Continental Divide is captured in catchment basins, and imported to the Turquoise Reservoir via the Boustead Tunnel. This gage is upstream of the reservoir, representing the runoff discharge without reflecting the VFMP’s augmentation. Figure 5.2 compares the cumulative daily discharge of the same four early runoff years highlighted above to the historical average. Cumulative discharge visualizes the rate of change and the timing of imports as snow melt. Clearly, each of these chosen seasons have an earlier Boustead Tunnel imports than the historic average, although the 2018 imports were entering the tunnel at roughly the same rate as usual. Also, Table 5.1 shows the calendar date that a given percentile of the cumulative total was hit. Roughly, 5% to 10% of total flow represents the beginning of runoff, while 70% represents the peak, or post-peak, runoff.

In summary, interviewees suggest that runoff is occurring earlier in the Upper Arkansas, but this cannot be ascertained definitively based on the data collected for this study, or the USGS study at Fremont Pass (Clow, 2010). Interviewees noted that the earlier runoff timing trend is

challenging for flow management because it threatens the efficiency of reservoir storage and can present a situation that is not optimal for the summer target. It also threatens the fish because the vital incubation period can be compromised by higher flows in March, April, and May.

Table 5.1 Boustead Tunnel Percentile and Date of Cumulative Discharge (DWR, 2021)

Year	5%	10%	70%
2009	10-May	14-May	19-Jun
2017	10-May	15-May	20-Jun
2018	7-May	10-May	1-Jun
2020	7-May	14-May	9-Jun
Average	14-May	21-May	24-Jun

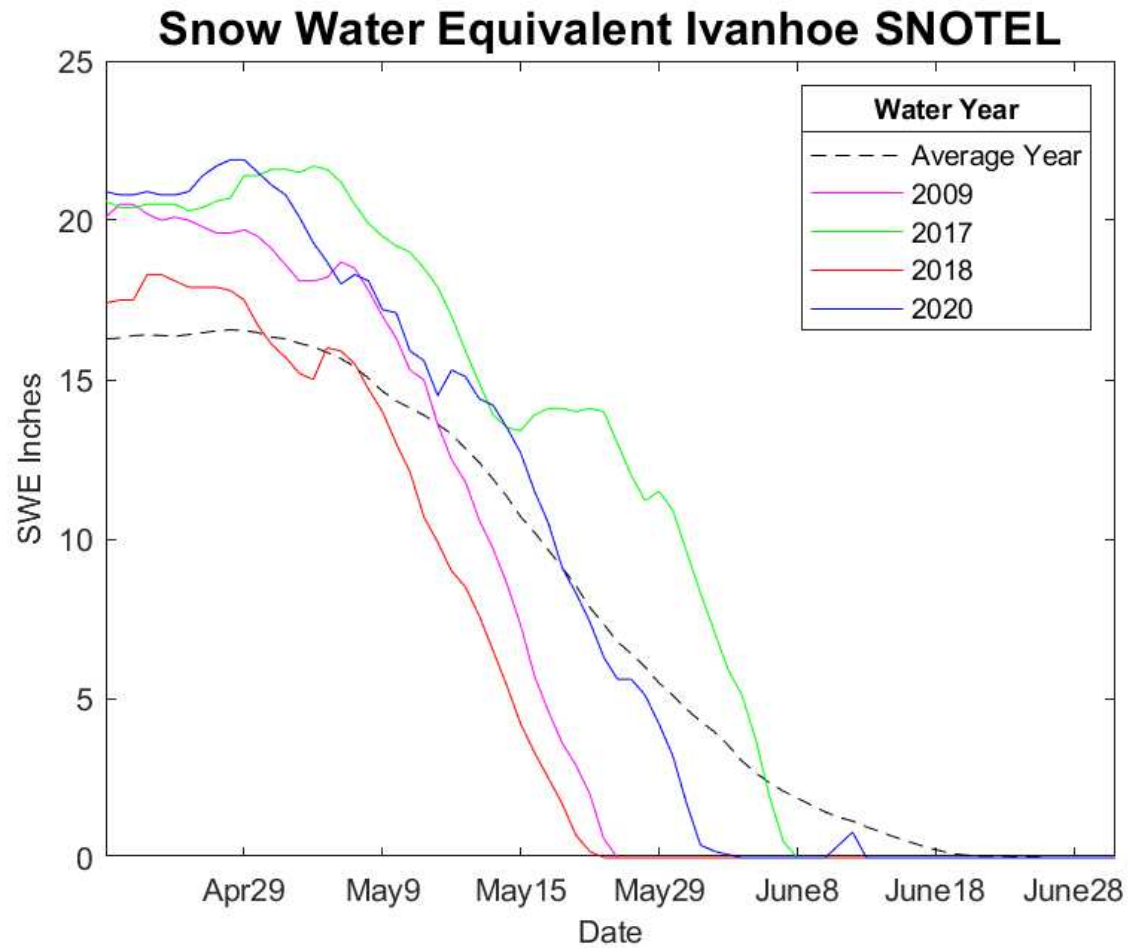


Figure 5.1 SWE at Ivanhoe SNOTEL (NRCS, 2021)

