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Ecological Drought: Accounting for the Non-Human Impacts of Water Shortage in the Upper Missouri Headwaters Basin, Montana, USA

Jamie McEvoy [1,*], Deborah J. Bathke [2], Nina Burkardt [3], Amanda E. Cravens [3], Tonya Haigh [2], Kimberly R. Hall [4], Michael J. Hayes [5], Theresa Jedd [2], Markéta Poděbradská [2] and Elliot Wickham [2]

[1] Department of Earth Sciences, Montana State University, Bozeman, MT 59715, USA
[2] National Drought Mitigation Center and School of Natural Resources, University of Nebraska, Lincoln, NE 68583, USA; dbathke2@unl.edu (D.J.B.); thaigh2@unl.edu (T.H.); tjedd2@unl.edu (T.J.); podebradska.marketa@huskers.unl.edu (M.P.); Elliot.wickham@huskers.unl.edu (E.W.)
[3] Fort Collins Science Center, U.S. Geological Survey, Fort Collins, CO 80526, USA; burkardtn@usgs.gov (N.B.); aecravens@usgs.gov (A.E.C.)
[4] North America Region, The Nature Conservancy, Haslett, MI 48840, USA; kimberly.hall@tnc.org
[5] School of Natural Resources, University of Nebraska, Lincoln, NE 68583, USA; mhayes2@unl.edu (M.J.H.);
* Correspondence: jamie.mcevoy@montana.edu; Tel.: +1-406-994-4069

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Abstract: Water laws and drought plans are used to prioritize and allocate scarce water resources. Both have historically been human-centric, failing to account for non-human water needs. In this paper, we examine the development of instream flow legislation and the evolution of drought planning to highlight the growing concern for the non-human impacts of water scarcity. Utilizing a new framework for ecological drought, we analyzed five watershed-scale drought plans in southwestern Montana, USA to understand if, and how, the ecological impacts of drought are currently being assessed. We found that while these plans do account for some ecological impacts, it is primarily through the narrow lens of impacts to fish as measured by water temperature and streamflow. The latter is typically based on the same ecological principles used to determine instream flow requirements. We also found that other resource plans in the same watersheds (e.g., Watershed Restoration Plans, Bureau of Land Management (BLM) Watershed Assessments or United States Forest Service (USFS) Forest Plans) identify a broader range of ecological drought risks. Given limited resources and the potential for mutual benefits and synergies, we suggest greater integration between various planning processes could result in a more holistic consideration of water needs and uses across the landscape.

Keywords: ecological drought; drought planning; prior appropriation; instream flows; Upper Missouri Headwaters Basin; Montana

1. Introduction

1.1. Overview

Water laws and drought plans are used to prioritize and allocate scarce water resources. Both have historically been human-centric, failing to account for non-human water needs. We begin this paper with an overview of water laws that govern water allocation in the western U.S. and the development of instream flow legislation to redress some of the ecological impacts caused by early water development. We then provide a brief history of drought planning, which has primarily focused on the agricultural and socio-economic impacts of drought. Utilizing a new framework for ecological drought, we introduce the case study and methods used to understand if, and how, the ecological impacts of drought are currently being assessed in seven watersheds in southwestern Montana (MT). After presenting the results of our analysis, we discuss the limitations of legislation and drought plans focused on minimum streamflows and suggest opportunities for more comprehensive approaches to watershed drought planning.

1.2. Water Rights in the Western U.S.

Often described as "first in time, first in right," the legal doctrine of prior appropriation that governs water allocation throughout most of the western U.S. is a system that gives those who first made use of water ("first in time") higher priority rights to the water ("first in right"). Unlike the common law system used in the eastern U.S. that tied rights to water to land ownership of land bordering a river, the prior appropriation system allowed users to divert water to properties away from the river, a key development in an arid environment. Prior appropriation assumes that someone is diverting water away from a stream to put it to a "beneficial use." The original 19th century notion was that beneficial uses included agriculture, mining, domestic use, and other industry; water left in the river was presumed to be available for someone else to divert and claim [1,2].

The prior appropriation doctrine has three important implications when water becomes scarce. First, in times of water shortage, the user with the most senior right to divert water ("water rights") receives their full allotment before the next user receives any water. Second, prior appropriation contains a provision (originally designed to prevent speculation and hording of water) that if a water right is not used regularly, it is considered abandoned; fear of this "use it or lose it" rule provides a disincentive for keeping water in the stream. Finally, if the number of water rights on a given section of river becomes great enough, the human needs for which water is being diverted (e.g., agriculture, mining, urban development) and the needs of species and ecosystems that depend on water being left in the river can come into conflict. Even in a "normal" year, there can be insufficient water left in the river for fish and other ecosystem needs during later summer months, especially in places where stream flows are fed by snowmelt. The scarcity of water during times of meteorological drought (i.e., dry weather patterns and below average precipitation) amplifies these tensions. In southwestern Montana, water shortages have led to the adoption of innovative new mechanisms aimed at keeping more water instream.

1.3. Mechanisms for Protecting Instream Environmental Flows

The early "beneficial uses" of water in the western U.S. were consumptive uses that diverted water away from a stream (e.g., mining, irrigation, municipal water use). With increasing recognition of the benefits of adequate water quantity and quality to ecological and human systems, state and federal legislation has more recently focused on protecting instream flow values. Federal laws such as the Wild and Scenic Rivers Act of 1968 [3] and section 404 of the Clean Water Act [4] provided instream flow protection for defined purposes and specific reaches of streams or rivers. The first state to give legal recognition to instream uses of water was Oregon, in 1955. Montana took steps toward instream flow protection in 1969 by establishing "Murphy Rights" for twelve Montana streams. The Montana Fish and Game Commission can file to allocate unappropriated water in the amount necessary to protect fish and wildlife habitat on these blue-ribbon streams [5].

