Title
Environmental Flows Decision-making and Implementation at Hydropower Project Facilities in the Western United States

Author
Cai, Alan

Publication Date
2020

UNIVERSITY OF CALIFORNIA, MERCED

Environmental Flows Decision-making and Implementation at Hydropower Project Facilities in the Western United States

A Thesis submitted in partial satisfaction of the requirements
for the degree of Master of Science

in

Environmental Systems

by

Alan Chengxi Cai

Committee in charge:

Dr. Joshua H. Viers, Chair
Dr. Leigh A. Bernacchi
Dr. Josué Medellín-Azuara

2020

The Thesis of Alan Chengxi Cai is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Leigh A. Bernacchi

Josué Medellín-Azuara

Joshua H. Viers, Chair

University of California, Merced

2020

Acknowledgements

I would like to acknowledge the following people for their advice and support during my program:

- The members of my committee: Drs. Joshua H. Viers, Josué Medellín-Azuara, and Leigh A. Bernacchi.
- My colleagues in VICE Lab.
- Collaborators at UC Davis and UC Merced who helped initiate this project.
- My fellow 2017 Environmental Systems cohort members.
- Staff members of the UC Merced Graduate Division and School of Engineering.
- My friends and family.

I also would like to acknowledge the funding for this thesis provided by the United States Department of Energy (Agreement #DE-IA0000018) and the California Energy Commission (Agreement #300-15-004).

Table of Contents

List of Figures

List of Tables

ABSTRACT

Environmental Flows Decision-making and Implementation at Hydropower Project Facilities in the Western United States

by

Alan Chengxi Cai

Master of Science in Environmental Systems

University of California, Merced, 2020

Committee Chair: Dr. Joshua H. Viers

The construction and operation of dams, reservoirs, hydropower plants, and water diversion infrastructure has significantly altered riverine ecosystems by disrupting natural hydrologic, geomorphic and ecological processes. These facilities release environmental flows to prevent and mitigate their negative impacts. Environmental flows implementation has advanced in recent decades through the development of the functional flows and active management paradigms, as well as an increasing emphasis on responsiveness to hydroclimatic variability. In order to facilitate the adoption of these modern approaches, this study establishes a baseline understanding of the extent to which these principles are currently being utilized, as well as the attitudes of facility operators regarding this topic. An online survey is used to solicit information from operators of hydropower facilities in the Western United States. We received 63 valid responses from 447 emailed survey invitations, yielding a 14 percent completed response rate. Descriptive and exploratory data analysis techniques were used to obtain insights. Results indicate that the regulatory framework and objectives for environmental flows are grounded in the protection of targeted species, especially fish. Respondents report widespread usage of traditional environmental flows techniques that are simple, static, non-collaborative, and reactive. The application of modern advances in environmental flows may be hindered by inadequate stakeholder consultation, infrastructure, and regulatory frameworks, as well as pressure to deliver for competing operational objectives (especially hydropower) after satisfying the minimum environmental regulatory requirements. Operators indicate general belief in climate change and approval towards current environmental flows regimes, yet a significant minority do not conceptualize climate change as impacting their local region or their ability to implement environmental flows in the future. Lastly, hydrologic basin and facility size may have associative relationships with the extent of environmental flows implementation. This study contributes to the body of interdisciplinary knowledge that aims to guide the siting and reoperation of river facilities for optimized ecosystem health, hydropower, and other benefits.

1 Introduction

1.1 Ecosystem Impacts of River Infrastructure

The impoundment and diversion of river water for human uses has significantly altered riverine ecosystems. For example, aquatic habitats associated with sixty-five percent of global river discharge are under moderate to high levels of threat to biodiversity (Vörösmarty et al. 2010). In the United States, extensive construction of river infrastructure in the early to mid-twentieth century has given humans control over many rivers' hydrologic regimes (Tarlock 2012), though unregulated tributaries below dams have provided some ability to counteract the resulting adverse impacts (Moyle and Mount 2007).

Dams, reservoirs, diversion conduits and hydropower plants (collectively "river infrastructure facilities") are operated for several types of human services, including flood control, water storage and delivery, and hydroelectricity. Each objective places demands on the quantity and timing of flow releases. For instance, operating a reservoir for hydropower can cause significant, short-term changes in flow releases corresponding to fluctuations in electricity demand and pricing. The overall impact to flows, across operational objectives, has been to reduce their short-term and seasonal variability (Magilligan and Nislow 2005). This homogenization, especially in the form of decreased maximum flow and increased minimum flow magnitudes, has been observed across a range of habitat types in the U.S. (Poff et al. 2007).

In addition to their hydrologic impacts, river infrastructure also affects riverine geomorphology, water quality, and ecology. Sediment trapping in reservoirs creates sediment-starved outflows, which can scour downstream riverbeds and compromise ecologically significant features like riffles and pools. Non-selective reservoir releases can result in inappropriate temperature regimes for aquatic species' metabolism and physiology (Olden and Naiman 2010). Collectively, these impacts can harm populations of fish, amphibians, insects, and riparian vegetation. Affected ecological elements include physical habitat, life history cues and strategies, habitat connectivity, and competition from invasive species (Bunn and Arthington 2002).

1.2 Current Innovations in Environmental Flows

River infrastructure facilities release environmental flows to mitigate their impacts to downstream ecosystem functions. Environmental flows describe the "quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being" (Arthington et al. 2018).

The scientific, legal, and management methods supporting environmental flows have become more sophisticated over the past 75 years (Tarlock 2012, Poff et al. 2017). The suitability of a specific method may depend on the particular geography, level of knowledge, and socioeconomic condition of the river system being studied (Tharme 2003). Still, examination of the historical trajectory of environmental flows indicates an overall evolution towards three interrelated, modern-day principles: functional flows, active management, and responsiveness to hydroclimate variability.

1.2.1 Functional Flows

The functional flows approach calls for using process-based models to prescribe flows that deliver desired geomorphic or ecological outcomes, such as floodplain reconnection or species migration (Yarnell et al. 2015). Examples of functional flows include wet-season initiation, spring recession, and peak flows (**Figure 1**).

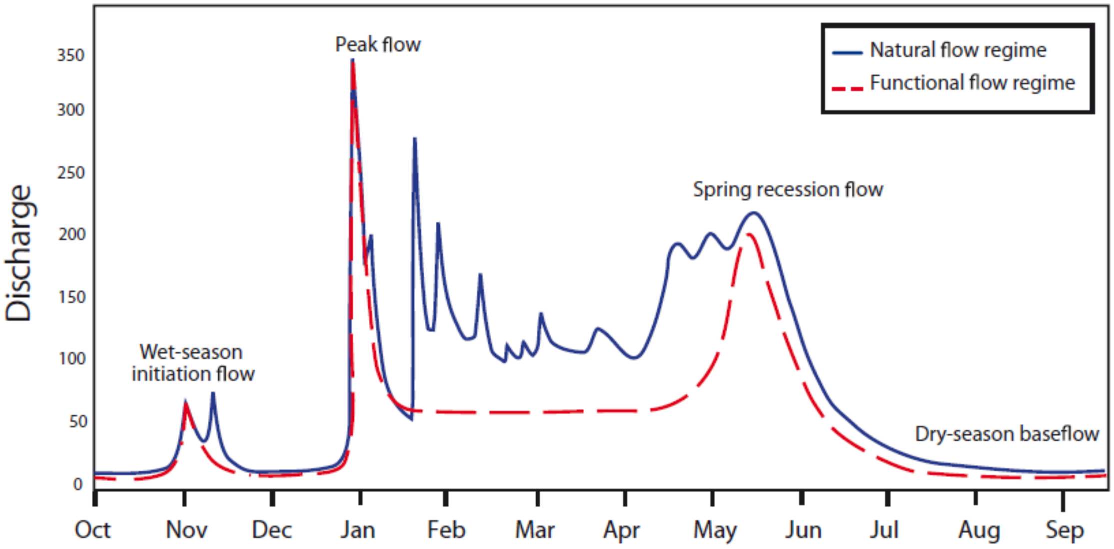


Figure 1*: Functional flow regime in a Mediterranean-montane climate, demonstrating preservation of geomorphically or ecologically significant flow components while allowing the flexibility for some deviations from the unimpaired flow regime (Yarnell et al. 2015).*

By contrast, the earliest American environmental flows methodologies in the 1940s often called for static “minimum instream flows”, narrowly targeted towards survival of a single desired fish species (Tarlock 2012, Thomas 2017). Federal and state legislation passed during the 1960s-1970s environmental movement spurred more rigorous modelling tools such as the Instream Flow Incremental Methodology (IFIM), which simulates fish habitat preferences and flow level-habitat tradeoffs (Stalnaker et al. 1995).

“Holistic” EFMs, which aim to achieve health for the overall ecosystem rather than a single species, emerged in the 1990s (Tharme 2003, Poff and Matthews

2013). For instance, the holistic Building Block Methodology (BBM) partitions the unimpaired regime into components that deliver geomorphically or ecologically significant functions (King et al. 2003), foreshadowing the functional flows approach.

The natural flow regime paradigm emphasized the ecological importance of natural hydrologic variability and dynamism to ecological health (Poff et al. 1997). However, the newer functional flows approach recognizes that a fully unimpaired flow regime may be unachievable for highly modified river systems under water supply-constrained, multi-objective management conditions (Yarnell et al. 2015). By prioritizing actualized results over strict adherence to an unimpaired flow regime, it is arguably better suited for delivering optimized ecological outcomes. Furthermore, because it is oriented around the re-establishment of complex riverine landscape components, the functional flows approach is well-positioned to be used in combination with channel-floodplain manipulation for novel process-based restoration strategies (Whipple and Viers 2019).

Successful implementation of functional flows will require a decision-making framework that fulfills flow prescriptions to the greatest extent possible during challenging or unanticipated operating conditions. One such framework is the active management approach.

1.2.2 Active Management of Environmental Flows

Active management of environmental flows is characterized by “adaptive and ongoing decisions on how to release water from storage to best meet downstream environmental needs” (Horne et al. 2018). It consists of flexibly responding to changing on-the-ground conditions, and attempting to achieve the best environmental outcome with the available resources. By contrast, though “passive management” certainly still requires decision-making, it relies more on adherence to comparatively inflexible and rules-based methods (e.g. minimum instream flows, release rule curves) to determine environmental water deliveries.

Several elements facilitate successful active environmental flows management. (1) Environmental water rights which give decision-makers the legal authority to flexibly activate environmental water releases when and how they are most needed (Horne et al. 2017b). (2) Ecosystem models which directly represent ecological outcomes and incorporate changing interannual ecosystem priorities to inform decision-making (Horne et al. 2018). (3) Consultation and collaboration among water management stakeholders, which enables active management strategies such as water trading, water transfers, and coordination of multiple storage releases for maximum ecological benefit (Stewardson and Guarino 2018). This empowered consultation also builds mutual trust and speeds decision-making during crisis events (e.g. severe drought, threat of flooding) (Doolan et al. 2017).

Use of legal and modelling techniques and stakeholder collaboration has increased in recent decades. Environmental water rights and preserves have proliferated through the efforts of non-profits, state agencies, and other coordinating entities (O'Donnell and Garrick 2017a). The sophistication of simulation and optimization models for aquatic ecosystems and reservoir operations has grown, aided by computational intelligence techniques including evolutionary computation, fuzzy set theory and neural networks. (Rani and Moreira 2010). Stakeholder consultation has increased as the discipline of environmental flows has grown more interdisciplinary, and as the importance of the "social license" to operate has become more evident (Doolan et al. 2017). ("Social license" refers to the level of support among community actors, and is developed by monitoring, consulting with and informing affected local entities about decision-making. Loss of social license hinders the implementation of long-term active environmental flow programs (Doolan et al. 2017).)

1.2.3 Responsiveness to Hydroclimatic Variability

Hydroclimatic variability, defined as variations in "natural hydrologic processes… which are directly and indirectly linked to climate features" (California Department of Water Resources 2017), is a fundamental concept which water managers should recognize and prepare for. The types of weather and climate features which require strategic water management range from individual rain-on-snow events, to multi-year droughts, to long-term warming of the climate. How effectively ecosystem functions are protected during these events depends on the ability and willingness of decision-makers to make such preparations.

Some environmental flows approaches are poorly equipped to account for hydroclimatic variability due to their reliance on historical hydrology and lack of incorporation of non-stationary behavior (Milly et al. 2008). For example, water year types indexed for a range of hydrological conditions are often used as the basis for environmental flows regimes, yet are likely to change under future hydroclimatological conditions (Null and Viers 2013). Flow alteration-ecological response relationships that are generated using historical datasets may also be invalidated by non-stationarity, thus heightening the need for information updates and adaptive management (Poff et al. 2009). By contrast, active management and functional flows approaches are better prepared to incorporate hydroclimatic variability. Active management enables short-term operational flexibility to address ecosystem perturbations caused by climatic events (e.g. insufficient water within a high-priority drought refuge) (Doolan et al. 2017). The functional flows approach suggests incorporating inter-seasonal and interannual variability into planning schemes (e.g. maintaining a suite of target hydrographs representing different water year types) (Yarnell et al. 2015).

One way to formally acknowledge the implications of long-term climate change for river infrastructure management would be to require revision of operational guidance documents as climate science advances and the effects of climate change become more evident. Yet, the extent to which this adaptive management occurs is mixed.

Regarding non-federally owned hydropower facilities in the United States, climate change studies are not factored into the issuance of multi-decade operating licenses by the Federal Energy Regulatory Commission (FERC) (Viers 2011). FERC argues that current climate change models lack the geographic granularity to inform individual licenses (Viers 2011). However, climate change simulations of specific watersheds and regions for environmental flows/hydropower tradeoff analyses exist (Rheinheimer et al. 2013, Zhou et al. 2018). Meanwhile, the “water control plans” that guide U.S. Army Corps of Engineers (USACE) operated hydropower facilities are more easily revised, though the extent to which climate change has driven modified operations for environmental flows is uncertain (Roos-Collins and Gantenbein 2007).

1.3 Research Motivation

Recent innovations advanced by the scientific literature promise to meaningfully advance the effectiveness of environmental flows. However, translating these theoretical insights into systemic, sustained on-the-ground implementation will require major changes to institutional decision-making, operational goals, and regulations. This suggests a new management regime will be necessary.

According to Pahl-Wostl et al. (2010), transitioning to new water management regimes may be guided by the use of a “policy cycle” (**Figure 2**). The policy cycle is a conceptual representation of the sequence/network of structured social interactions that comprise complex policy processes.

An early step in the policy cycle is to assess the current state of the system, including measuring stakeholder satisfaction and the perceived need for change. The assessment yields an understanding of baseline conditions which subsequently informs new operational goals, measures, and implementation strategies.