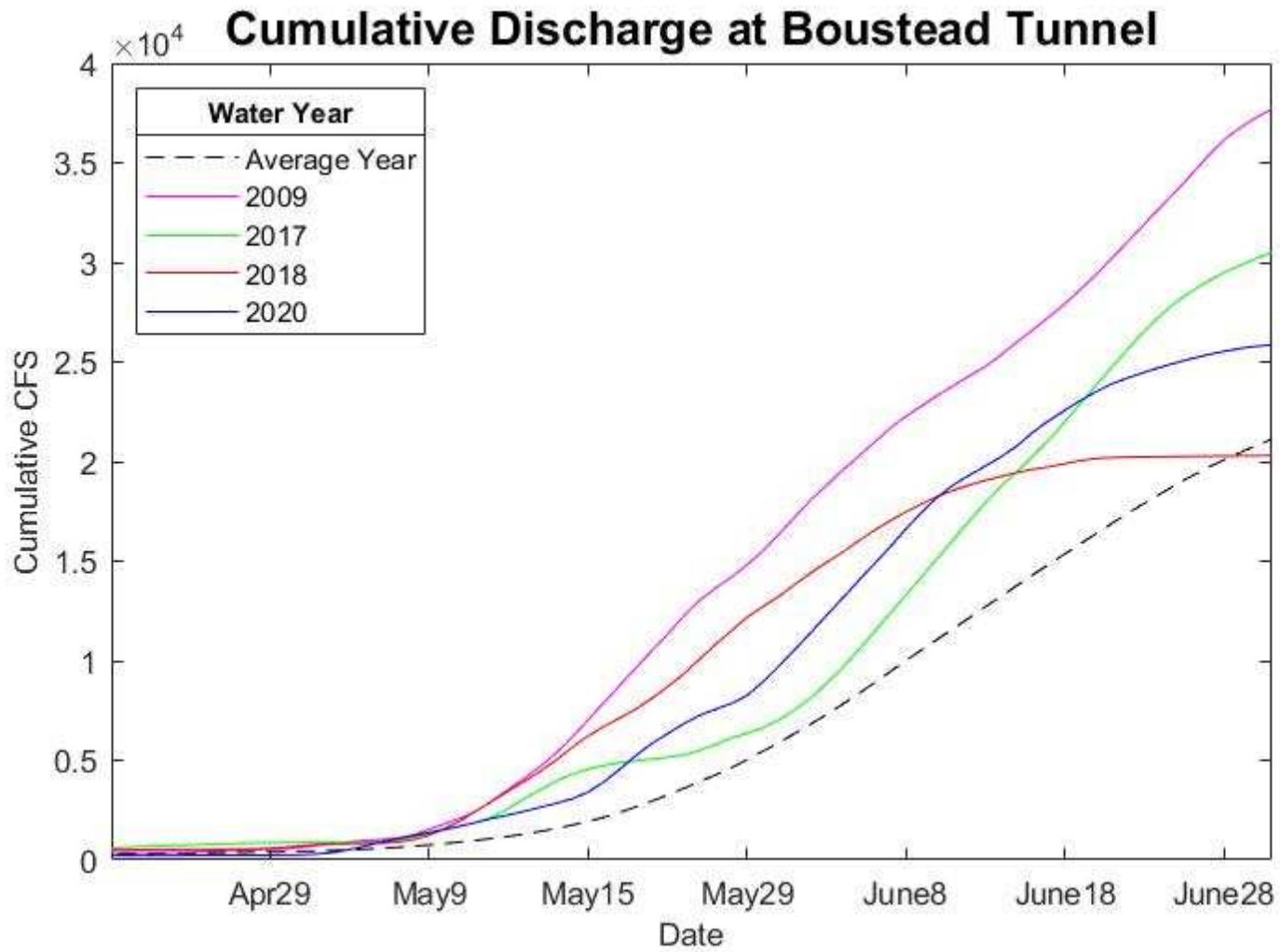


Figure 3.2 Discharge at Boustead Tunnel (DWR, 2021)

## 5.2 Seasonal Drought

The summer flow target was designed to withstand moderately dry seasons. The executive director of AROA said “the VFMP works really well when you only need augmentation of like 50 or 100 cfs for not even the whole 45, 50 days.” A water resource engineer for CPW added, “when we're facing a dry year, that 10,000 AF can get used up pretty quickly if we're trying to keep 700 cfs.” In this system, 10,000 AF is helpful around the margins, but it is not sustainable for a major drought.