The Montana Water Use Act of 1973 [6] established a mechanism for state and federal entities to seek limited instream flow protection; these rights are held by Montana Fish, Wildlife, and Parks (MFWP). The allowable purposes of an instream flow are broad in Montana and include protection of existing or future beneficial uses, or maintenance of minimum flow, water quality or water level. When an existing consumptive water right is changed to an instream flow use, the original date of the water right applies. For example, in the Blackfoot drainage public recreation water rights exist with dates as far back as 1928, while public recreation claims in the Bitterroot basin are quite junior, with priority dates in the 1970s.

Minimum flow is usually a single threshold beyond which water cannot be withdrawn for consumptive use, and frequently provides sub-optimal habitat conditions for aquatic species [7]. The "wetted-perimeter" method, which calculates the amount of water needed to sustain critical habitat for fish migration, spawning and food production at the shallowest part a river (usually a riffle) is one of the more common ways of quantifying the instream flow needs of fish [8]. As scientific understanding of the dynamic nature of river ecosystems has increased, some laws and regulations have shifted to support variable flow regimes, rather than minimum flows. Processes for establishing instream flow recommendations, especially more comprehensive methods, can be costly, time-intensive, and require specialized knowledge [9].

Limitations of instream flow policies in Montana include: (1) Instream flows are bounded by original 'dates of use,' making it difficult to transfer to use for a specific time of year; (2) even the oldest instream flow rights are quite junior and are subject to the "first in time is first in right" rule. As an example, Murphy rights are junior in priority and can be revoked if a District Court determines the water should be put to use in a way that is more beneficial to the public; (3) instream flow rights are subject to reviews and can be modified or revoked if the objectives of the reservation are not being met [10], if another applicant is deemed to be a "qualified reservant" [11], or if the reservation may harm future development [12]; (4) rights cannot exceed 50% of the annual flow of the stream, which may not be adequate to protect some values [12].

Another set of mechanisms for maintaining instream flows include cooperative agreements and drought planning. In some cases, the threat of an endangered species listing provides an incentive for water users to proactively develop a plan to mitigate the impacts of water shortage through a Candidate Conservation Agreement with Assurances (CCAA). These agreements between the U.S. Fish and Wildlife Service (USFWS) and any non-Federal entity allow the latter to voluntarily implement conservation activities that remove threats to endangered or threatened species in exchange for assurance that, if the species were to become listed under the Endangered Species Act (ESA), the landowner or water user would not be subject to additional restrictions [13]. In the Upper Missouri Headwaters (UMH), the fluvial artic grayling (*Thymallus arcticus*) is the target species for CCAAs which aim to:

1. Improve streamflows;
2. Improve and protect the function of riparian habitats;
3. Identify and reduce or eliminate entrainment threats for grayling;
4. Remove barriers to grayling migration [14].

Beyond these contractual agreements, there are also examples of extralegal "shared sacrifice" agreements [15,16] whereby neighbors agree to reduce irrigation withdrawals in dry years, typically based on a predetermined streamflow level and/or water temperature that triggers a reduction in irrigation withdrawals. In some cases, these "shared-sacrifice" agreements are very informal—based only a handshake. In other cases, these agreements are made legible through a written and publically-available document. In the UMH basin, these documents range from a 1988 *Plan to Avoid Dewatering of the Ruby River Project* [17] that is primarily focused on ensuring that senior water rights holders receive their full allotments in dry years to a recent 2016 *Beaverhead Watershed Drought Resiliency Plan* [18] that provides a detailed assessment of the regional geography and climate, a relatively broad list of drought impacts, and an overview of current and potential drought indicators. As discussed below, the development of watershed drought plans is a priority for the state of Montana.

Other legal mechanisms for protecting instream flows in Montana include leasing or conversions, authorized by the Water Leasing Bill (HB 707; 1989); purchase or service contracts for water delivery from water storage projects, and designation of closed basin watersheds. However, it is beyond the scope of this paper to discuss these mechanisms.

1.4. History of Drought Planning

Droughts in the United States have a long legacy of devastating agricultural impacts that have affected crop production and disrupted settlement patterns and livelihoods [19]. The quantification of agricultural impacts is still the main source of additions to the list of 25 "Billion Dollar" drought disasters across the U.S. since 1980 [20]. Recently, however, there is a growing awareness of the complex range of drought impacts that affect a broad spectrum of sectors including natural resources, energy, recreation and tourism, and public health [21,22]. Although less apt to be quantified [23], the impacts of droughts on non-agricultural livelihoods and ecosystems are considerable. Past droughts impacts, and the projections that future droughts may become more frequent and severe in some parts of the country [24,25], illustrate that planning ahead for drought events at a variety of scales and sectors is essential.

Drought planning in the U.S. is a relatively recent phenomenon that has lagged behind the planning for other natural hazards. It first appeared as a concept when Don Wilhite, at the University of Nebraska, analyzed the federal response to the severe 1976–77 drought event and began advocating for proactive drought risk management at the state and local levels [26]. Three key elements of drought risk management include: (1) early warnings of drought risk, based on the continuous assessment of appropriate indicators, (2) impact and vulnerability assessment, and (3) response and mitigation strategies [26,27]. Accurate early warning information is essential for drought risk management because decision makers require this information to implement effective drought response activities, recovery programs, and proactive drought policies [28]. Impact and vulnerability assessments identify the principal activities, groups, or regions most at risk and why. The response and mitigation component should identify both actions that minimize impacts during a drought event (response strategies) and actions that reduce risk in advance of drought (mitigation strategies). While drought impacts are increasingly recognized across multiple sectors [21], incorporating the full suite of sectors into drought planning is a challenge. In particular, the ecological impacts of drought, and the connections between natural systems, ecosystem services, and societal values (e.g., non-agricultural livelihoods, public health, recreational opportunities) have not been accounted for in most drought plans. Case studies from across the globe, including California [29,30], Australia [31,32], Kenya [33], and Bangladesh [34] have brought attention to the need for assessing and understanding the ecological impacts of drought.