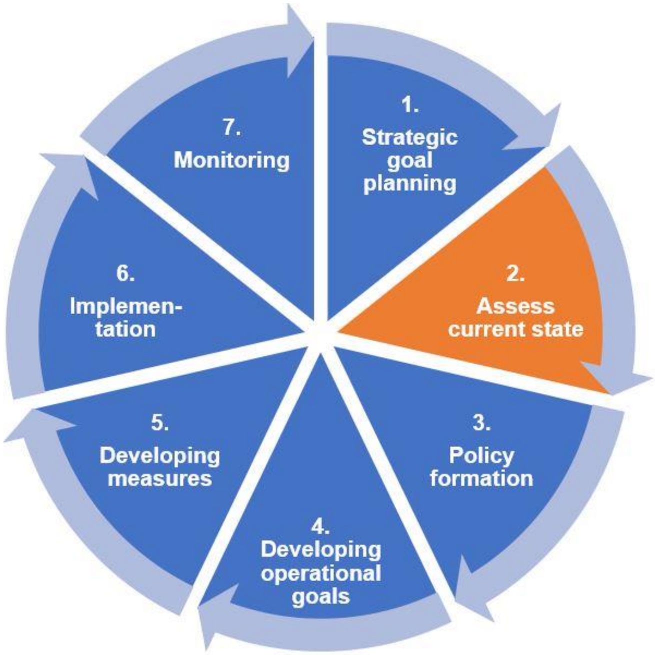


***Figure 2**: Stages of the "policy cycle" analytical device for use in water management regime transitions (Pahl-Wostl et al. 2010). The stage of the cycle which this study addresses, "assess current state", is colored orange.*

This conceptual framework may be applied to the topic of environmental flows implementation. Methodologies for functional flows, active management, and responsiveness to hydroclimate variability are still developing; if and how they are currently being utilized on-the-ground is uncertain. Assessing this, as part of developing a fundamental understanding of current implementation practices and attitudes, will contribute meaningfully to widespread application of improved environmental flows management regimes, where facility reoperation results in improved ecosystem function and status (Krchnak et al. 2007). (This study's focus on environmental flows *implementation* is explained in the next section.)

In brief, this project's research motivation is to facilitate greater application of recent advances in environmental flows implementation approaches. It contributes to that effort by establishing a baseline knowledge of current methods and attitudes regarding environmental flow implementation.

1.4 Research Population and Scope

In practice, environmental flows proceed through several phases, including assessment, allocation, implementation, and evaluation. Many actors exert influence throughout these phases, including scientists, regulators, environmental organizations, water customers, and river infrastructure facility operators. And, only seven percent of the dams in the USACE National Inventory of Dams (NID) database are hydropower-enabled (National Inventory of Dams 2016). This study focuses specifically on the implementation of environmental flows by operators of hydropower-enabled facilities.

Publicly accessible documentation of environmental flows implementation is relatively sparse. By contrast, within the regulatory framework for FERC-regulated hydropower plants, environmental flows assessments often entail exhaustive scientific environmental impact studies (Federal Energy Regulatory Commission 2017). Regulators justify environmental flows allocations in licensing documents and in online databases of environmental water rights. During these two phases, input from environmental organizations, water customers, and other stakeholders is solicited and incorporated into the public record. Scientific evaluations of the efficacy of environmental flows may be required as a license condition and are submitted back to the regulating agency as a precursor to possible license modification. All of this information is prepared in a deliberative manner and publicly accessible to some extent, helping inform the modelling of relationships such as the dependency of the duration of FERC relicensing processes on the level of stakeholder collaboration (Ulibarri 2018).

As the actor responsible for physically implementing environmental flows deliveries, river infrastructure facility operators utilize a variety of stakeholder and modelling inputs, timescales, and management strategies. It is neither required nor possible to document all of these numerous complex decisions. While operator-issued brochures, stakeholder convenings, and published case studies offer some knowledge, there remains a large knowledge gap. Facility operators can offer direct insight into present-day environmental flows implementation because of their lived experiences on the job.

Hydropower-enabled facilities present a particular challenge for water, energy, and ecosystem management. Hydroelectricity accounts for 48 percent of renewable energy in the United States (Federal Energy Regulatory Commission 2017), and “peaking” hydropower facilities help address periods of peak energy demand without emitting greenhouse gases, unlike natural gas-powered peaking plants. Thus, there is a dual environmental imperative for hydropower: minimize hydropower-enabled facilities’ damage to river ecosystems, while still contributing to climate change mitigation through renewable power production (though Soumis et al. (2004), which studied six Western United States reservoirs, suggested that reservoirs could emit sufficient fluxes of carbon dioxide and methane to appreciably influence their greenhouse gas budgets). Also, scenarios of increased numbers of hydropower facilities, including through retrofitting existing dams, has been evaluated by federal agencies (U.S. Department of Energy 2016). Should additional hydropower installations proliferate in the U.S., an expanding set of facilities will need improved environmental flows decision-making and implementation.

Finally, the research population consists only of facilities located in the Western United States, as detailed in Section 2.1 below.

1.5 Context for Methodological Approach

This study assesses the current state of environmental flows implementation through an online survey of individuals within the specified research population. Administering surveys, and related social science methods such as interviews, to natural resource management professionals has provided needed insight and clarity into topics that are not often found in academic literature, as the following two examples demonstrate.

Drevno (2018) documented declining trust among farmers towards California water management agencies, and suggested agencies' lack of collaborative spirit during regulatory negotiations over agricultural pollution as a possible cause. This dialogue around trust is also evident in a survey by Rodriguez et al. (2018) testing which personal values, when appealed to, most effectively convinced farmers to adopt private land stewardship. Framing stewardship as a "service to future generations and families" was found to be a broadly effective approach.

Modern American water management also utilizes procedures drawn from the social sciences. The call by Pahl-Wostl et al. (2010) to measure stakeholder satisfaction exemplifies the value of assessing and integrating multiple stakeholder opinions. For environmental flows, real-world examples of these procedures range from public comments during the licensing and implementation planning processes, to formalized stakeholder workshops (King et al. 2008), to ongoing public-private collaborations (Warner et al. 2014). The purpose of these procedures is to achieve stakeholder consensus, in part by facilitating the accessibility of all relevant information and by flagging problematic issues to be addressed earlier on (King et al. 2008).

Despite these examples, within water management there remains a relative lack of integration of decision-making and implementation processes with scientific and technical processes (Lund 2015). Research of social processes within institutional decision-making is also not widely utilized (Lund 2015). As an example of addressing these gaps, anthropology and sociology can help explain how particular behaviors manifest in different situational contexts (Bennett and Roth 2015). As Drevno (2018) and Rodriguez et al. (2018) illustrate, surveys can offer insights into the relationships among the situational contexts, attitudes, values, and behaviors underlying water management.

1.6 Research Questions

This study’s research questions are based on the (a) current directions of environmental flows research, (b) guidance from the policy cycle framework to determine the baseline “current state”, “degree of satisfaction” and “need for change” for the water system in question, and (c) lines of inquiry that surveys are well-suited for.

1) What types of environmental flows are currently implemented at hydropower facilities, and for what objectives?
2) What are the considerations, consultations, and tools that guide how environmental flows are currently implemented?
3) What attitudes do operators have towards their current implementation of environmental flows?
4) What outlook do operators have towards future changes to environmental flows?

Given the relevance of functional flows, active management, and responsiveness to hydroclimatic variability to each of these topics, evidence for these modern approaches (or the lack thereof) is incorporated and discussed as part of answering the four research questions.

2 Methods

2.1 Study Site Description

The area of study for this research is the Western United States, which in this study is defined as the area comprising the Rocky Mountains extending west to the Pacific Ocean. Hydrologically, this area is dominated by the Columbia, Sacramento-San Joaquin, and Colorado Rivers, and the arid Great Basin.

The Western U.S. has a history of intensive and extensive government-sponsored river development (i.e. built infrastructure) towards the goal of a human-controlled water supply. This history is exemplified by the federal Bureau of Reclamation (BOR)'s construction of major reservoirs and dams in the Colorado Basin, the BOR and United States Army Corps of Engineers' thorough control of the Columbia River Basin, as well as the state-managed State Water Project and federally-managed Central Valley Project in California's Sacramento-San Joaquin system.

The steep elevation gradient provided by the Sierra Nevada and Cascade Mountains, as well as their proximity to centers of high energy demand, have facilitated the installation of significant hydroelectricity generation capacity in Washington, Oregon, and California. Smaller amounts of hydropower are generated in the non-coastal Western U.S. (**Figure 3**).

As **Table 1** further illustrates, the Western U.S. hydrologic regions contain 33 percent of the U.S.'s operational hydropower facilities, 61 percent of its conventional hydropower capacity, and 62 percent of its average net hydropower generation (see **Figure 4** for depiction of the Western U.S. hydrologic regions as defined by this study).

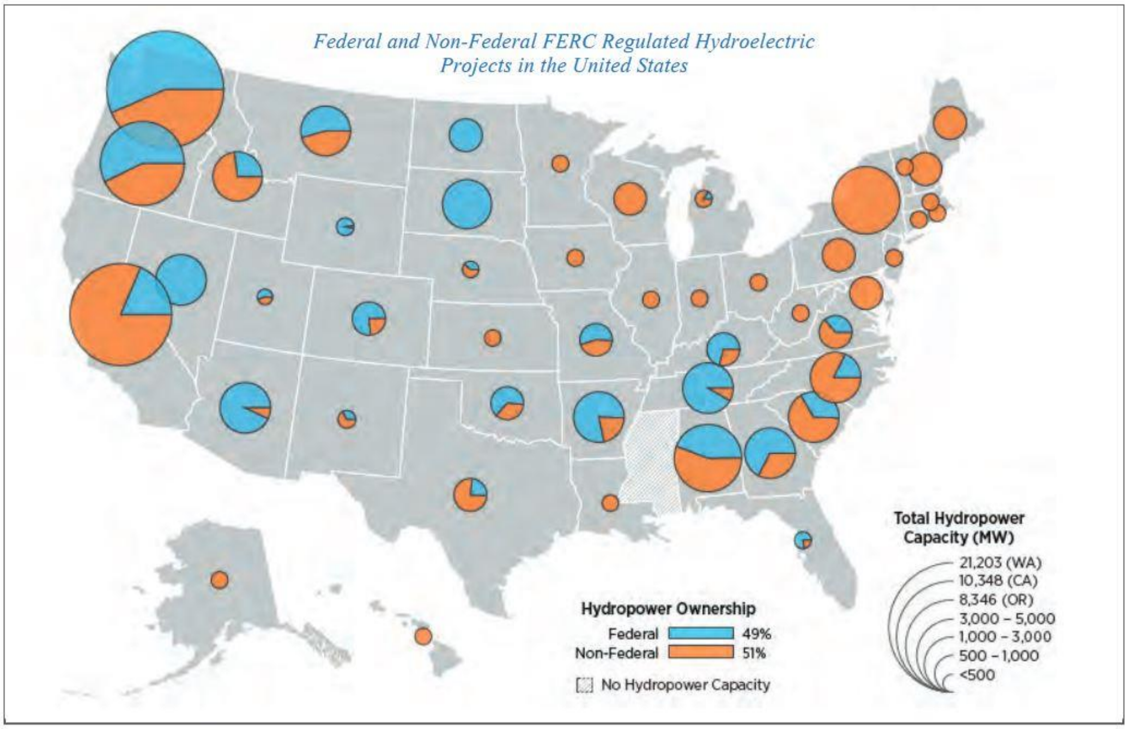


Figure 3*: FERC-provided distribution of capacity and ownership type for United States Hydropower. Source: Federal Energy Regulatory Commission (2017).*

Table 1: United States Hydropower Statistics by Hydrologic Region (Samu et al. 2018)

Hydrologic region	Total number of hydropower facilities	Cumulative conventional hydropower capacity (MW)	Cumulative average annual net conventional hydropower generation (millions of MW-hr)
Upper Colorado	59	1,920	5.27
Lower Colorado	33	2,628	5.91
Great Basin	76	229	0.51
Pacific Northwest	343	33,751	128
California	386	10,281	30.8
Sum of U.S. Hydrologic Regions	**897**	**48,809**	**170.5**
Remainder of the U.S.	1,784	31,263	103

One hydroclimatic simulation model projects the Western U.S. will experience a near-term decrease in snow-water equivalent, a decrease in summer and autumn runoff, and increases in high runoff (Naz et al. 2016). Another model of the Western U.S. predicts reduced annual streamflow due to spring and summer warming, with the Colorado and Columbia basins experiencing a greater decrease than the Sierra Nevada (Das et al. 2011); the discrepancy between regions is explained by the Sierra Nevada's greater ability to compensate for warm season aridity with the increased precipitation, snowmelt, and streamflow triggered by cool season warming.

As the two above examples demonstrate, the particular choice of global climate model and downscaling method produces significant variability among simulations of regional-level hydroclimatic change (Nover et al. 2016); using median-value results from a multi-model ensemble helps to alleviate this variability (US Department of Energy 2017). One such ensemble analysis of climate change's effects on U.S. federal agency-owned hydropower facilities predicts that higher temperatures in the Pacific Northwest will trigger higher winter precipitation and earlier snowmelt by 2050 (US Department of Energy 2017). Similarly, the ensemble predicts higher winter precipitation and decreased springtime and summertime precipitation for the lower Colorado River and Sierra Nevada regions. Across geographic regions, hydroclimatic changes are predicted to increase hydropower generation during the winter and spring, and decrease it during the summer and fall.

Finally, turning to this region's place in the historical development of environmental flows methodologies, during the 1940s the Western U.S. became one of the earliest to implement environmental flows in order to protect cold-water fisheries from the dewatered bypass reaches created by diversion hydropower facilities (Tharme 2003, Poff et al. 2017, Thomas 2017). During the 1960s to 1970s, many MIFs for the purposes of protecting Pacific salmon and freshwater trout were developed using hydraulic rating methodologies (Stalnaker et al. 1995). More advanced, active tools such as water budgets and multiple-use management were prominently utilized beginning in the 1980s and 1990s by the Bonneville Power Authority and others (Stalnaker et al. 1995).

In summary, the Western United States has a high level of existing hydropower generation, is expected to experience shifting hydroclimatic conditions that affect hydropower and environmental flows operations, and a long-established history of environmental flows implementation. It is a relevant geographic area for this study.

2.2 Development of Survey Instrument

Our multi-disciplinary team, consisting of social scientists, engineers, ecologists, and hydrologists, developed an online-administered survey instrument to answer the research questions (**Appendix I**). A survey was utilized rather than the related technique of interviews due to the lesser logistical challenges of executing an online survey as well as the large number of questions (42) that we included in our instrument. Use of an online survey was also motivated by the wide geographic distribution of our target population.