These challenges worsen if the 10,000 AF dedicated to the VFMP is not available at all due to a lack of snowpack. Less (or zero) imported Project water means less water for augmentation in the summer target period. The AROA director continued, “when you need to start putting in 300, 400 cfs to try to hit 700, you only have a few days’ worth of water at best. In years like 2002 or ‘12, there was no water to give us. In those years, we were running at those sub-300, 400 cfs levels without any help from the VFMP because there's nothing to give us.” He also added that the white-water rafting experience suffers at these extremely low levels “because of the inability of outfitters to be able to run certain trips when it just gets to be ridiculously low.”

Paradoxically, a drought season can actually be beneficial to the fishery. Naturally, the Upper Arkansas River runs at much lower flows. The VFMP artificially augments the river with trans-basin imports. A 1994 report showed that fish habitat for fry is negatively affected by flows over 500 cfs (Andersen and Kriger, 1994). So in drought years like 2002, 2012, and 2018, when the flows are consistently under 500 cfs, the fishery is successful. The CPW fish biologist described the 2002 drought from the fishery’s perspective. “It was an amazing year because there was no argumentation that happened that year and the flows stayed near optimum for trout from

spring all the way through the summer and into the fall. We had like an eight-fold increase in brown trout biomass during that one summer. It was an amazing response.”

Even if the fisheries see improvements during low flows, a hydrologic drought can be detrimental to the entire watershed health. Both the fish biologist and the white-water rafting representative agreed that increased forest fires during these years harm the goals of fishery and the bottom line for rafting, respectively. For example, strict fire bans and threatening fires will discourage camping and other tourism. Recent fires like Hayden Pass have left burn scars on the landscape, exposing sediments to be washed into the river after a runoff event. These fires “really can have some profound impacts,” the fish biologist said. “The impact [from the Hayden Pass Fire] was clear to Cañon City.”

Project water imports for VFMP in 2002, 2013, and 2018 summer season was very limited due to a drought. Reclamation, Southeastern, and the municipalities had to prioritize their other needs and, essentially, the VFMP was hamstrung by the lack of water. Figure 5.3 shows the number of days where the VFMP missed the target flow (700 cfs) and the average cfs of these dry days, to show the magnitude of the drought. The summers of 2002, 2012 and 2018 missed every day of the target flow. The three summers following 2002 also saw target dates short of the target flow. The 2012 season is about as bad as it gets with a drought in the Upper Arkansas Basin. 2013 was another year that saw low imports and fires across the state. Also, notably, the 2018 drought was followed up with big snowpack and Project imports in 2019. Table 5.2 shows the high and low flows from some notable years.

In contrast, the fishery benefits when the flows at Wellsville are less than 500 cfs. Figure 5.4 shows the number of days when flows were below the 500 cfs mark during the most vital times of the year. The VFMP tries to limit moving large amounts of water during the early spring

incubation period. When done effectively, Project water is moved during other times of the year, like during the summer target. Besides a couple short seasons in 2014 and 2015, the VFMP has become more successful with managing flows for the fish. A 2019 River Survey showed that the biomass of the Trout at Wellsville have been at a high standard overall, but the seasons with many days below 500 cfs saw bigger and healthier fish (Atwood, 2019).

In summary, in these drought seasons, the summer target flow is more difficult to achieve and the rafting industry's bottom line can suffer. The fish population on the Arkansas seems to thrive in these low water years, but a drought can be detrimental to the overall health of the ecosystem.