Following a recent publication by Crausbay and Ramirez et al., highlighting the importance of considering risks to people and nature from ecological drought impacts [35], we investigated the extent to which ecological risks are already being incorporated into drought planning in the Upper Missouri Headwaters (UMH) region in southwestern Montana. Ecological drought is defined as "an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems" [35] (p. 24). Crausbay and Ramirez et al. [35] pair this definition with a framework (Figure 1) that promotes a holistic consideration of drought in which natural processes (e.g., precipitation, transpiration by plants) and human actions (e.g., water use, land management that interact with hydrologic processes) interact to influence drought impacts [21,36]. The premise behind this definition and framework is that a more complete accounting of what influences water availability and drought risks to both ecosystems and people will lead to more effective plans and more sustainable communities (see also [37,38]).

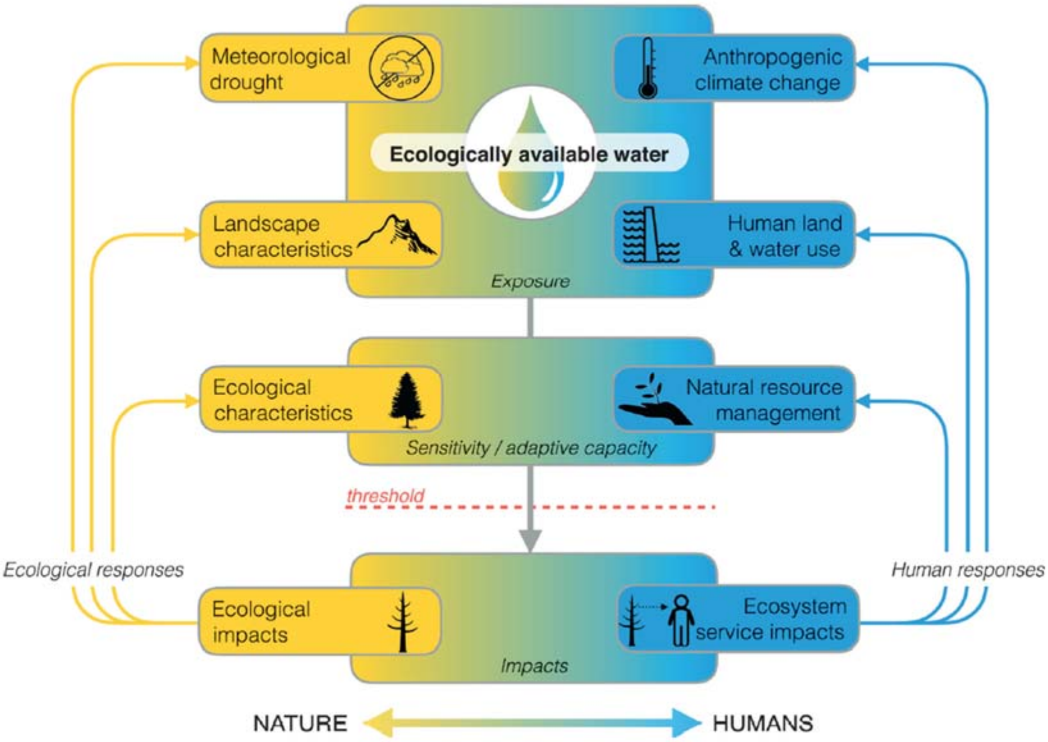

Figure 1. Ecological drought framework from Crausbay and Ramirez et al. [35].

2. Case Study Description

Drought preparedness and planning are named as priorities in Montana's 2015 State Water Plan, which emphasizes that:

> Drought preparedness requires a collaborative approach within small- to medium- sized watersheds. Working together, water users and water management agencies can develop adaptive management strategies that can yield benefits to water supply, fisheries, and water quality. Adaptive management also requires effective coordination between state and federal agencies responsible for managing water supply, water quality, fisheries, and drought and water supply forecasting [39] (p. 69).

One region within Montana that has been the particular focus of such an approach is the Upper Missouri Headwaters (UMH) in southwestern Montana (i.e., Missouri Headwaters HUC 6 Watershed; Figure 2). The UMH was selected as one of two demonstration projects by the Obama Administration's National Drought Resilience Partnership (NDRP). The State of Montana and the NDRP—a "collaborative of federal and state agencies, non-governmental organizations (NGOs), and watershed stakeholders--are working together to leverage and deliver technical, human and financial resources to help address drought in the arid West" and particularly in the UMH [40] (p. 2). The UMH region has experienced frequent droughts, changing land use practices, and population growth. The landscape holds a variety of ecological values, including connectivity within the northern Rockies ecoregion, that are important to a variety of species and human stakeholders. The NDRP project focuses on providing state and federal resources to meet the goal of "empowering local communities to prepare for and mitigate the impacts of drought on livelihoods and the economy" [40] (p. 2). It thus builds on Montana's strong legacy of local watershed groups working to restore and protect watersheds [41] both within the UMH and farther afield; these groups have pioneered local-scale solutions to drought preparedness, including "shared sacrifice" agreements between farmers and anglers [40,41].