Section I - **System Information**: This section asked the respondent to characterize their facility's structural specifications and geographic location, and the type of facility owner. To establish rapport with the respondent, this section opens with a few questions regarding the respondents' job title and the scope of their responsibilities.

It was recognized that many respondents likely manage multiple facilities. Requesting information about several or all these facilities was judged to be unreasonable and likely to increase attrition. Instead, respondents were asked to provide project facility information about the furthest downstream facility they manage, in an attempt to target information about the generally larger and hydrologically significant facilities known as rim dams.

Section II - **Technical Decision-making about Environmental Flows**: This section asked about the models, decision-support rules, and consultations which influence decisions around environmental flows at the organizational level. Additionally, it asked about operations for functional flows components, operational changes during emergency situations, and operational tradeoffs.

Section III - **Environmental Flows: Challenges and Opportunities**: This section asked the respondent for their opinions regarding environmental flows, including their efficacy, their proper priority level, and implementation challenges and limitations. It also asked about their attitudes towards climate change, regulations, and the future of environmental flows management.

Section IV - **Demographics**: This section asked about the personal and geographical demographics of the respondent. The survey concludes with an invitation to share further thoughts and provide contact information for potential follow-up questions.

Given the potential sensitivity surrounding questions about personal beliefs and operational methods, respondents were not required to provide their names and contact information. We also emphasized that their data would be kept confidential. These steps were taken to alleviate respondents' potential concerns over privacy and security.

2.3 First Phase of Survey Deployment

The 2016 USACE National Inventory of Dams (NID) was used to extract a list of target dam facilities and owners (United States Army Corps of Engineers 2016). The United States Geological Service (USGS) Hydrologic Unit Map was used to define the Western U.S. study area as comprising the Hydrologic United Code

(HUC) regions of California, Pacific Northwest, Great Basin, Upper Colorado, and Lower Colorado. The subset of NID dam facilities within the Western United States whose operational purposes included “hydroelectricity” were selected for further analysis.

It was assumed that dams, reservoirs, and hydroelectric power plants are typically operated as an integrated project. Thus, we assumed the owner/operator of the dam would also be responsible for and knowledgeable about the overall project (including its hydropower operations) and was a suitable target for the survey.

Internet searches, telephone calls, and email inquiries were used to obtain relevant employee contact information at selected facilities. Preference was given to managerial employees, given their potential for a higher level of operational insight.

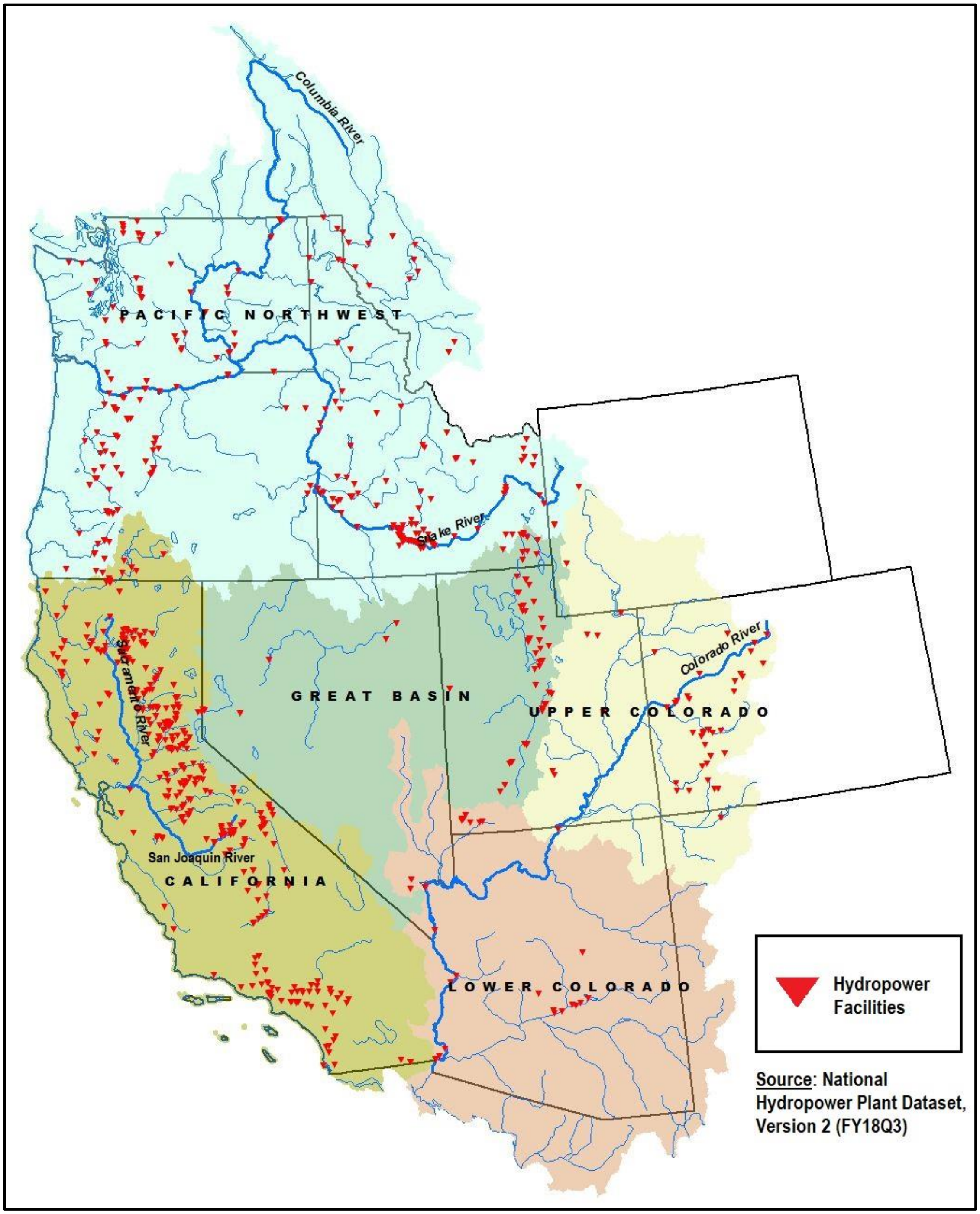
Three successive email invitations to complete the survey were sent to these individuals as needed, following the suggested methods of Dillman et al. (2014). The survey was hosted on the JotForm platform (https://form.jotform.com/citrisucmerced/hydropower-and-flows). Data collection occurred from February to December 2018, and was performed in accordance with the conditions of Institutional Review Board (IRB) #UCM2017-50.

2.4 Second Phase of Survey Deployment

To gather additional responses, a second phase of data collection occurred. In this phase, the Oak Ridge National Laboratory (ORNL) HydroSource project’s FY18Q3 National Hydropower Plant Dataset (NHPD) database of currently operational hydropower plants was used to derive the target sample (Samu et al. 2018). As it only includes hydropower-enabled facilities, the NHPD was judged to be a better-tailored dataset for the survey’s target population than the NID.

In addition to filtering by the HUC regions as before, the NHPD’s “operational mode” attribute was used to exclude two classifications of hydropower plants from the sample. Hydropower plants constructed on canals and conduits were excluded, because canals and conduits are built using engineered materials and lack potential for ecosystem habitat functionality or rehabilitation. Facilities with any amount of pumped storage hydroelectric capacity were also excluded because they are operationally different from conventional hydropower given their operational objective to reverse direction of flow under off-peak market conditions, and thus are not subject to environmental flows requirements.

The geographic distribution of targeted facilities during the second phase of survey deployment are illustrated in **Figure 4.**



Source: National Hydropower Plant Dataset, Version 2 (FY18Q3)

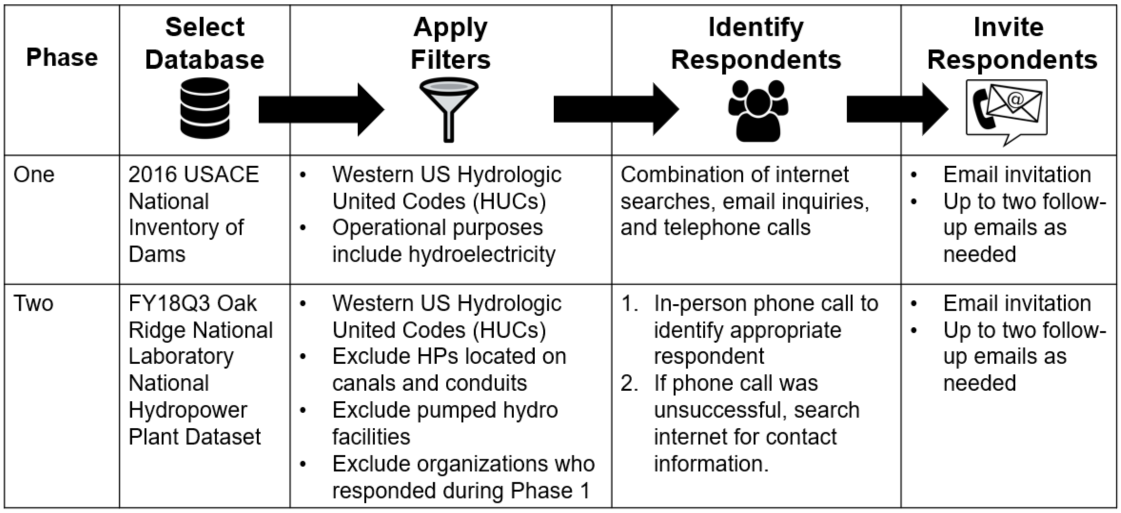
Figure 4: *Locations of targeted hydropower facilities during the second phase of survey deployment. The five USGS Hydrologic Unit Map HUC 2 regions which this study defines as comprising the Western United States, as well as major rivers, are labeled. The facilities’ longitude and latitude coordinates are sourced from the National Hydropower Plant Dataset, Version 2 (FY18Q3) (Samu et al. 2018).*

For all potential respondents, contact information was obtained first through in-person calls placed to operator organizations if possible. This helped verify that the person(s) receiving the survey invitation would be the most knowledgeable about the facilities appearing in the NHPD. Also, this person-to-person conversation was meant to increase the likelihood that the respondent treated the subsequent e-mail invitation as legitimate. If a phone conversation was not possible, an online search for contact information was attempted.

To avoid receiving information redundant to the responses from the first survey deployment, the identities of phase one respondents and their corresponding organizations were discerned to the best extent possible. These organizations were then specifically excluded from the second survey deployment.

As before, three successive email invitations were sent as needed. Data collection for this phase occurred from March to July 2019.

The approaches used for each phase of the survey deployment are summarized in **Figure 5**.



Phase	**Select Database**	**Apply Filters**	**Identify Respondents**	**Invite Respondents**
One	2016 USACE National Inventory of Dams	• Western US Hydrologic United Codes (HUCs) • Operational purposes include hydroelectricity	Combination of internet searches, email inquiries, and telephone calls	• Email invitation • Up to two follow-up emails as needed
Two	FY18Q3 Oak Ridge National Laboratory National Hydropower Plant Dataset	• Western US Hydrologic United Codes (HUCs) • Exclude HPs located on canals and conduits • Exclude pumped hydro facilities • Exclude organizations who responded during Phase 1	1. In-person phone call to identify appropriate respondent 2. If phone call was unsuccessful, search internet for contact information.	• Email invitation • Up to two follow-up emails as needed

Figure 5*: Summary of survey deployment methods, demonstrating improvements in facility targeting and respondent identification and outreach during the second phase.*

2.5 Survey Response Rate and Data Cleaning

The first survey deployment targeted 659 facilities, included 341 email invitations, and produced 29 responses, yielding an 8.5 percent response rate. The second deployment targeted 632 facilities, included 106 email invitations, and produced 42 responses, yielding a 40 percent response rate. This indicates that the Phase Two investment in phone calls and respondent targeting successfully raised the response rate.

Out of 71 responses, a total of eight responses met one of the following criteria, and were deemed invalid and excluded: (1) the response was a duplicate submission from a previous respondent; (2) the response was submitted by a colleague of a previous respondent, thus providing redundant information (and violating the assumption of independent observations); (3) the respondent wrote that the survey’s questions did not apply to their facility and/or organization; or (4) the submission was garbled and unintelligible.

This process resulted in 63 total valid responses, which were then merged for further data analysis. Thus, the 71 responses we received from a combined 447 email invitations yielded an overall 16 percent response rate, and the 63 valid responses yielded an overall 14 percent completed response rate.

3 Results

3.1 Overview of Analytical Approach

In determining the most prudent analytical approach for this dataset, the following points are relevant:

1. The maximum number of responses available for analysis is 63.
2. As detailed more fully in Section 4.8 (study limitations):
    a. Several aspects of the data collection procedure likely caused the final dataset to be a non-random sample of the target population.
    b. The survey does not attempt to produce evidence of causative relationships between responses to multiple questions.
3. The data collected are almost entirely categorical, including binary, nominal, and ordinal data. Textual data were also collected.

Applying these circumstances to a data analysis question type flow chart taken from Leek (2015), the survey dataset was judged to be amenable to descriptive as well as exploratory data analysis (EDA). By contrast, inferential analysis (“quantifying whether your discoveries are likely to hold in a new sample”), predictive analysis (“trying to predict measurements for individuals”) (Leek 2015), and formal significance testing in general were potentially limited by uneven sampling and a small sample size.

Thus, EDA, which “generates ideas or hypotheses” by “searching for discoveries, trends, correlations, or relationships” but which “rarely can confirm these discoveries” (Leek 2015) was the primary approach used for this analysis. Descriptive data analysis is included within EDA. For categorical data, applicable techniques included frequency tables, crosstabulations and chi-square tests, and clustering algorithms (Gotelli and Ellison 2013).

The resulting ideas, patterns and relationships were then synthesized as prospective insights that can serve as the basis for further investigation. The analytical workflow used here is shown in **Figure 6**.