Table 5.2 Highs and Lows at Wellsville (DWR, 2021)

All Time High Yearly Peak Flows		
CFS	Year	Date
6020	1995	June 23
5360	2015	June 18
4770	2019	June 15
4480	2010	June 6 & 7
4200	1996	May 20
4170	2014	June 6 & 7
4130	2017	June 20
4000	2011	July 10
Lowest Yearly Flow during VFMP Target		
CFS	Year	Date
225	2002	June 12
272	2012	August 6
300	2018	August 15
341	2003	August 15
576	2004	August 3
569	2013	July 27

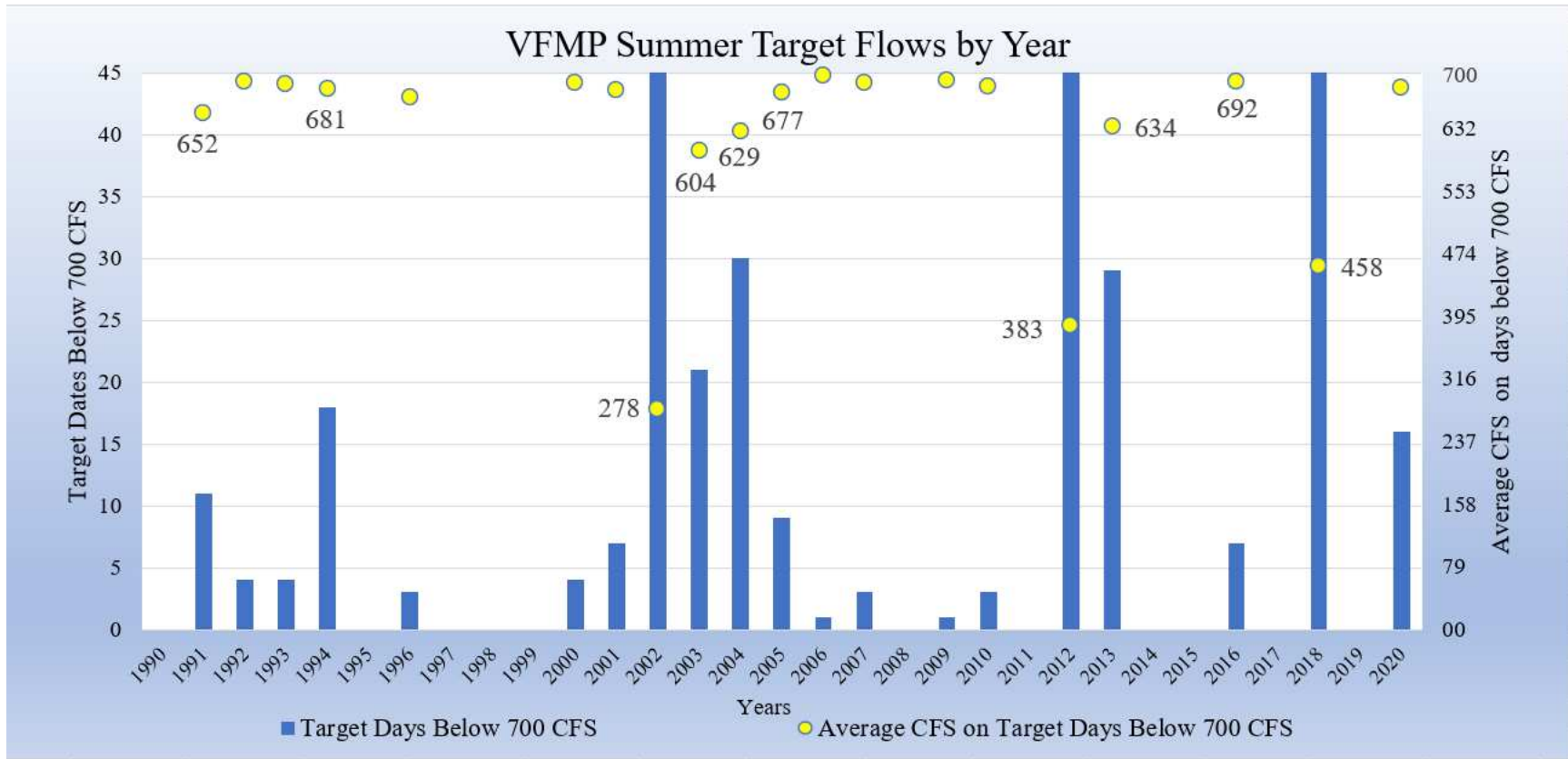


Figure 5.3 VFMP Summer Target Flows by Year (DWR, 2021)