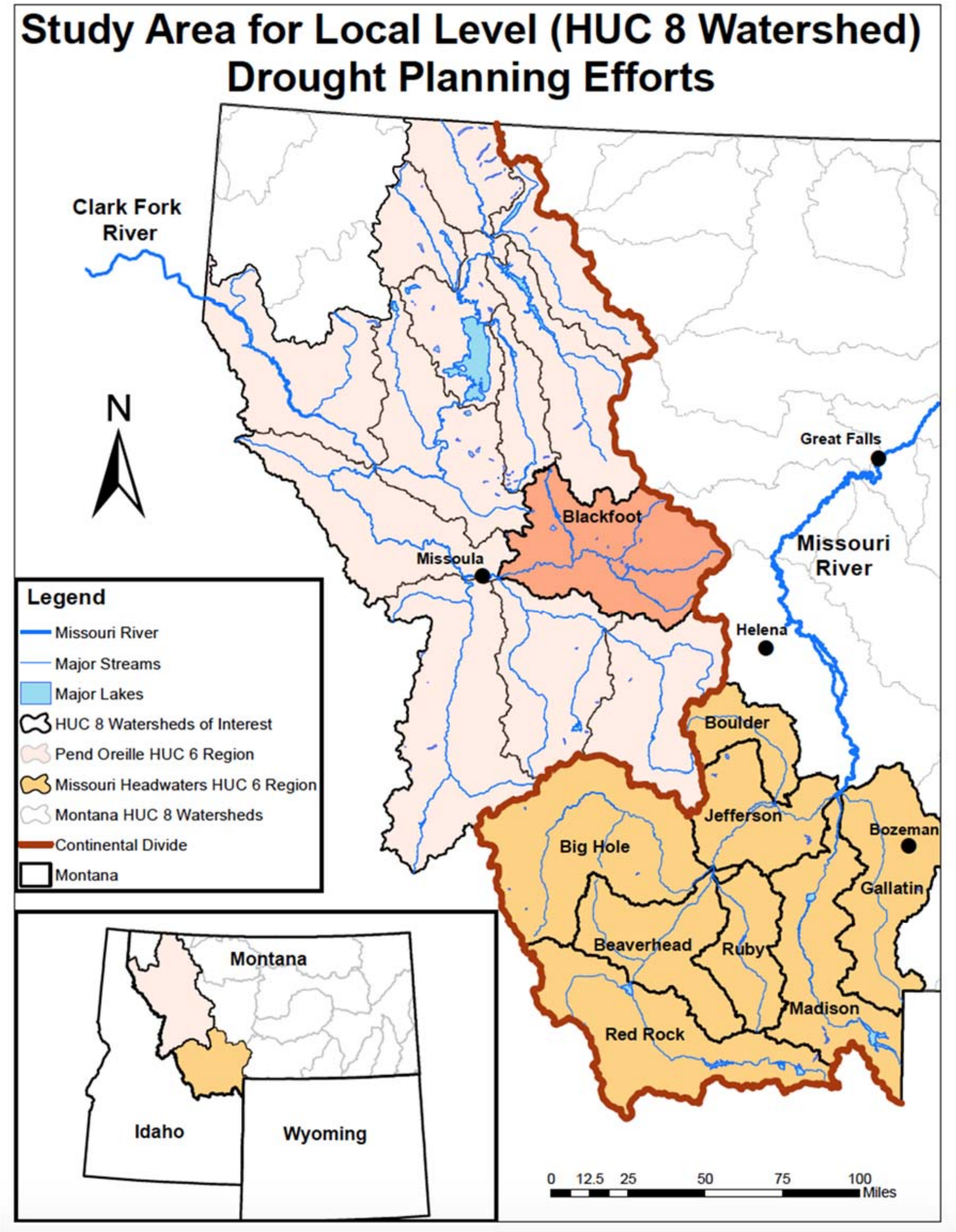

Figure 2. Map highlighting watersheds in the Upper Missouri Basin, and the Blackfoot watershed.

This study focuses on the six watersheds of the UMH basin (Boulder-Jefferson, Big Hole, Gallatin, Madison, Ruby, and Beaverhead-Red Rock), as well as the Blackfoot watershed (Figure 2). The reasons for selecting this region as a case study for examining ecological drought are twofold. First, given the ecological values within the basin, including blue-ribbon trout streams and proximity to National Parks and wilderness areas, we expected that some drought plans would already address ecological impacts. Second, as discussed above, this region has been the focus of a pilot project for the National Drought Resilience Partnership. The Blackfoot watershed, which is outside the UMH boundaries, is included in our analysis because it was one of the earliest watersheds to adopt a "shared-sacrifice" model for addressing water shortages and is often referenced by water planners from the Montana Department of Natural Resources and Conservation (DNRC) as an excellent model for drought planning.

3. Methods

Of the seven watersheds in our study area, five have some form of drought plan [17,18,42–44] (Table 1). Currently, there are no drought plans for the Gallatin River or Madison River watersheds (The city of Bozeman, the largest town in the Gallatin Watershed, developed a Drought Management Plan in 2017. However, the scope of this city drought plan is different than a watershed drought plan and, therefore, was not included in this analysis. Efforts to update or create drought plans for all six UMH watersheds is currently underway as a part of the UMH-NDRP project). All six UMH watersheds and the Blackfoot watershed have restoration plans. We collected copies of all available plans and qualitatively coded and analyzed the plans.

Table 1. List of drought plans, year of publication, and associated watershed.

Plan Name	Year of Publication	Watershed
Jefferson River Watershed Committee (JRWC) Drought Management Plan [Jefferson Plan]	First published in 2000. Updated in 2007.	Jefferson and Boulder Rivers
Big Hole River Drought Management Plan and Plan Amendments (2002–2016) [Big Hole Plan]	First published in 2002. Amended through 2016.	Big Hole
Plan to Avoid Dewatering of the Ruby River Project [Ruby Plan]	1988	Ruby
Beaverhead Watershed Drought Resiliency Plan [Beaverhead Plan]	2016	Beaverhead and Red Rocks Rivers
Blackfoot Drought Response Plan [Blackfoot Plan]	Revised 2016	Blackfoot [1]

[1] The Blackfoot watershed is located outside the UMH Basin.