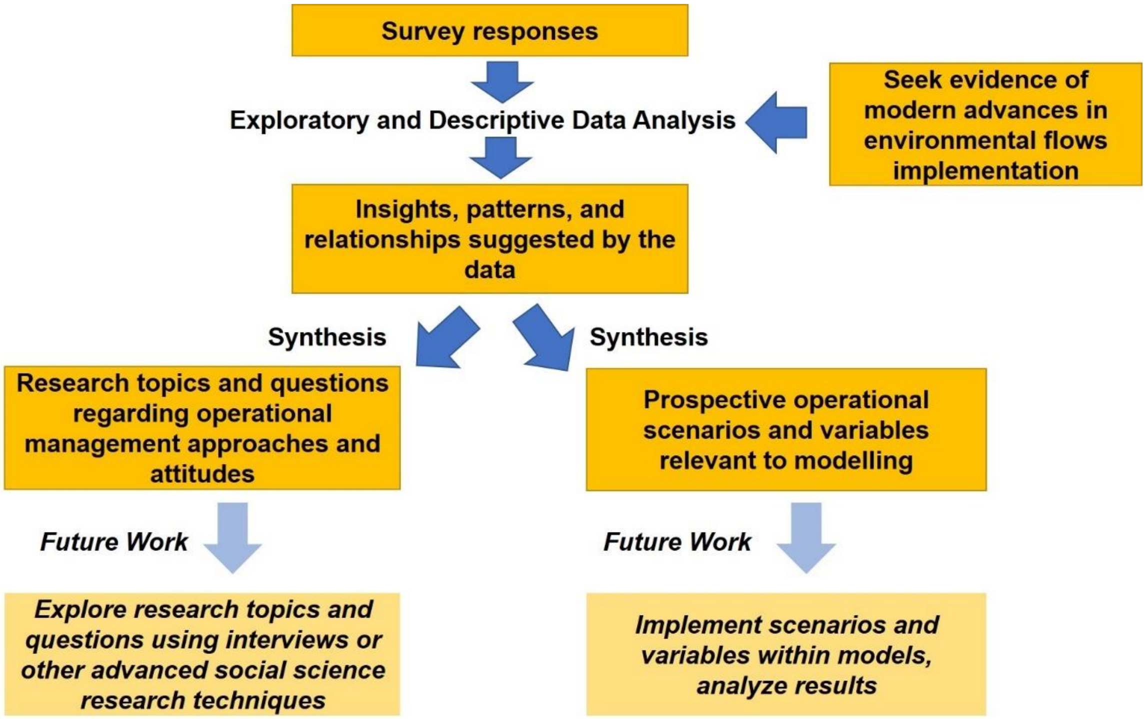


Figure 6*: Conceptual diagram of survey analytical workflow and proposed future work.*

3.2 Representativeness of Survey Responses

The questions in Section I of the survey concern the structural characteristics of each respondent’s furthest downstream facility. Using the National Hydropower Plant Dataset, Version 2 (FY18Q3) as the population-level database, a comparison of variable distributions is possible for three facility attributes: federal/non-federal ownership, geographic basin, and FERC licensure status (**Table 2**).

Table 2: Comparison of Attributes of Target Population versus Valid Completed Sample

Hydropower Plant Attribute	Level	Targeted Facilities in the National Hydropower Plant Dataset, Version 2 (FY18Q3) (n = 632) (%)	Facilities Described by Valid Survey Respondents (n= 63) (%)
Ownership Type	Federal	56 (8.9)	11 (17.5)
	Non-Federal (including those located on Federal facilities)	576 (91.1)	52 (82.5)
Hydrologic Basin	Pacific Northwest	250 (39.6)	27 (42.9)
	California	279 (44.1)	19 (30.2)
	Great Basin	54 (8.5)	3 (4.8)
	Upper Colorado	40 (6.3)	12 (19.0)
	Lower Colorado	9 (1.4)	1 (1.6)
FERC Licensure Status	Is not licensed	118 (18.7)	12 (19.0)
	Is licensed	514 (81.3)	51 (79.4)

Due to the low number of valid responses received from the Great Basin and Lower Colorado regions, these 4 responses were merged with those from the Upper Colorado region for all analyses which used hydrologic basin as a variable.

3.3 Qualifications of Respondents

Forty-one percent of respondents self-identify as operations managers, and another 11 percent are general managers or owners. Sixteen percent are engineers, 5 percent are operators, and another 5 percent are technicians (**Figure 7**). Thirteen percent are environmental scientists, and 5 percent are responsible for regulatory compliance.

Respondents have been in their current role for an average of 10 years (SD = 8.7) and with their current employer for an average of 17 years (SD = 11.8).

These distributions of respondent roles and job longevity indicate that the survey reached individuals with the necessary expertise and knowledge. Fifty-two percent are in a managerial-level or higher position, and all have a job title of some relevance to operational decision-making.

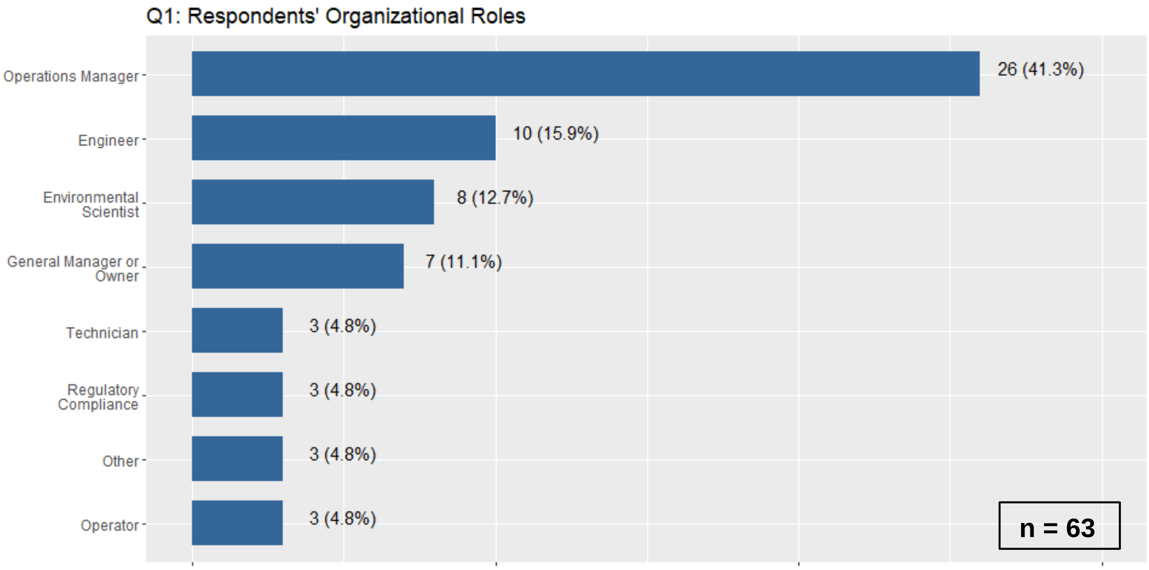


Figure 7*: Distribution of respondent organizational roles, demonstrating a high incidence of mid-to-upper-level technical staff.*

3.4 Research Question 1: Environmental Flows Types and Objectives

Determining the types and objectives of environmental flows to be implemented is a highly deliberative and multi-criteria process. With regards to FERC's oversight of non-federal hydropower projects, the Commission ensures project compliance with pertinent laws and regulations, incorporates "agency management objectives for the river or water body", and prepares documents that "evaluate [environmental] mitigation and enhancement measures" (Federal Energy Regulatory Commission 2017). The results of these analyses are recorded in licensing documents, which detail required environmental flows rules and sometimes state the natural flow components which the rules are designed to deliver.

According to the response distribution of regulations considered with respect to environmental flows (**Figure 8**), the regulatory framework surrounding the protection of targeted species, both on the state level and under the Endangered Species Act, drives a large share of environmental flows requirements. Regulations specifically for the protection of water quality are not as commonly applied for environmental flows.

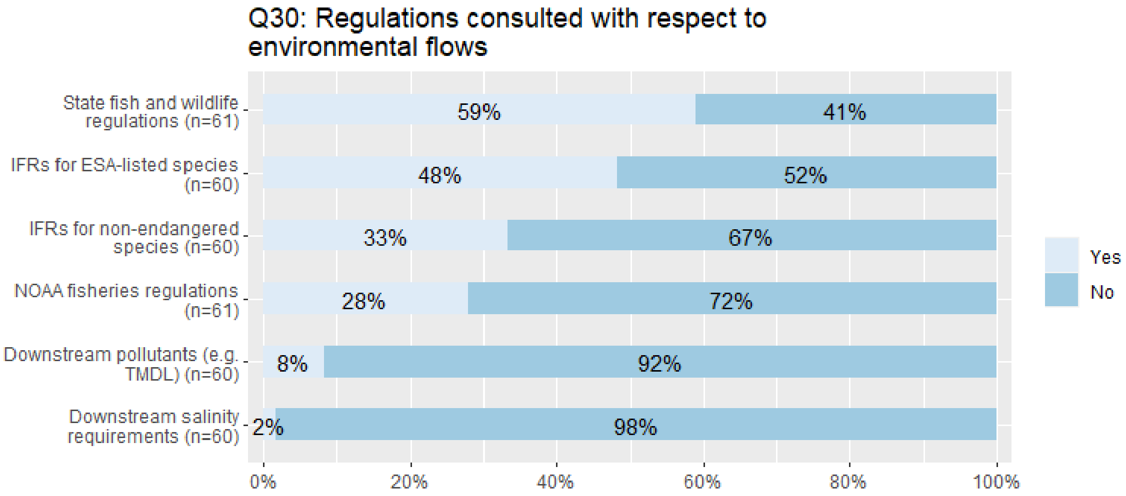


Figure 8: *Environmental regulations considered with respect to implementation of environmental flows, ordered from most prevalent to least.*

Consistent with the distribution of consulted regulations (**Figure 8**), the response distribution of top environmental flows objectives (**Figure 9)** indicates the primacy of using environmental flows to protect fish species through their stages of life. As with the consultation of regulations, objectives directly relating to water quality (pollutant and salinity management) are rarely prioritized. Other significant objectives include maintaining and improving aquatic ecosystems and habitats, as well as temperature and sediment management.

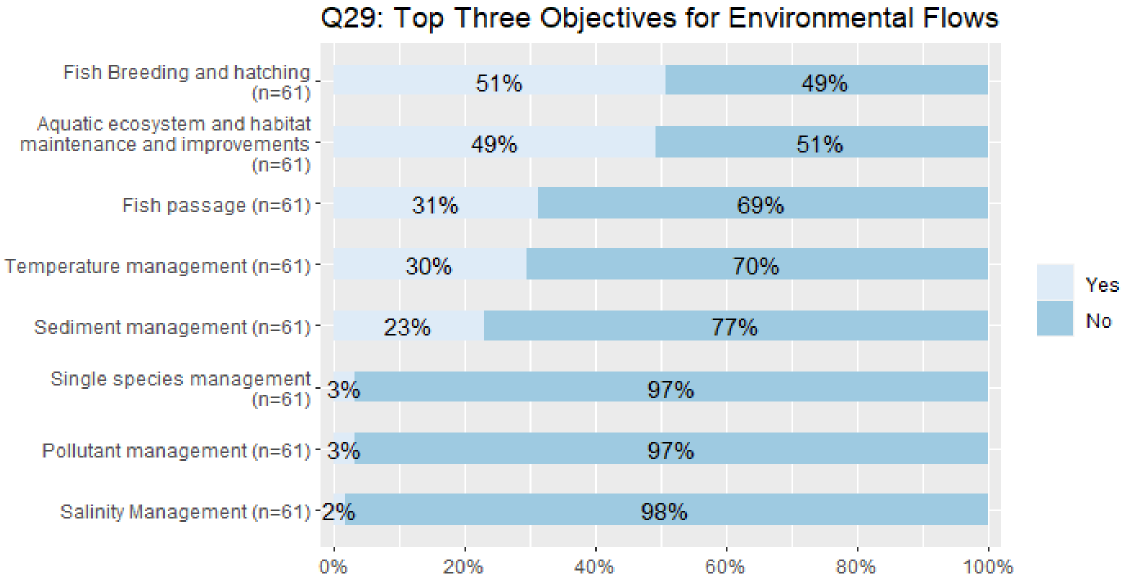


Figure 9: *Top objectives for environmental flows, indicating an emphasis on fish protections.*

Minimum instream flows (MIF), a simple, static approach which is the most historically predominant type of environmental flows rule, has near-universal usage (**Figure 10**). By contrast, the two more dynamic rules which reflect more recent advances in the scientific literature – temperature objectives and pulse flows – are the least-frequently used rule types. (They are dynamic in the sense that they sometimes are activated by an ecologically significant “trigger”, e.g. crossing a threshold flow rate or temperature, and thus may require ongoing monitoring of hydroclimatic conditions to be implemented properly.) Ramping rates have intermediate usage, with 62 percent of respondents using them all or most of the time.

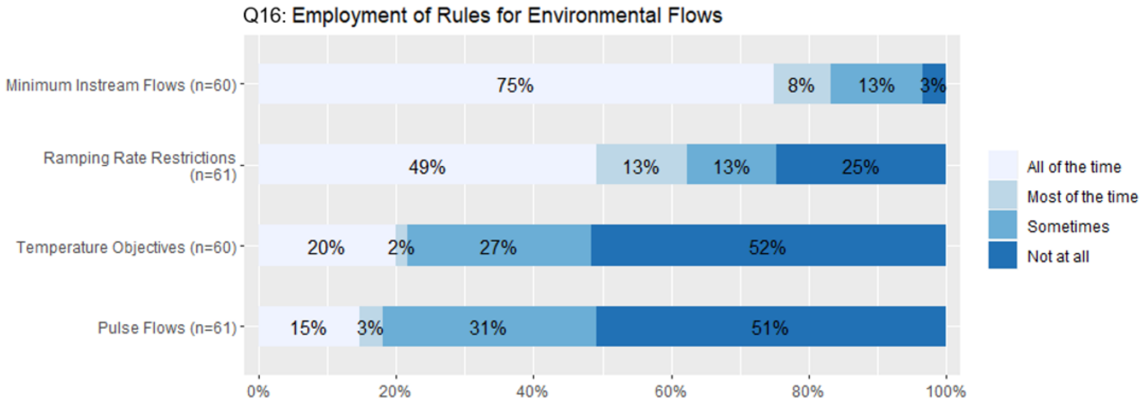


***Figure 10**: Employment of rules for environmental flows, showing the predominance of static flow rules over more dynamic rules whose implementation depends on monitoring of hydroclimatic conditions.*

The natural flow component most frequently operated for is dry season baseflows, while the series of three wet-season natural flow components is less frequently operated for, suggesting that the paradigm of functional flows generally has not been integrated into environmental flows implementation (**Figure 11**). This pattern is consistent with the distribution of environmental flows rule usage (**Figure 10**), where MIFs (analogous to baseflows) had much higher usage than pulse flows (analogous to wet-season flows).