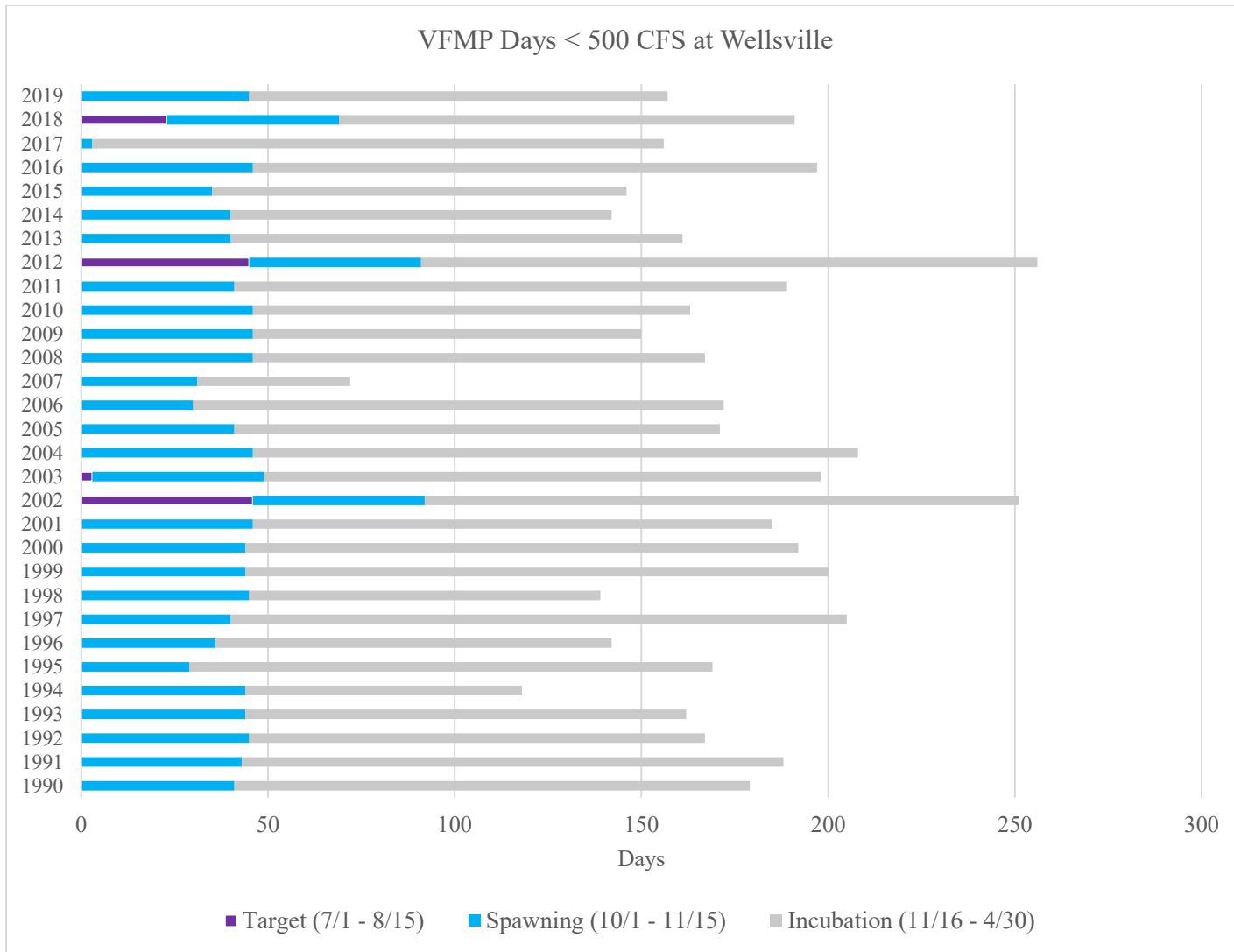


Figure 5.4 VFMP Summer Target <500 (DWR, 2021)

### 5.3 VFMP Social Dynamics

An examination of the VFMP's social structure is key to understanding how this program responds to hydrologic change. The VFMP has important characteristics that can help buffer the program from hydrologic stress and unpredictability. As described by AMC literature, the VFMP's success is boosted by a commitment to a collaborative, multi-stakeholder program, and a shared, social learning process where adaptable decisions can be made.

Because of these social buffers, when the flow targets are not met, the VFMP can still preserve the ability to achieve good faith planning and goodwill from other parties. These social dynamics allow the VFMP stakeholders to adapt to different hydrologic stressors. For example, they can adjust the program according to the flows and they learn unique lessons from it each year.

The social capital of participating in a collaborative program is a driving force for cooperation that does not show up in the text of formal documents and legal degrees. When parties other than the VFMP signatories participate voluntarily, the other stakeholders notice. For example, Pueblo is a major contributor to the summer flow program and the rafting community is aware of that. The PBWW manager explained the two-way benefit that goodwill can bring to a group. "It pays for itself. If you have a good relationship with other people on the river, it makes it easier to do projects because you've built up a level of trust among different parties." The AROA director, representing the rafting community, confirmed that the municipalities participation has been positive. "It is such good PR and such a great model that everybody loves being part of it."