Our multi-disciplinary team (climatologists, ecologists, and social scientists) developed a drought plan coding scheme through an iterative process [45]. This coding scheme was informed by reviews of drought impact literature [46], the three pillars of drought management [27] and the framework for ecological drought [35]. We developed coding categories, co-coded sample plans, and compared inter-coder interpretations to arrive at common definitions and codes. The full coding scheme for each plan includes the planning background, overall plan approach, planning process, all drought impacts, climate change impacts, descriptions of vulnerability factors, indictors and monitoring, and plan actions. Each plan was coded independently by two team members, using NVivo 11 (QSR International). We assessed inter-coder reliability through team discussion and refinement of definitions and codes.

In this paper we focus on the degree to which each drought plan (1) identifies ecological impacts of drought (including mentions of impacts to fish, wildlife, other species, water quality, groundwater, wetlands, rivers, snowpack, wildfire, forests, grasslands, and ecosystem services), (2) identifies indicators of drought, and (3) states whether those indicators trigger drought mitigation or response actions. We summarized coded sections for each of these elements for further analysis, and recorded every mention of an ecological impact (Table 2) or drought indicator (Table 3) from each plan. Given that some impacts and indicators were thoroughly addressed while others were simply mentioned, we developed a scoring system for ecological impacts and indicators (Tables 2 and 3), following the criteria provided by Steinemann et al. [47]. Drought planning literature [26] emphasizes the need for specificity in the indicators and triggers portion of a drought plan. Plans should contain sufficient information about how indicators are measured, and the values used to trigger drought responses to assist current and future personnel in managing water resources during drought [48].

To help provide context for understanding the extent to which ecological impacts of drought were recognized by stakeholders within these watersheds, we also coded a set of Watershed Restoration Plans for the study area using the same coding scheme. In compliance with Section 319 of the federal Clean Water Act, these plans identify the causes and sources of water impairment within the watershed, identify indicators for monitoring water quality, and describe management activities that can help achieve watershed goals. This analysis allowed us to compare the list of impacts and indicators (Tables 2 and 3) from the drought plans to another list of ecological impacts and indicators, highlighting differences in the types of ecological drought impacts addressed. While this is a preliminary assessment, the comparison allows us to explore additional impacts and indicators used in other planning processes that could be applied to drought planning.

4. Results and Discussion

> "When people say 'health of the river', what they really mean is the health of the fisheries in the river. [It's a] fairly narrow ecological view."
>
> —local watershed coordinator, UMH

In our drought plan analysis, we found that some ecological impacts of drought were considered in all five drought plans (Table 2). Given the dominant focus in drought planning on agricultural and socio-economic impacts, the recognition of *non*-human impacts is an important finding. However, the analysis shows that the scope of ecological impacts mentioned within these watershed plans is generally limited to fish populations and fish habitat (Table 2) as monitored through two primary indicators: streamflows and water temperatures (Table 3). While this finding suggests a narrow view of ecological impacts, it is useful to show some examples of the way ecological impacts and indicators were discussed in the drought plans to provide more nuance.

4.1. Ecological Impacts

Some plans clearly demonstrate consideration of scientific information from the fields of ecology and fisheries biology. For example, the Blackfoot Plan discusses how drought affects fish populations, fish habitat, and briefly mentions native fish recovery and management. The plan provides detailed biological and ecological information, including the following description of the importance of riffles (rocky or shallow sections of a stream with rough or rippled water) for fish habitat:

> Riffles are critical because they produce the chlorophyll (plant life) and forage (insects and small fish) that fuels the upper trophic levels (e.g., larger trout) of the ecosystem. In addition to basic river productivity, riffles provide spawning areas and habitat for juvenile trout and forage-fish alike. Entire communities—species ranging from midge to salmonfly, dace, sculpin and juvenile whitefish live in the cracks and crannies of cobbles that form the riffle. This forage base—the grocery list at the lower end of the food chain—sustains predatory species like trout as well as dependent wildlife in the upper food chain. When the wetted-width of the riffle narrows, river productivity rapidly declines and the forage base that sustains thriving trout fisheries is greatly diminished.
>
> As the habitat base shrinks below minimal flows, it sets in motion a series of complex biological processes. These involve increased competition within fisheries communities for food and space; restricted movements between critical habitats (e.g., spawning sites and refugia); elevated mortality (at all trophic levels) as prey is concentrated; and cold-water communities become vulnerable to temperatures stressors depending on species and location. Juvenile fish are highly vulnerable to habitat loss and related stress and are the first to undergo population-level declines.
>
> As flows decrease, water temperature increases. With elevated water temperature, metabolic rates increase and dissolved oxygen levels decline, pollutants concentrate and coldwater trout become more susceptible to pathogens like fungal infections and whirling disease ([44], pp. 2–3).

While this description documents a broad understanding of the ecological impacts of drought across multiple species and processes in streams, the focus remains tied to the health of specific fisheries.

Similarly, the Big Hole Plan mentions broader ecological processes that can be affected by drought, such as changes in spring runoff conditions that are important for maintaining stream channels and moving sediment that would otherwise degrade riffles and other habitat features. This broader lens for understanding ecological impacts provides the potential for considering other interacting factors, such as land use near streams that can influence sediment movement. However, this plan, again, focuses on the relatively narrow objective of protecting to the health of fisheries and fish habitat, rather than considering how the stream ecosystem, and the watershed as a whole, may be at risk.