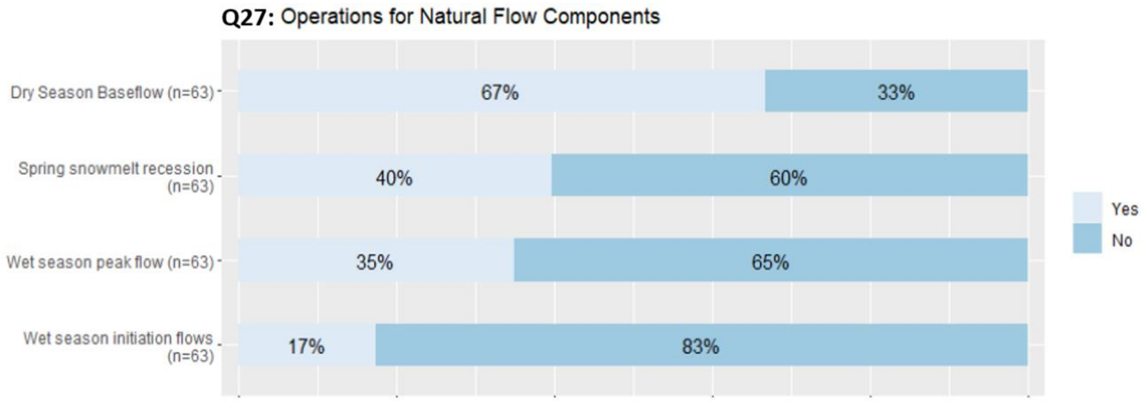


***Figure 11**: Natural flow components that are operated for, indicating higher incidence of simpler minimum instream flows than the components of functional flows.*

3.4.1 Association between Hydrologic Basin and Environmental Flows Rule Usage

As an initial step towards exploring differences in environmental flows regime implementation among hydrologic basins, crosstabulations **(Table 3)** and association plots (**Figure 12**) for respondents' hydrologic basin versus their usage of the four environmental flow rules listed in **Figure 10** were performed. Examining **Figure 12**, the consistent directionality of each basin's sequences of residuals across the ordinal scale for the four rule types suggest that California facilities (negative slope) have higher-than-average usage rates of each flow rule, Colorado/Great Basin facilities (positive slope) have below-average usage rates, while the Pacific Northwest (flat slope) is generally average.

Table 3: Sample Crosstabulation of Hydrologic Basin against an Environmental Flow Rule Type, "Temperature Objectives"

		Usage of Temperature Objectives			
		All of the time	Most of the time	Sometimes	Not at all
Hydro-logic Basin	Pacific Northwest	19	3	3	1
	California	16	1	0	0
	Colorado or Great Basin	9	1	5	1

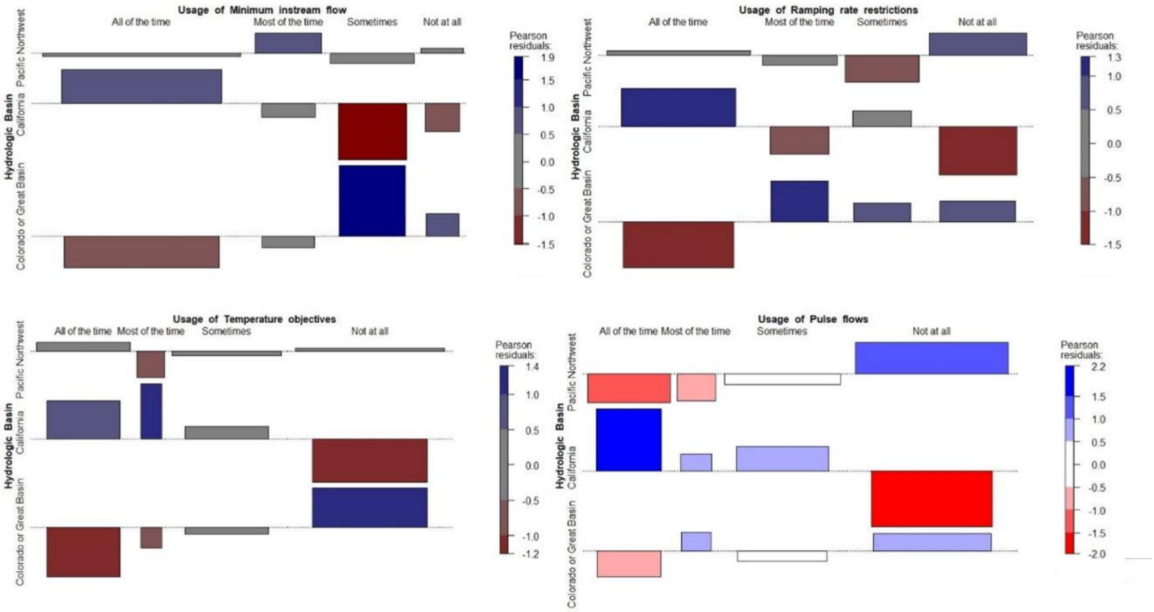


***Figure 12**: Association plots of four environmental flow rules grouped by hydrologic basin, suggesting California has above-average usage of environmental flow rules, the Pacific Northwest generally has average usage, and Colorado and the Great Basin have below-average usage[1].*

3.5 Research Question 2: Environmental Flows Implementation Methods

3.5.1 Consultation of Models

The distribution of primary tools used to determine releases did not appreciably differ between those supporting short and long-term releases (**Figure 13**). For both timeframes, about one-fourth of respondents use release rule curves as their primary tool. While release rule curves provide for some responsiveness to hydroclimatic variability and changing operational conditions, they are still static, pre-fabricated guidelines that can lead operators to make decisions reactively and somewhat inflexibly.

The three types of modelling (simulation, optimization, and proprietary modelling software) collectively received approximately 25 percent of responses. Use of these modelling techniques is more conducive to advanced environmental flows approaches, since potential flow regimes may be modelled using various data inputs to guide selection of a release schedule which best satisfies operational criteria. These tools are also more conducive to active management, which

---

[1] The different color palette used for the “Usage of Pulse Flows” subplot reflects the significant p-value which that analysis produced. However, formal significance testing is not within the scope of this thesis.

requires modelling to be done iteratively and on-the-fly to take advantage of evolving conditions, for example during an unexpected rain event.

Personal experience was chosen by 17-19 percent of respondents. Specific aspects of personal experience cannot be further explored using this dataset.

The seven to ten percent of respondents answering “run of the river” may have been indicating that they do not control releases downstream due to the negligible storage capacity at their disposal. Some run-of-river facilities may have the ability to adjust how much water is flowing through their hydropower turbines while others may not, but in either case the water flowing downstream of the bypass reach should be the same.

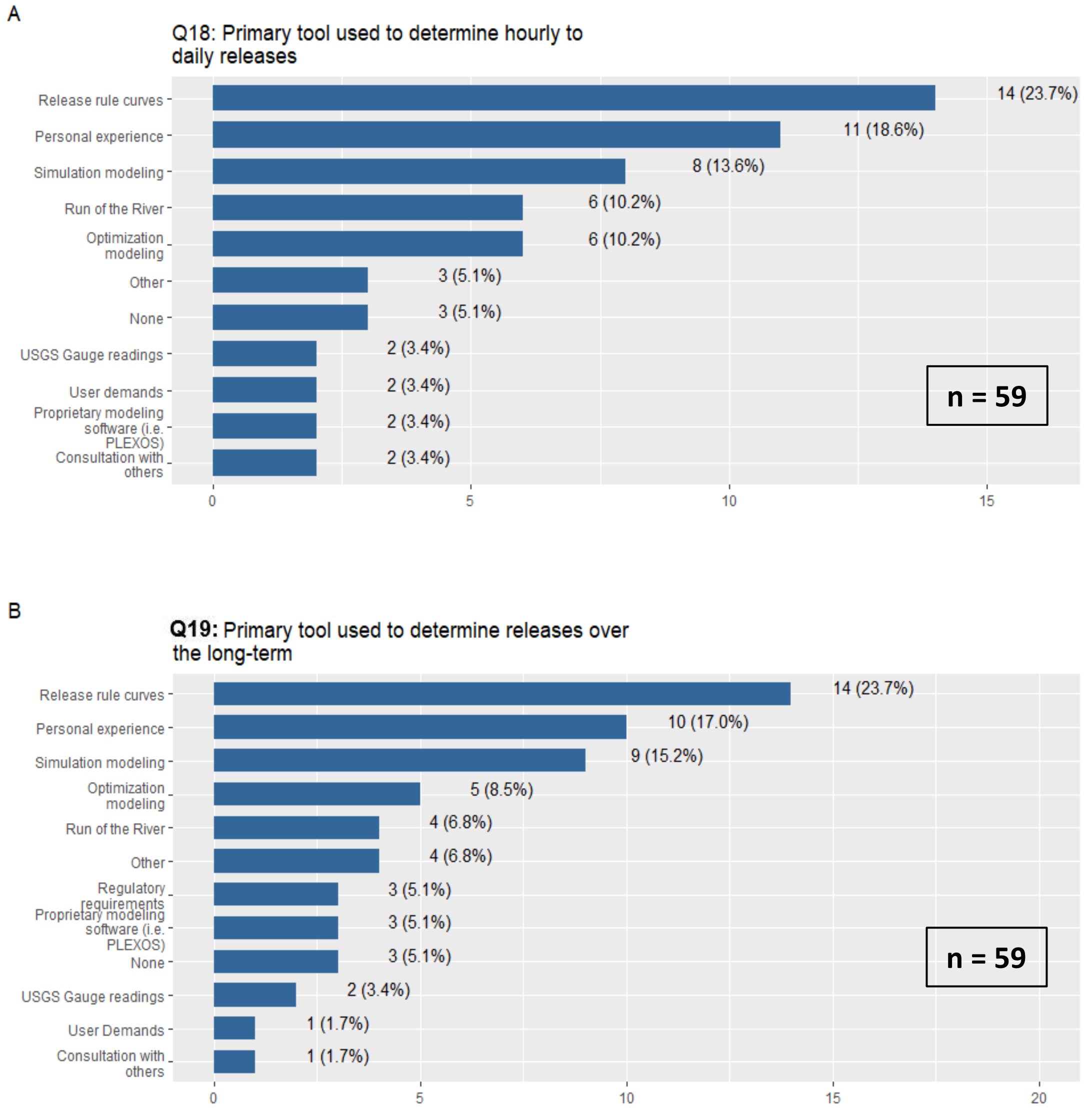


Figure 13: *Primary tools used for determining (A) short-term and (B) long-term releases.*

3.5.2 Consultation with Stakeholders

The distribution of stakeholders that are consulted regarding environmental flows suggests that facilities are most strongly concerned with regulatory compliance, and are less inclined to consult with entities that do not have legal oversight over them (**Figure 14)**. The high response rates for fish and wildlife regulators versus other federal and state agencies, re-emphasizes the apparent primacy of fish and wildlife protections in driving environmental flows. Some licenses may require consultations with certain non-agency stakeholders, and this may be the case with the respondents who consult with tribal entities.

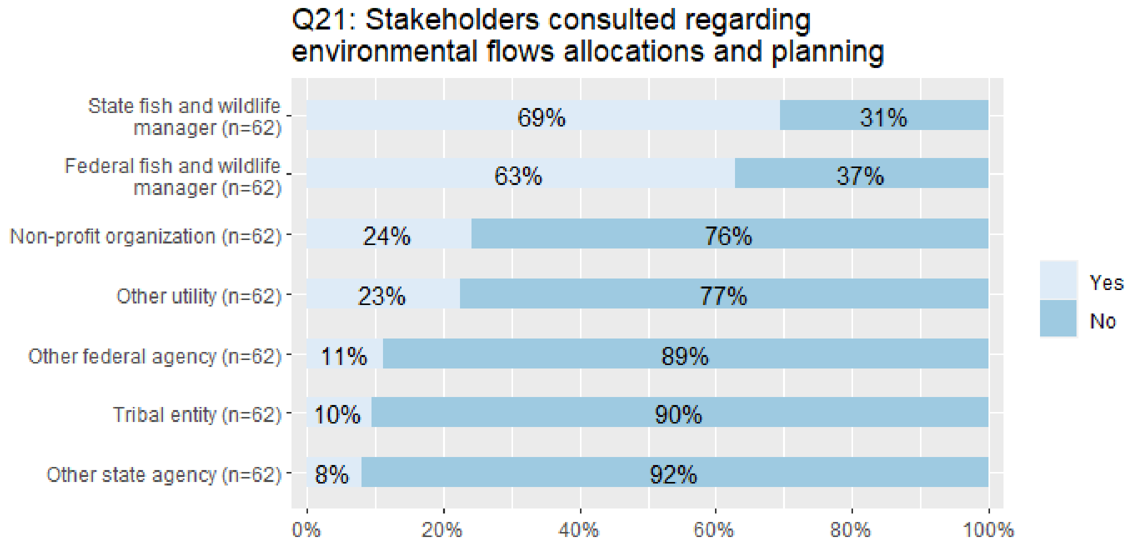


Figure 14: *Stakeholders consulted with by facilities regarding environmental flows allocations and planning, indicating a high level of consultation with regulatory oversight agencies.*

The distribution of temporal frequency of required communication with regulatory agencies (**Figure 15a)** indicates that required communication with regulatory agencies generally only occurs occasionally. The lower proportions for daily, weekly and monthly communications versus annual communications indicate that this important element of active management is not commonly required. When coding the free response responses to this question, if a respondent cited multiple time periods, the shortest time period was selected to represent the respondent.

The most cited type of event that triggers required communication with regulatory agencies is “deviation from license requirements” (**Figure 15b)**, which is a common legal mandate written into licenses. Notably, notifying agencies after a deviation is reactive, in contrast to active management and responsiveness to hydroclimatic variability, which are facilitated by proactive consultations to shape future releases and prevent undesirable operational and ecological outcomes. Periodic reports, relicensing, and FERC inspections are either retrospective or multi-year processes, and are also not the best context for active management to occur in. “Setting flow requirements” and “voluntary and/or ongoing communication” are most in line with active management, but only make up a combined 18 percent of responses.