A Chaffee County Commissioner took notice of the municipalities' willingness to consider the flow program in their water rights and exchanges. "It quickly became this thing

where people started having to build... around the flow program,” he said. “Because once we asked it of one, it started to become required of all... everybody's invested in it. Everyone's built their ... water management practices around it. It's here to stay. And it also isn't going to change.”

To help formalize the participation, some water rights holders with rights junior to the VFMP now have a legal obligation to acknowledge to program. Chaffee County holds a Recreational In-Channel Diversion right for recreational flows on the Upper Arkansas, and water rights junior to 2006 cannot injure it (Pueblo West Metro, 2006). A related 2006 MOU even further solidified these agreements. A supervisor from Colorado Spring Utilities (CSU) expressed the importance of the MOU agreements. “We have a pretty well-established set of rules where maybe we're not technically like hard and fast bound to, but we've agreed that we're going to try our best to support the VFMP goals.” For example, there are some limitations on moving water into Pueblo Reservoir during the winter because of the VFMP. There is also a legal expectation that certain exchanges and water rights will not limit the 10,000 AF of Project water during the summer flow target dates. For example, a 2007 water right by Pueblo West at Ranch Hill was legally opposed from diminishing the designated Project water (District Court Water Division 2, 2008).

The program relies heavily on established lines of communication to make decisions that benefit all parties. Every interviewee referred to the importance of communicating at multiple different levels and scales. A 5-year renegotiation of the VFMP and seasonal meetings in the spring and fall, bookending the summer target flow, are examples of a formal correspondence explicit in the VFMP text. During the most stressful seasons, informal lines of communication

ramp up. The CSU supervisor explained, “especially in drier years- as you can imagine, there will be phone calls. If things are going bad, there'll be weekly phone calls.”

The benefits of these long term established lines of communication, both formal and informal, are apparent. Decisions and ideas are exchanged quickly and regularly. The representative from Southeastern described the process during the dynamic summer of 2020. “We were on the phone every week with Colorado Parks and Wildlife, Pueblo, the South East District, and some of the representatives from the outfitters, and Trout Unlimited talking about what those flows would do throughout the summer.” The parties are aware of the each other’s situations so factors like the status of reservoir storage and exchanges are not an unwanted surprise to an unsuspecting party. This allows for the most efficient use of water and the ability to be flexible for any sort of hydrologic challenges.

For example, the summer target flow target has been lowered midseason, if need be, to prevent a total loss. The AROA director recalled an example where the 10,000 AF of flow was not enough to hit the 700 cfs target. “If it's not going to supplement the flow to keep it at that level then we start to work on trying to figure out a lower target.” In 2013, they actually adjusted the target flow midseason. Drought conditions for a second consecutive year was devastating and stressful for recreation and other water users. Starting in the second week of July, the target was adjusted up and down through August, reaching as low as 600 cfs. There were mixed feelings about this tactic. On the one hand some VFMP participants were happy to allocate the valuable water during a desperate summer while still being able to salvage flows for recreation. On the other hand, some members of the rafting community were disappointed about lesser flows. In Browns Canyon, 600 cfs not ideal, but can still support rafting compared to sub-400 cfs.

Hydrologic factors can compromise the ability for these entities to contribute voluntarily to the VFMP; but because of the social capital earned throughout the years, a great deal of trust has been built among the VFMP stakeholders. For example, the water operations specialist from Reclamation talked about a situation where Reclamation/Southeastern may not be able to provide 10,000 AF. “But the State [AHRA] understands that. If we don't have the water then we just don't send it down. So, when we are short on water, they [the VFMP stakeholders] work to make sure what we're doing maximizes what's available.”

Similarly, if the water is not available, the municipalities might have to move water to meet their own demands at a time that is harmful for the VFMP. The CSU supervisor recounted a rare season when the municipalities were hamstrung by low flows. “I think 2012 and 2013 was the last time where we kind of butted heads a little bit just because we were desperate to get water upstream. We didn't really have any paper trade opportunities. We did have to institute a bit of a river exchange just to get some water upstream.”

Besides being able to make adaptable decisions and compromises, trust and frequent communication also allows social learning to prosper in the VFMP. According to ACM literature, social learning is the “mutual development and sharing of knowledge by multiple stakeholders... through learning-by-doing” (Armitage et al, 2009). Learning as a group is an on-going process that relies on a variety of expertise and ideas to be most effective.