The Beaverhead Plan provides the most exhaustive coverage of ecological drought impacts including not only fish populations, but also wildlife, habitat, forest and range productivity, invasive weeds, forest fires, and ecosystem services. However, this exhaustive coverage of impacts did not translate into a high degree of specificity regarding how these impacts should be measured; nor did the ecological status of non-fisheries impacts trigger action (Tables 2 and 3). As a document designed to guide decision-making before, during, and after a drought, a drought plan should have specific indicators and actions. As Wilhite [26] notes:

> Drought indicators and triggers are important for several reasons: to detect and monitor drought conditions; to determine the timing and level of drought responses; and to characterize and compare drought events. Operationally, they form the linchpin of a drought management plan, tying together levels of drought severity with drought responses (p. 72).

Table 2. Ecological impacts mentioned in drought plans.

Ecological Impacts Mentioned in Drought Plans		**Blackfoot Plan**	**Big Hole Plan**	**Jefferson Plan**	**Ruby Plan**	**Beaverhead Plan**
Ecological Impacts	Fish mortality or fish populations	**3**	**3**	**3**	1	**3**
	Fish habitat	**3**	2	-	1	1
	Water Quality	-	-	-	-	2
	Native Fish Recovery & Management	1	-	-	-	1
	Aquatic ecosystems	1	-	-	-	1
	Wildlife habitat	1	-	-	-	1
	Concentrated pollution	1	-	-	-	2
	Wildfire or forest fires	1	-	-	-	**3**
	Forest productivity	1	-	-	-	-
	Tree mortality	-	-	-	-	1
	Wildlife mortality or wildlife populations	1	-	-	-	1
	Non-ag, natural resource-based livelihoods	1	-	-	-	1
	Ecosystem services	-	-	-	-	1
	Weed pressure	-	-	-	-	1
	Range and forage productivity	1	-	-	-	1

Ecological impacts mentioned in drought plans were assigned a numerical value based on the level of detail provided in the plan and if it was associated with a specific indicator [- = Not mentioned in plan; 1 = Impact mentioned, but no details provided; 2 = Impact discussed in some detail, but no indicator mentioned; 3 = Impact discussed with an indicator for monitoring].

4.2. Ecosystem Services Impacts

As emphasized in the Ecological Drought Framework [35], ecological drought affects humans through its impacts on ecosystems services [49]. While this is a human-centric way of assessing the effects of drought, it provides a conceptual approach for broadening the range of ecological impacts considered. We found some examples of this approach in the drought plans we reviewed.

For example, the Beaverhead Plan acknowledges that the blue-ribbon trout fishery supports an important angling and tourism sector in the area. The plan notes that low stream flows and high water temperatures affect the fishery and outfitters, as well as "local hotels, restaurants, and other businesses" ([18], p. 14). The plan mentions that drought conditions can affect wildlife populations and hunting access (p. 36), forest lands and associated ecosystem services (p. 22), and causes "proliferation of noxious weeds" which costs time, money and, human resources to control (p. 62).

The Blackfoot Plan mentions impacts to natural resource-based livelihoods and the potential loss of income and jobs for those who "depend on water and other natural resources" ([44], p. 3). However, the discussion is limited to impacts on crop production, livestock, outfitters, and "other businesses that depend on visitors [who will seek] other areas for fishing and recreational opportunities" (p. 3). While a link could be made between drought and forest-dependent livelihoods (e.g., timber, wildlife hunting outfitters), this is not explicitly stated; only impacts to agricultural and river-based livelihoods are mentioned. Given that the water available for streams and agriculture is connected to snow abundance and related run-off from forested uplands [39], a lack of consideration of forest health could lead to further degradation of the system. However, the drought plans do not make this link.

4.3. Indicators and Triggers

As shown in Table 3, the most common indicators that trigger some type of drought mitigation or response action are streamflows (cubic feet per second [cfs] or gage height) and water temperature. The minimum streamflow requirements established in the Blackfoot Plan, the Big Hole Plan, and the Beaverhead Plan are based on the same "wetted stream perimeter" (or "wetted-riffle") method that is used to calculate instream flow rights for legal purposes (see Section 1.3 above). These plans also have water temperature thresholds that trigger a response designed to protect fish populations (e.g., angling restrictions or river closures). While streamflow and water temperature are the key indicators used to trigger mitigation or response actions, some plans mention other indicators that are used to assess drought conditions (Table 3).

Table 3. Indicators mentioned in drought plans.

Indicators Mentioned in Drought Plans		**Blackfoot Plan**	**Big Hole Plan**	**Jefferson Plan**	**Ruby Plan**	**Beaverhead Plan**
Indicators	Streamflow (cfs or gage height)	3	3	3	3	3
	Water temperature	3	3	3	-	3
	Spring runoff	1	-	-	-	2
	Forecasted water supply, stream levels	-	2	-	1	3
	Other forecasted information	-	-	-	-	1
	Wetted-riffle or wetted stream perimeter	1	2	-	-	2
	Reservoir storage	-	-	-	1	3
	Snowpack or Snow Water Equivalent	1	2	-	1	2
	Precipitation	1	-	-	1	2
	CoCoRaHS rain gages	-	-	-	-	2
	Groundwater levels	-	-	-	-	2
	Air temperature	-	1	-	1	2
	Evapotranspiration	-	-	-	-	2

	Soil moisture	1	-	-	1	1
	Soil health	-	-	-	-	1
	Surface Water Supply Index (SWSI)	1	-	-	-	2
	Montana water supply index	-	-	-	-	2
	Biotic conditions	1	-	-	-	-
	Dissolved oxygen	1	-	-	-	-
	Forage production	-	-	-	-	1
	Basin scale wildfire risk indices	-	-	-	-	2
	Irrigation demand or ditch withdrawals	1	-	-	1	1
	US Drought Monitor (USDM)	-	-	-	-	**3**
	Palmer Drought Severity Index (PDSI)	-	-	-	-	1
	Drought Impact Reporter	-	-	-	-	2
	Drought Risk Atlas	-	-	-	-	1
	Gravity Recovery and Climate Experiment (GRACE)	-	-	-	-	1
	Normalized Vegetation Difference Index (NDVI)	-	-	-	-	1
	El Niño Southern Oscillation (ENSO) Outlook	-	-	-	-	2

Indicators were assigned a numerical value based on the degree of specificity used to describe it and if it was used to trigger a specific action [- = Not mentioned in plan; 1 = Indicator mentioned, but no description of how indicator is used; 2 = Indictor mentioned along with specific information about when, where, how and/or how often indicator is to be used and/or where the indicator information comes from; 3 = Indicator mentioned and used to trigger a specific action to mitigate or respond to drought].