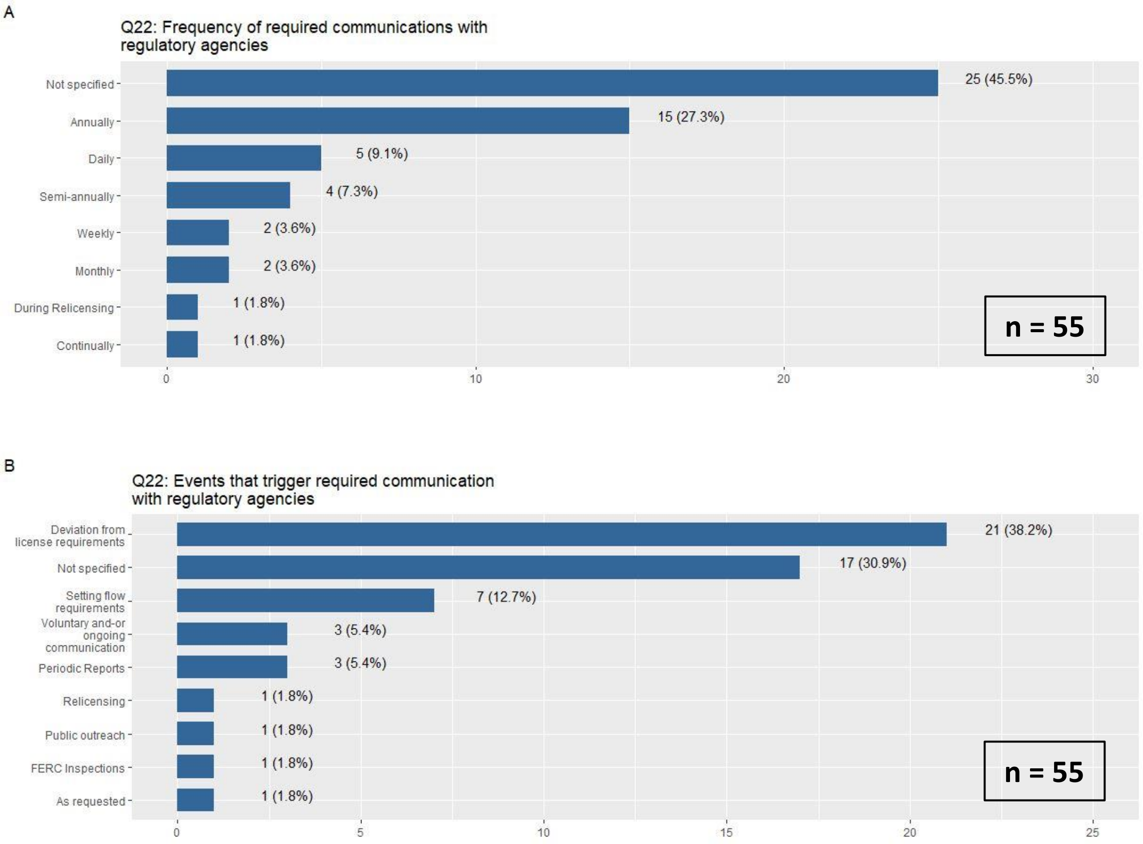


Figure 15: *Aspects of required communications with regulatory agencies regarding environmental flows, indicating that communication is generally rare and most commonly triggered by deviations from regulatory requirements.*

During operational emergencies, decision-making consultations are most commonly held with regulatory agencies and emergency action plans (**Figure 16**). A smaller group of respondents cites their reliance on internal staff guidance and ability to make decisions autonomously, though this group very well could also contact agencies and action plans (since multiple responses were allowed).

Figure 16*: Entities who are consulted with for guidance during an operational emergency, showing a reliance on regulators and internal deliberations.*

3.5.3 Structural Tools for Implementing Environmental Flows

The distribution of structural tools that are used for implementation of environmental flows indicates that basic, mandatory tools (data collection, sensors, and release capacity) are nearly universal (**Figure 17**). Meanwhile, auxiliary tools requiring significant capital costs (fish bypass systems and selective withdrawal devices) are relatively uncommon. Notably, 80 percent of respondents indicate at least some ability to implement ramping rates through fine release controls on flow rates, in line with the 75 percent who said they employ ramping rate rules at least sometimes (**Figure 10**).

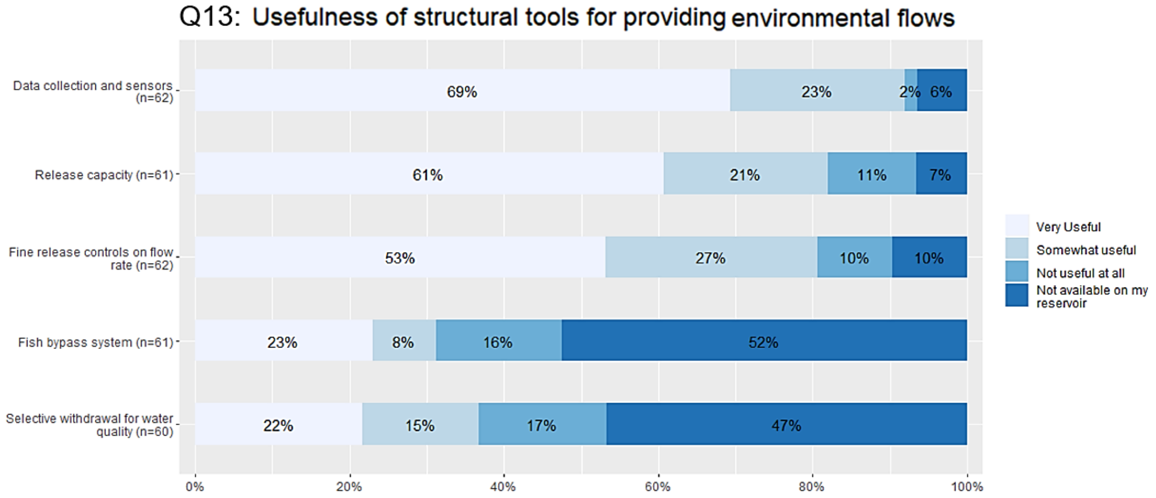


***Figure 17**: Usefulness of structural tools for providing environmental flows, indicating frequent usage of basic dam facility structural tools and lesser usage of auxiliary structural tools.*

As an initial step towards exploring differences in environmental flows regime implementation among hydropower facilities of different structural capacities, association plots for a facility's qualitative level of hydrologic impact versus its usage of the five structural tools listed in **Figure 17** were performed.

The qualitative level of hydrologic impact was determined by performing a k-modes clustering in R using the *klaR* package's *kmodes* function **(Table 4)**. The three ordinal variables relating to hydrologic impact level that were included in the clustering were reservoir storage capacity, hydroelectric capacity, and reservoir storage variability. With the exception of reservoir storage variability in Clusters 2 and 3, each cluster's modal values followed the expected trend of increasing size from Cluster 1 through to Cluster 3.

Table 4: Results of k-Modes Clustering for Facility Hydrologic Impact (k=3)

	Cluster 1	**Cluster 2**	**Cluster 3**
Reservoir Storage Capacity [Modal value]	10,001 - 100,000 AF	100,001 - 1,000,000 AF	> 1,000,000 AF
Hydroelectric Capacity [Modal value]	1-10 MW	101 - 300 MW	> 300 MW
Storage Variability [Modal value]	Run of River	> 365 days	31 - 365 days
Cluster Size	36	19	8
Cluster Interpretation: Level of Facility Hydrological Impact	Small	Medium	Large

Next, association plots of assigned hydrological impact cluster against usage of structural tools for environmental flows implementation were created (**Figure 18**). With a handful of exceptions, medium and large facilities have above-average usage, and small facilities have below average usage. Notably, these trends hold for the most fundamental structural tools for delivering environmental flows – data collection and sensors, and release capacity. This suggests that smaller facilities are disproportionately unequipped to provide even basic environmental flows in a well-informed way.

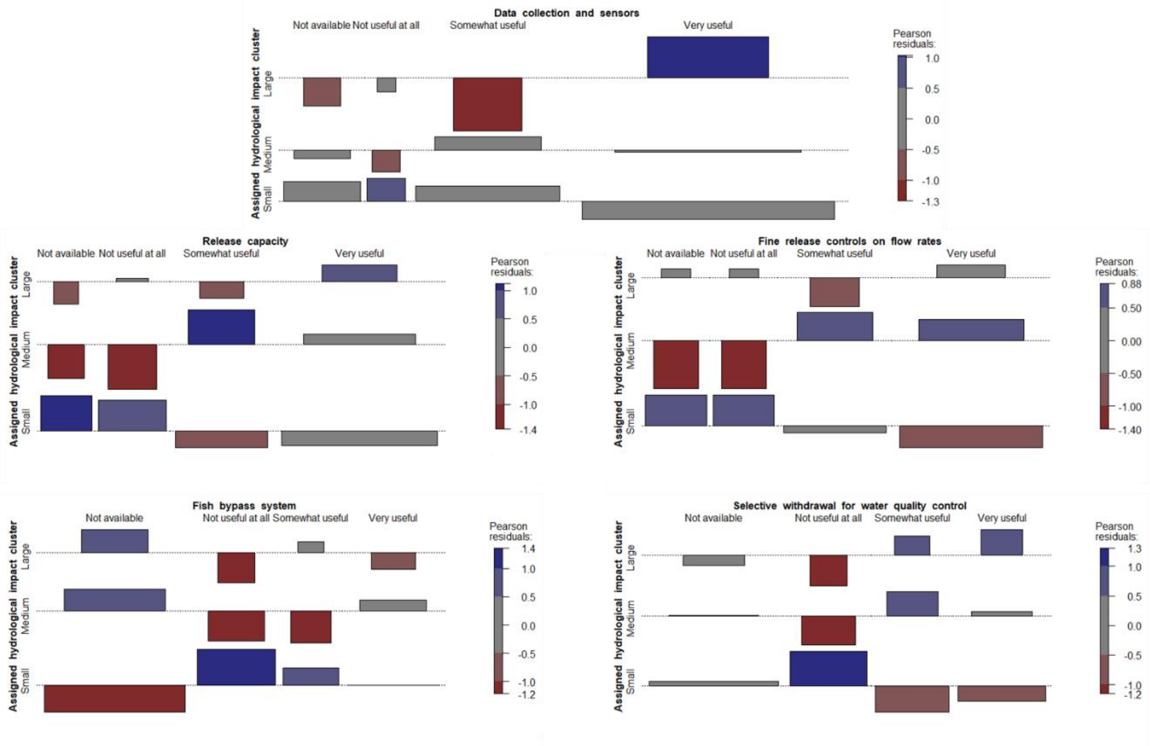


***Figure 18**: Association plots of usefulness of structural tools for environmental flows against a classification of facility degree of hydrological impact as determined by a k-Modes clustering algorithm. Results include lesser than average usage of data collection, sensor, and release capacity structural tools among small facilities.*

Lastly, respondents provide a wide variety of responses regarding structural updates their most downstream facilities had undergone to enhance the delivery of environmental flows (**Figure 19**). Two of the most common responses are the addition of multiple level intake systems (infrastructure type) and water temperature regimes management (purpose), where the former enables the latter. Despite this, only 29 percent of respondents list temperature management as among their top three environmental flows priorities (**Figure 9**), indicating that temperature management is a growing yet still relatively uncommon element of environmental flows regimes in the Western U.S.

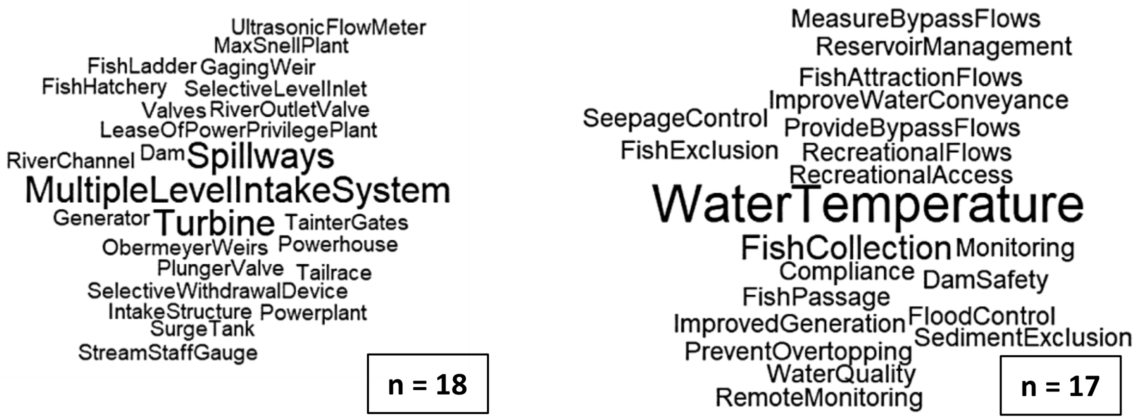


***Figure 19**: Word clouds of types of infrastructure added to facilities for environmental flows enhancement (left) and the environmental objectives of those structural updates (right), showing a high occurrence of multiple level intake systems being installed to upgrade water temperature regime management capabilities.*

3.6 Research Question 3: Operator Attitudes Towards the Current Implementation of Environmental Flows

3.6.1 Challenges to Environmental Flows Implementation

Evaluating respondents' responses about challenges to environmental flows implementation, infrastructural deficiencies are the greatest perceived barrier (**Figure 20** and **Figure 21**). Both maintenance of infrastructure, as well as minor and major improvements, are commonly cited. Regulatory constraints are also a major challenge for environmental flows, recalling earlier results indicating that operators emphasize regulatory compliance as the context for their consultations.

"Inaccurate models", "lack of information for inflows" and "lack of information for outflows" are in the center or towards the bottom of the distribution in **Figure 20**. Similarly, while improved scientific insights from sensors were the top priority for additional funding for 27 percent of respondents, this is outstripped by the 49 percent who found prioritize funding for the maintenance and improvement of infrastructure. These results suggest that added insights from sophisticated modelling or enhanced data availability are by themselves insufficient to overcome the more pressing challenges to environmental flows posed by physical and legal barriers.