Trust building and productive social learning within the VFMP took decades to create and cannot be taken for granted. The former AHRA park manager worked hard during his career to establish a trusting environment. “It's no singular person that made this work. It was a lot of trial and error and a lot of head scratching and a lot of phone calls between people and a lot of ‘what really worked this year’ and ‘how can we make it better,’ and thinking outside the box and

doing things differently.” At the inception of the VFMP, it took exceptional effort to effectively present new ideas and gain the trust of the other stakeholders. The long-time fish biologist explained that there was no precedent for water managers to acknowledge recreation or aquatic ecology as important factor in the Basin. “It took a lot of really good data driven studies to be able to show them the relationship with a high degree of confidence.” This early struggle founded the symbiosis of recreation and fish health central to the VFMP today.

Through decades of a deliberate learning process, the VFMP stakeholders have developed nuanced understanding of Upper Arkansas flows. The success of the summer target flow is largely dependent on the water managers who draw on a combination of quantitative hydrologic data and hard-won personal experience to inform their day-to-day water management decisions. Interviewees mentioned relying on SNOTEL sites for snowmelt runoff timing and amounts and National Oceanic and Atmospheric Administration (NOAA) forecasting models that can help predict monthly climate trends. A water resource engineer from CPW elaborated on why these tools alone were not sufficient for decision-making, however. “You have enough people that have enough experience on the river too that their intuition really comes into play. We definitely trusted that throughout this past [2020] summer as well... Ultimately that's the biggest gut check on any data- having a real intuitive feel on what the numbers should be and when to throw out bad data, and whatnot.”

Also, interviewees mentioned that a new generation of forecasting and watershed modeling technologies are expected to come online in the near future to assist the decision-making process in the Upper Arkansas Valley. Reclamation, CPW, and CSU already use in-house spreadsheet models to help keep track of their water. In addition to the in-house models and spreadsheets, the Division of Water Resources is preparing a new model available to the

public that will count the exchanges and additions of flows in the Upper Arkansas. Hopefully, this new tool will add some consistency to the data that will help the VFMP stakeholders revisit and remember exactly what happened in previous years. Then, they can learn lessons from every season, regardless if there was success or failure. There are a limited number of SNOTEL sites in the Upper Basin so air-based LIDAR technology may have the ability to more accurately observe a larger range of high elevation snow conditions, and thus more accurately predict the runoff trends. Also, the instillation of new fiber optic cables will make new connections to remote mountainous areas so Reclamation can increase the response time to spring runoff and, thus increase the efficiency of catchment basins' ability to collect runoff.

The CPW engineer was optimistic about this new generation of technology. "In my eyes, developing more tools and more ways to collaborate, look at numbers, and modeling and scenarios might have some really big benefits." Individually, these examples might only help with the efficiency of the VFMP flows around the margins, adding or saving a few AF, if at all. But collectively, a new generation of technologies and ideas may have greater potential to help the VFMP respond and adapt to the looming hydrologic variations in the Basin.

Because the VFMP is collaborative in nature, everyone involved needs to be accepting of new tools and models. He continued, "ultimately, I think a tool that's used for a group needs to be done organically." Introducing new tools and models to a group with a plurality of ideologies can be a challenge. The pattern of social learning in the VFMP shows adaptability as much more of a process than a product. An on-going conversation is going to uphold the VFMP's collaborative nature, trustworthy environment, and frequent communication, and likely, it will yield the most informed decisions.

## CHAPTER 6

### DISCUSSION

The results section examined the ways the VFMP can be resilient to hydrologic variations due to climate change. Furthermore, the discussion considers if the VFMP needs to change in the future to maintain or increase its resilience. If these climate change realities come to fruition in the most extreme scenario, 30 years from now what would the water managers of the Upper Arkansas Basin be thinking? 30 years ago, at the inception of the VFMP, water managers did not yet experience the deep and serious drought of 2002. They did not have to deal with the extraordinary population growth in Colorado. The gold medal fishery was not established yet and white-water rafting was not as popular as today. And despite these changes and challenges, the VFMP can be considered as successful as ever given its overwhelming support by the stakeholders. Evidence of this is in the MOUs that parties outside of the VFMP have been willing to sign, and the pattern of cooperation to meet the VFMP's goals.

A commitment to collaboration and an active social learning processes has given the VFMP the ability to adapt over the past 30 years. But like the 2002 drought, the VFMP is bound to encounter future "pivot points" that will challenge the program's social adaptations that buffer hydrologic disturbances. These adaptations appear to be adequate for holding the VFMP thus far, but it remains to be seen how far they will take the VFMP into the future. Optimistically, the VFMP is on a strong course to maintain its inherent ability to adapt for the next 30 years, and hopefully beyond.