The two-page Jefferson Plan is notable for its brevity, as well as its specificity. While it only uses streamflows and water temperatures as indicators, the plan clearly indicates where streamflow should be measured, i.e., "Twin Bridges Gaging Station (06026500)" ([42], p. 2). It also specifies what actions are triggered at the 600 cfs (e.g., voluntary conservation and angler awareness) and 280 cfs (e.g., possible fishing closure, voluntary reduction in irrigation and municipal water use, weekly meetings) stream flow levels. It notes that "the angling closure will remain in effect until flows reach or exceed 300 cfs for seven consecutive da*ys* at the Twin Bridges Gage" (p. 2). Additionally, "when maximum daily water temperature equals or exceed 73 degrees F (23 degrees C) for three consecutive days" the river will be closed to angling from 2pm to 12:00am (p. 2). These specific streamflow and temperature indicators are linked to specific actions and therefore score a three (Table 3). No other indicators are mentioned in this plan.

The Big Hole Plan is notable for the degree of specificity in describing how the wetted perimeter inflection points, which determine streamflow triggers, were calculated (see Plan Amendments, p. 6). Interestingly, the plan notes the complicated reality of enforcing ecologically-based minimum flow requirements, stating:

> The wetted stream perimeter (i.e., flow below which standing crops of fish decrease) of the upper Big Hole River is 60 cfs (DNRC 1992). While this flow may be reasonable to maintain in ample moisture years and should be the goal for flow preservation efforts, in most years it is not a realistic quantity. Fish population and flow data indicate 40 cfs is feasible to maintain while still sufficient to protect the Arctic grayling population. A minimum survival flow of 20 cfs will provide flows necessary to maintain a wetted channel, provide connectivity to thermal or flow refugia habitats, and ensure survival of the grayling population during brief, critical periods ([43], p. 5).

The Big Hole Plan mentions snowpack and forecasted low stream levels and specifies the agencies that will provide this information (i.e., Montana Department of Natural Resources and Conservation [DNRC], U.S. Geological Survey [USGS], Montana Fish, Wildlife and Parks [MFWP], and Natural Resources Conservation Service [NRCS]) (p. 2). However, the only indicators that are used to trigger actions are streamflows (cfs) and water temperature.

This plan is unique in listing three different streamflow triggers for each river reach. The first trigger level is to "prepare for conservation" (e.g., present data, notify water users and anglers of low water conditions and encourage conservation, etc.), the second trigger level is to "conserve" (e.g., use Phone Tree to request that anglers limit their activities to cooler hours of the morning, contact media to inform public, etc.) and the third trigger level is for "river closure" (e.g., MFWP will close river sections, notify the public of closures, and encourage conservation, etc.).

In the upper and middle reaches of the Big Hole River, a fourth, and much earlier streamflow trigger is listed. These are reaches where Candidate Conservation Agreements with Assurances (CCAAs) are in place. The specified streamflow trigger (cfs) requires water users with CCAAs to implement their plans. Other water users are encouraged to implement conservation measures. On one particular river section (USGS Gage Number 06024580), a streamflow of 450 cfs triggers the implementation of CCAA plans. It is not until much lower flows of 170 cfs are reached that "preparation for conservation" is triggered. "Conservation" actions are triggered at 140 cfs (p. 6). In other words, the CCAA plans allow drought actions to be taken at a much earlier stage. Arguably, CCAA plans function as a mitigation strategy, rather than response strategy [50].

The Ruby Plan is the oldest plan, published in 1988. In contrast to the ecologically-based minimum streamflow levels in other plans, the Ruby Plan specifies that minimum streamflows levels were established to ensure that downstream senior irrigators receive their full water allotment. The primary indicator is gage height (i.e., streamflow). While water temperature is never mentioned in this plan, it does instruct the DNRC to "confer with the [Water User's] Association to discuss the snowpack, reservoir storage, streamflow, streamflow forecast, and soil moisture" (p. 7). The concept of "dewatering" suggests an early recognition that meteorological drought conditions combined with irrigation and water management decisions can affect downstream water availability.

The Blackfoot and Beaverhead Plans list a wider range of drought indicators (Table 3). However, the Blackfoot Plan states, "Stream flows are a primary indicator of drought conditions and can determine when specific actions under the Blackfoot Drought Plan will be implemented" ([44], p. 6). It adds that "Water temperature can also trigger drought response measures" (p. 6). The plan directs the Blackfoot Drought Committee to "examine other factors such as time of year, water demand, climatic conditions, weather projections and resource conditions" (p. 6). However, no further detail is provided about how, when or where these measurements will be taken. Interestingly, the plan states, "When all factors are considered, it is possible for stream flows and water temperatures to exceed trigger levels without the Drought Response being implemented" (p. 6).