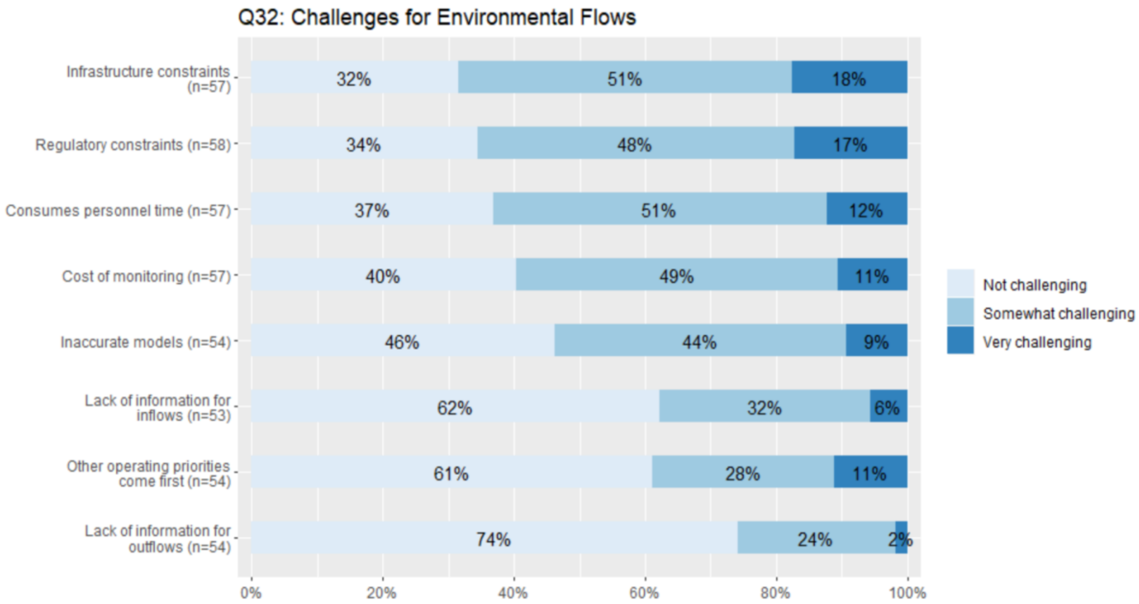


Figure 20: *Degree of challenge to environmental flows posed by varying criteria, indicating physical and legal constraints pose a greater challenge for environmental flows implementation than inaccurate models or insufficient information.*

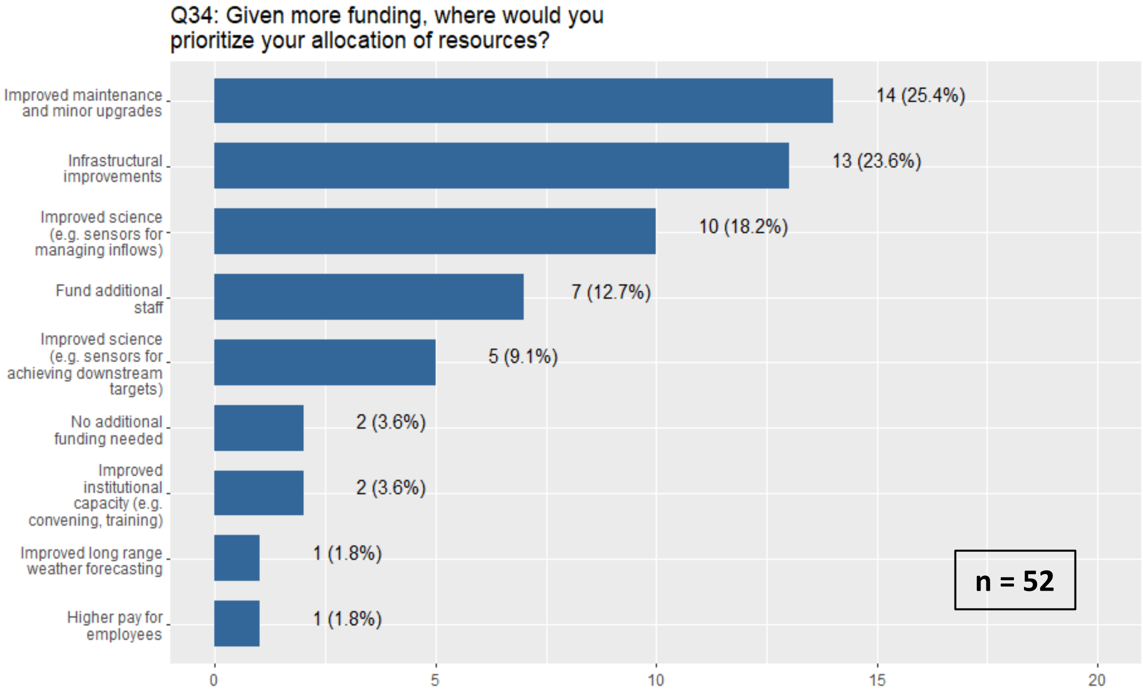


Figure 21: *The highest operational priority for allocation of additional funding, indicating that the physical condition of infrastructure is most in need of support.*

3.6.2 Operational Priorities Conflicting with Environmental Flows Implementation

Regarding conflicts between environmental flows and other operational priorities, a majority (20 out of 35, or 57 percent) of substantive responses stated that tradeoffs made to meet environmental flows targets affect hydropower generation (**Figure 22**). This is particularly striking considering that some facilities balance 3 to 6 (if not more) operational priorities, including environmental flows, water storage and delivery, flood control, recreation, and navigation.

***Figure 22**: Word cloud of operational priorities which require tradeoffs in order to meet environmental flows targets, demonstrating operators' overwhelming view that hydropower generation most conflicts with environmental flows.*

The conflict between hydropower generation and environmental flows is further evidenced by **Figure 23**, which shows that about two-thirds of respondents strongly or somewhat agree that their goal is to maximize hydropower revenue, as long as operational constraints are met. About two-thirds of respondents also disagree that they often have to sacrifice environmental flows to meet hydropower revenue targets, likely an indication of the legal rigor of mandated environmental flows regimes.

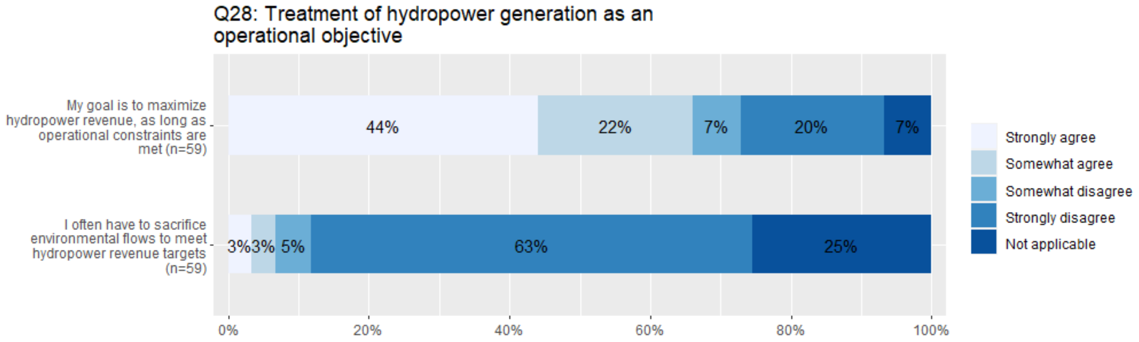


***Figure 23**: Opinions regarding hydropower generation as an operational objective, demonstrating that while hydropower generation revenue is a major priority, it is not allowed to override the delivery of environmental flows.*

3.7 Research Question 4: Operator Attitudes Towards the Future of Environmental Flows Implementation

3.7.1 Challenges Posed by Climate Change to Meeting Environmental Flows Requirements

Climate change is predicted to have major implications for the future of environmental flows implementation, as previously discussed. To assess respondents' awareness of and responsiveness towards this issue, the survey asked for their opinions on climate change and on how they perceive climate change as intersecting with the delivery of environmental flows.

Asked to describe the biggest challenge they faced in meeting environmental flows requirements under climate change (**Figure 24**), nearly half of the respondents either did not cite a specific manifestation of climate change (these were coded as "Not specified"), or stated that they foresee no applicable manifestation of climate change that would affect their implementation of environmental flows (these were coded as "None or not applicable").

The top substantive response is "reduced snowpack because of shift to rainfall" (17 percent), an unsurprising result given that the major river basins of the Western United States have their headwaters in mountain ranges. Several other answers relate to the increased severity and flashiness of hydrologic events ("Increased weather volatility and extremes", "increase in rainfall/flood events", and "droughts"), together making up about 22 percent of the responses.

Another group of answers relate to seasonal shifts in the availability of inflowing water ("earlier snowmelt runoff", "reduced summertime flows", "increased summer low flows") that together make up about 22 percent of the responses. Lastly, the infrequent references to temperature regimes and oxygen levels (together, 6 percent) continue an overall pattern of less attention being paid to water quality as opposed to the quantity and timing of water flows.

All of the substantive responses and the thematic groupings of these responses are consistent with the scientific consensus regarding predicted regional hydroclimatic effects (see **Section 2.1: Study Site Description** for comparison).

While coding answers to this free-response question, responses containing more than one type of climate change manifestation were allowed to contribute to more than one coded response choice.

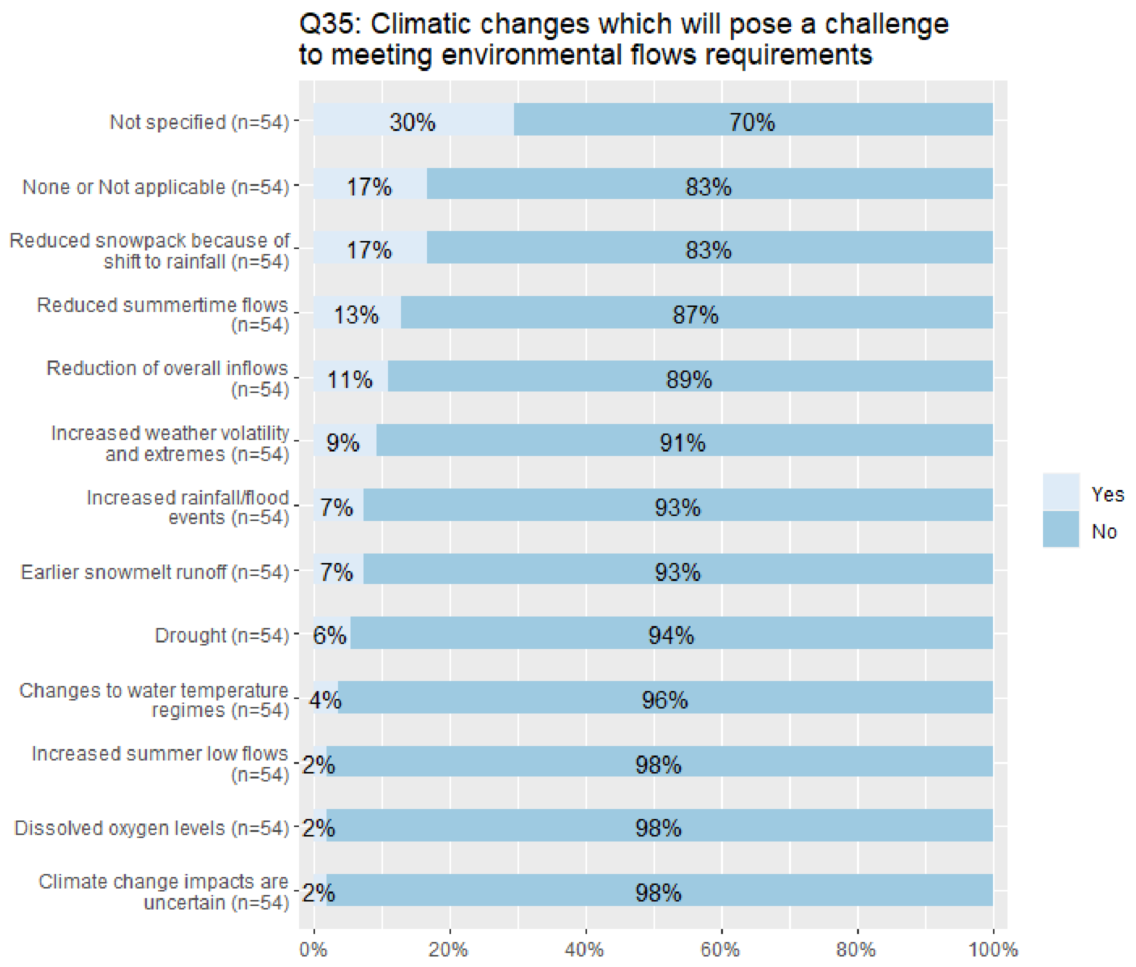


Figure 24: *Hydroclimatic manifestations of climate change which respondents believe will pose a challenge to environmental flows implementation, which are in line with the scientific consensus.*

Similar to the roughly half of respondents who did not cite an impactful manifestation of climate change, about half also did not cite a resulting management challenge for meeting environmental flows (**Figure 25**). Among the meaningful responses, an identifiable grouping can be made of challenges to the ability to allocate water for competing purposes, including instream flow requirements and hydropower generation (42 percent of responses). A secondary grouping of respondents is concerned about whether the operating requirements contained in licenses, as well as models, will remain appropriate and sufficiently flexible under changed climatic conditions (11 percent of responses). Lastly, a handful of responses (six percent) express concern over temperature regime management, erosion and turbidity.

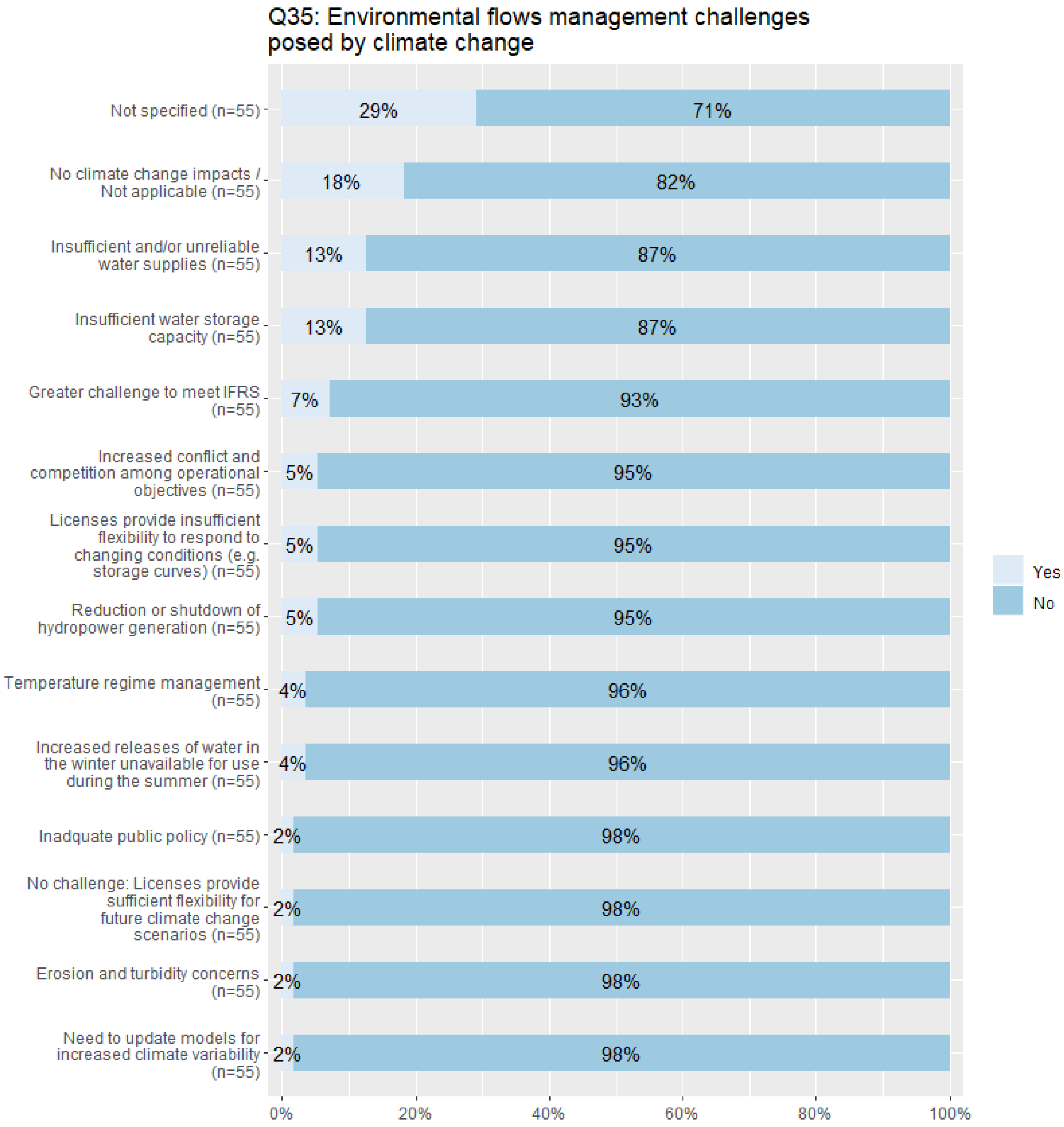


Figure 25: *Types of environmental flows management challenges which respondents believe will be caused by climate change. Increased conflict among operational priorities and the inadequacy of regulatory and modelling frameworks are two identifiable groupings of responses.*

3.7.2 Associations between Respondents’ Attitudes towards Climate Change and Environmental Flows

An analysis was conducted to test whether respondents’ personal attitudes towards climate change (**Figure 26**) and environmental flows (**Figure 27**) affected their awareness of the challenges to operational management posed by climate change (**Figure 24**, **Figure 25**).