The VFMP relies so heavily on the supplemental 10,000 AF of Project water. In some years when that water is not available, the program has completely failed to reach the summer target. 700 cfs was not hit for a single day in 2002, 2012, and 2018. Clearly, the VFMP was not

designed for an extreme drought, and the rafting industry would suffer from it. However, there are two unique adaptations in which the VFMP can still derive success during low water conditions. One, there is a positive benefit to the fish population during these years, and this contributes to the Gold Medal standard on the Upper Arkansas. Two, water managers have adjusted the flow target in order to respond to a variety of water needs and still somewhat protect the white-water rafting experience.

These features are important to the VFMP, but it remains to be seen if they are long-term adaptations to more frequent droughts. In theory, there must be breaking point where a drought could have a major negative effect on aquatic ecology and threaten the Gold Medal Fishery. Also, adjusting the flow target frequently and often during drought years could add concern to the recreation industry. The white-water outfitters might have to decide if a scenario of a shorter season with higher flows or a longer season with lower flows would be better for business. Extra economic stress would add pressure and urgency to any water management decision.

While the characteristics and consequences of a drought is more obvious, the challenges from earlier spring runoff also present significant “pivot points.” In the climate change literature, this phenomenon is occurring throughout the American West, but it is still anecdotal in the Upper Arkansas Valley given the noisy signals. The inherent variability in the system makes it hard to monitor and forecast runoff. Datasets like percentage of annual snowpack and snow-water equivalent can be monitored throughout the winter and spring, possibly informing water managers of an impending drought. Unlike drought, runoff occurs quickly, and the SNOTEL observations may not have the ability to forecast it. A sudden heat wave can turn on the faucet fast. Water managers have shorter windows to really adapt to early runoff.

Currently, there are not many adaptations in the VFMP to address climate change challenges, besides quick, reactionary action. Therefore, continuing the social learning around spring runoff is super important to future success. Quick fix solutions are not readily available because these climate change challenges are long-term and ongoing. Right now, for example, the fiber optic technology can improve Reclamation's ability to control catchment basins in order to optimize runoff imports into the Boustead Tunnel. SNOTEL sites observe important parameters, but are few and far between, and may not be very indicative of runoff in system as a whole. Potentially, air-based LIDAR technology can give water managers real time information about snow conditions across a greater area during the short windows of runoff. The development of DWR tool could provide a consistent data set for all interested parties, possibly informing decisions that set up the rest of the water year.

Looking back at the 30 years of the VFMP, the consistent buy-in from all the major players in the basin was key for the VFMP's ability to adapt and be successful in the face of several hydrologic challenges. The achievements of this collaborative effort should be celebrated. The social capital and goodwill amongst all parties was earned. Good relationships allow for the VFMP to adapt- and this success leads to more goodwill. But these past accomplishments are not given as climate change challenges become more urgent and. So far, they have been able to build a buffer with social relationships and communication, but it is unknown if these relationships will continue to hold together as the hydrology changes. A few difficult seasons could challenge the positive feedback loop of adaptability and good relationships. Based on interview data, despite some rough patches, there is strong social capital in this system. They haven't found the limits to this yet- or the breaking point. With strong legal

mechanisms in place and a consistent dedication to a long-term goal, the hope is that the VFMP will never find this breaking point.

## CHAPTER 7

### CONCLUSION

The current success of the VFMP is a tribute to 30 years of stakeholder commitment, trust building, and compromise. The long struggle has allowed its stakeholders to refine it into a program where the expectations of the participants are obvious and it fulfills everyone's needs. Future hydrologic variations caused by climate changes will challenge the VFMP in its current iteration. Early spring runoff and droughts are the most urgent examples of climate change in the Basin. However, the VFMP stakeholders continue to move forward diligently so the program can remain resilient to major challenges.

Future research questions surrounding the VFMP may be examining the transferability of the program. The physical infrastructure of the Upper Arkansas Basin is a factor that can hinder transferability, but a further study could contemplate the social aspects of the program that can be universal to water management. This program can be used as a model for other flow management programs that deal with trans-basin diversions, dam management, recreation, or a fishery. A formal study regarding the locations for new storage facilities could help benefit the VFMP and the interests of other water users. Continuous updates on climate change scenarios within the Basin would benefit hydrology literature as a whole and add to the limited research in the Upper Arkansas Basin.

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