The Beaverhead Plan, published in 2016, is the first drought plan to be completed as part of the National Drought Resilience Partnership project. While streamflows and water temperature are key indicators, this is the only plan that uses additional indicators—such as forecasted water supply, reservoir storage, and information from the U.S. Drought Monitor—to trigger actions. The plan provides website links and lists specific agencies or other resources where additional monitoring information can be found (these indicators received a score of two in Table 3). Additionally, the plan specifies indicators and information sources that are underdeveloped or underutilized in the watershed, including soil moisture, evapotranspiration, groundwater levels, streamflow gages for measuring reservoir inflow, and the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network, which collects and reports precipitation measurements from their backyards of volunteer observers. The Beaverhead Plan calls for the development of a Drought Early Warning System website that would serve as a clearinghouse for information from all available climate and hydrology monitoring networks.

4.4. Other Resource Management Plans that Inform Drought Planning

The Beaverhead Plan describes several other resource management plans that identify drought-related vulnerabilities or have implications for drought resiliency, including, Western Governors' Associations Drought Forums, National Drought Forum Reports, State Water Plans, Bureau of Land Management (BLM) Resource Management Plans and Watershed Assessments, U.S. Forest Service (USFS) National Forest Plans, Watershed Restoration Plans, County-level Pre-Disaster Mitigation

Plans (PDMS), and County Wildfire Protection Plans. As part of a preliminary analysis of potential synergies between planning documents, we conducted a brief review of the Watershed Restoration Plans for the seven watersheds in this study area (Figure 2), focusing again on ecological impacts and indicators. Relative to the drought plans, these plans significantly expand the range of ecological impacts that could be linked to drought resiliency, including interactions with water quality (eutrophication from nutrient inputs, sediment and pollutant loads), water temperature, whitebark pine populations, pest and pathogen outbreaks (e.g., mountain pine beetle outbreaks, white pine blister rust), invasive species, conifer encroachment, grassland productivity, soil erosion, wetlands, wildlife, and wildfire. These plans also expand the range of indicators that could be used in drought planning including measurements of nutrient or pollutant concentrations, macro-invertebrates, and streambank vegetation and shading, which can help to reduce water temperatures. Future research should examine a variety of resource management plans (BLM, USFS, DMPs, etc.) to better understand how, where, and by whom ecologically available water is being managed and how these plans can be used to improve watershed-level drought planning efforts.

5. Conclusions

In this paper, we have argued that in the western U.S., water laws and drought plans are used to prioritize and allocate scarce water resources. However, both have historically failed to recognize non-human water needs. Recent legislative efforts to establish instream flow rights at the state and federal levels are one mechanism for redressing the ecological harm caused by early water development. Another mechanism is a new framework for drought planning that accounts for the non-human impacts of drought. Our analysis of five watershed drought plans in southwestern Montana found that while current plans do consider some of the ecological impacts of drought, it is generally through the narrow lens of impacts to fish populations and fish habitat as monitored through two primary indicators: water temperature and streamflow (Tables 2 and 3). The latter is typically based on the same ecological principles and methods that have commonly been used to develop minimum instream flow legislation.

While minimum instream flow legislation and drought plans that use minimum streamflows to trigger responses are vast improvements over the status quo, they have two major limitations. First, minimum flows often result in sub-optimal conditions for aquatic species and do not account for the dynamic nature of river ecosystems. Legislation that supports variable flow regimes, rather than minimum flows, can help address this issue. Second, the reliance on streamflow levels as the primary indicator of drought, encourages individuals and communities to focus on reactive drought strategies, rather than developing longer-term drought mitigation strategies. One exception is the use of CCAA plans which require drought actions (e.g., reducing irrigation diversions) to be taken at a much earlier stage, thus functioning more as a mitigation strategy than a response strategy.

The drought plans themselves have further limitations, including a lack of sufficiently specific indicators, a narrow consideration of ecological impacts that ignores other drought risks, and a missed opportunity to link to other resource planning processes. Given that livelihoods in this region are based on traditional agriculture, as well as angling, river recreation and tourism, it is not surprising that drought plans focus on the ecological value of fisheries. It may also be that fisheries impacts are more immediate and visible (e.g., floating dead fish) as compared to forest impacts and drought-induced tree mortality, which can be more complex, harder to see, and happen over longer time scales. Furthermore, existing and commonly used drought indicators (e.g., streamflows) are useful indicators for the health of fisheries. In contrast, indicators that may be more useful for monitoring impacts to rangeland and forest systems (e.g., soil moisture, Normalized Difference Vegetation Index [NDVI]) may be more expensive, less available, less familiar to drought planners, and/or less widely used.

Despite these criticisms, our findings suggest that the drought plans from southwestern Montana provide a starting point to account for the ecological impacts of drought, monitor for ecological impacts, and identify who manages ecologically available water. As the contrast between the 2016 Beaverhead Plan and earlier drought plans suggests, a holistic view of drought risk is likely to produce a more comprehensive approach to drought planning. The efforts of the NDRP have focused on building ongoing communication and strong relationships between local watershed drought planners and other resource managers who develop and use plans such as Watershed Restoration Plans, BLM Watershed Assessments, and USFS Forest Plans. As these efforts continue and synergies emerge, the hope is the new drought plans will reflect the full range of ecological impacts, include the suite of indicators available for measuring drought conditions, and focus on mitigation strategies that increase the resiliency of both human and natural systems. Our analysis of existing drought plans in the UMH emphasizes the importance of integrating these three elements. Furthermore, it is critical to understand that watershed communities are composed of humans, as well as the non-human entities that co-habit this world; both are affected when conditions are hot and dry. Watershed planning efforts in the UMH are well on their way to incorporating a diversity of drought impacts, but would benefit from a deeper consideration of the health and functioning of a range of ecological processes that take place within and around streams, waterways, and riparian areas.

Our findings contribute to recent work by Mount et al. [30] on ecological drought in California which calls for the development of "watershed-level plans that set ecosystem priorities and identify trade-offs" (p. 3) and echoes their conclusion that better integration of various planning processes will likely improve drought preparedness. These findings are applicable to arid and drought-prone regions across the globe.

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