Regarding respondents’ personal attitudes towards climate change, recognition of both global and regional-scale climate change was robust, with acceptance of global climate change slightly higher than acceptance of regional climate change (**Figure 26**). However, recognition that climate change threatens local water quality and quantity was significantly lower.

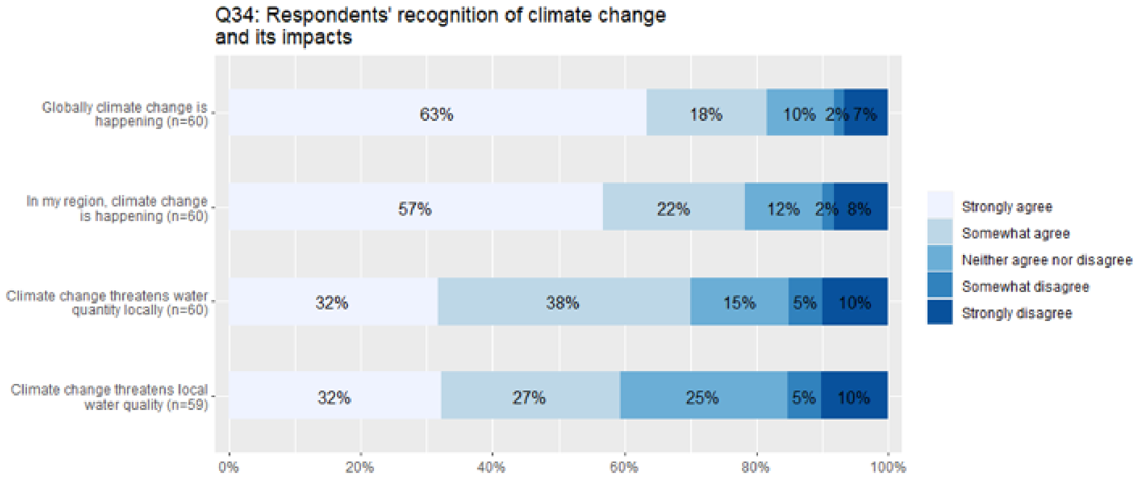


***Figure 26**: Respondents' recognition of climate change and its impacts. Recognition of climate change is meaningfully higher than recognition of the threat it poses to local water. A meaningful minority does not acknowledge climate change or its impacts.*

Regarding respondents’ personal attitudes towards environmental flows, they generally hold a positive opinion, with solid majorities either strongly or somewhat agreeing that they could be improved through better science, that they accomplish the goal of improving the environment. Lower proportions of respondents say that they aggressively adopt new environmental flows practices or view environmental flows as not too strict (**Figure 27**).

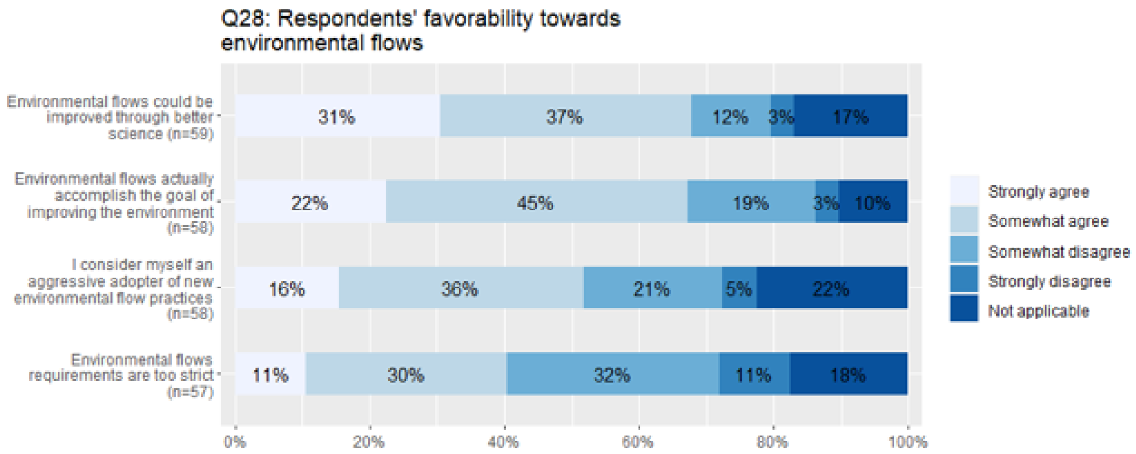


***Figure 27**: Four measures of respondent's favorability to environmental flows, including views on their efficacy, improvability, whether they are appropriately strict, and whether the respondent aggressively adopts new environmental flows practices.*

The thematic cohesion of each group of four questions (**Figure 26** and **Figure 27**) permits the use of Likert scaling, where the ordinal responses to several questions are converted into integers and then averaged, forming a composite score which measures a broader concept. The broader concepts are defined here as “Personal belief in climate change and the threat it poses to local water” and “Personal favorability towards environmental flows”. (The numerical coding for “Environmental flows requirements are too strict” was done in reverse order to match the ordering of the other three items.)

Each respondent’s Likert scale scores were plotted against each other in a scatterplot (**Figure 28**), and each dot was color-coded based on the respondents’ ability to provide meaningful examples of climate change’s impacts to environmental flows management (see **Figure 24** and **Figure 25**). Respondents who did not answer any of the Likert items used for this analysis were excluded from this analysis.

According to **Figure 28**, a majority of respondents both believe in climate change and its impacts, and have a favorable attitude towards environmental flows. However, the minority of respondents who do not fit the above description are more likely to be unable to cite meaningful examples of climate change or impacts to their facility operations. This disparity is quantified using relative risks in **Table 5** and **Table 6**, which correspond to the two plots in **Figure 28**. For both plots, the relative risk values are greater than 1 (2.19 and 1.80). This indicates a greater likelihood of being to cite meaningful examples if respondents have greater than neutral Likert scores (i.e. they believe in climate change and are favorable towards environmental flows).

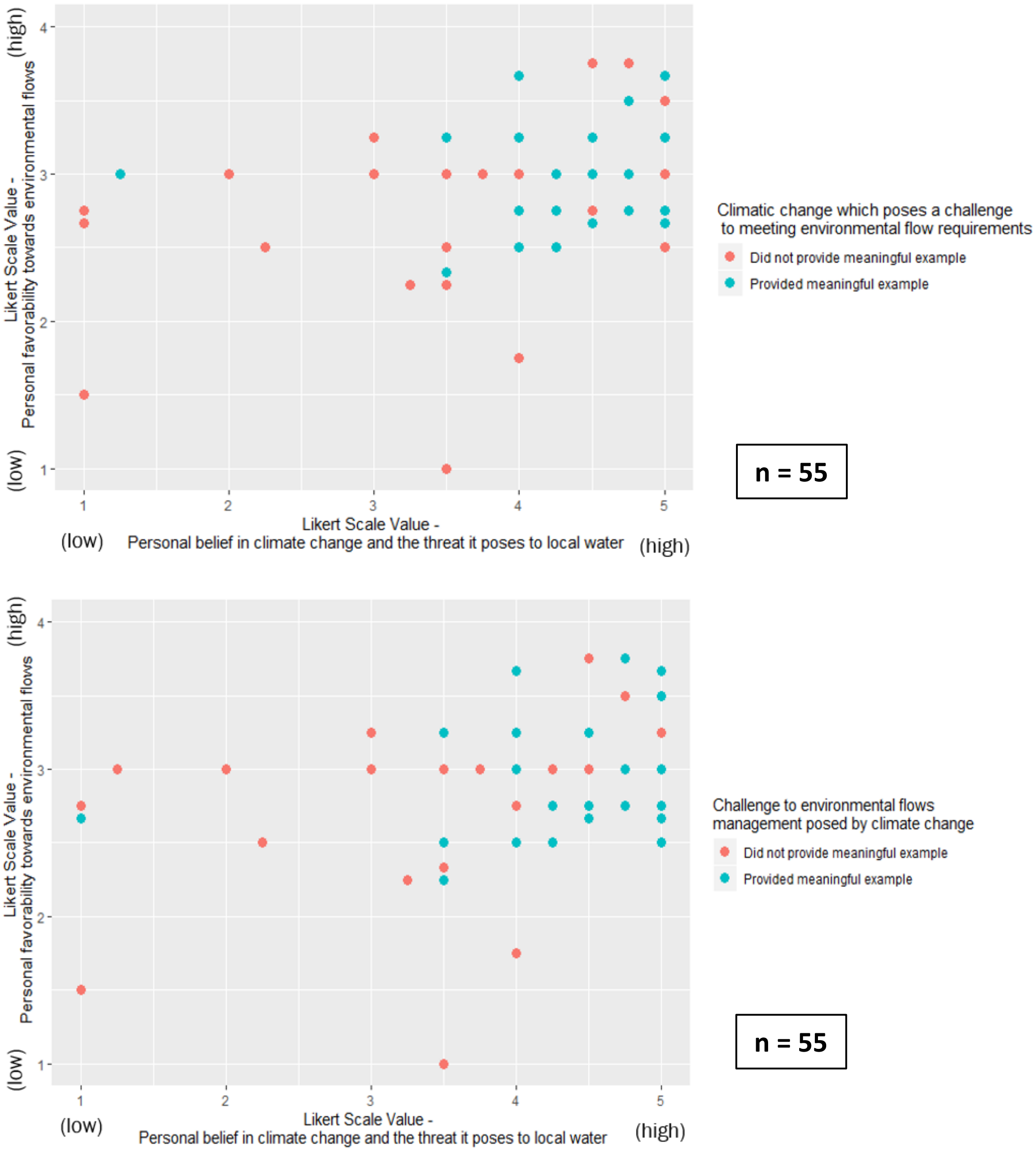


Figure 28: *Scatterplots of Likert scores measuring personal attitudes towards climate change and environmental flows. The respondents' ability to provide meaningful examples of climate change's impacts to environmental flows management is also depicted.*

Table 5: Relationship between Respondent Attitudes and Response Regarding Climatic Change that Poses a Challenge to Environmental Flows Implementation (Relative Risk = 2.19)

		Able to provide a meaningful example of a climatic change which poses a challenge for meeting environmental flows requirements?	
		Yes	No
Greater than neutral Likert scale scores for both climate change and environmental flows attitudes?	Yes	23	12
	No	6	14

Table 6: Relationship between Respondent Attitudes and Response Regarding Environmental Flows Management Challenges Posed by Climate Change (Relative Risk = 1.80)

		Able to provide a meaningful example of a challenge to environmental flows management posed by climate change?	
		Yes	No
Greater than neutral Likert scale scores for both climate change and environmental flows attitudes?	Yes	22	13
	No	7	13

4 Discussion

4.1 Relevance of Results to the Evolution of Environmental Flows Implementation Methodologies

This survey seeks a baseline-level understanding of present-day environmental flows implementation and of operators' attitudes towards their work. The purpose of seeking this knowledge is to help inform the development of a future-oriented environmental flows implementation paradigm. This paradigm should be better-equipped to handle increasing challenges caused by hydroclimatic instability, greater competition for water supplies, as well as a constellation of other potential threats not directly within the purview of facility operators (e.g. land use change, invasive species). The evolved paradigm should also leverage recent increases in the sophistication of modelling techniques and in avenues for multi-stakeholder communication and collaboration.

Functional flows, active management, and responsiveness to hydroclimatic variability meet the above criteria, and should be integral to the evolved paradigm. Therefore, evaluating if/how the survey's major insights are relevant to these three modern approaches **(Table 7)** is important, as it places the survey's insights in the correct context to help "assess the current state" and move towards the next phases of Pahl-Wostl et al. (2010)'s "policy cycle" for transitioning water management regimes. These next phases include forming new policies, and developing new operational goals and measures (**Figure 2**).

The remainder of the discussion section focuses on: (1) exploring what the survey's major insights indicate about the prospects for implementing functional flows, active management, and responsiveness to hydroclimatic variability; (2) future research topics and approaches which the survey may have brought up and provided insights for; (3) recommended actions for hydropower facilities operators based on this body of work; and (4) study limitations.

Table 7: Major Insights and their Relevance to Modern Environmental Flows Approaches

Report Section	Insight, Pattern or Relationship	High Degree of Relevance to Modern Environmental Flows Approaches		
		Functional Flows	Active Management	Responsiveness to Hydroclimatic Variability
3.4	Regulations to protect targeted species (especially fish), rather than those directly targeting water quality, drive most environmental flows.	✓		
3.4	Environmental flows rules and flow components that can be implemented with simple, static methods are more commonly used than those which support advanced environmental flows approaches.	✓	✓	✓
3.4.1	Facilities in California consistently have higher rates of usage of environmental flows rules than those in Colorado/Great Basin. Pacific Northwest facilities generally have intermediate usage.	✓		
3.5.1	About a quarter of facilities each use models and release rule curves as the primary tool for determining releases. Personal experience also commonly plays this role.	✓	✓	✓
3.5.2	Communication with regulatory agencies is much more common than with non-governmental stakeholders.		✓	✓
3.5.2	Required communication with federal agencies is mostly infrequent, reactive and associated with an operating license condition.		✓	✓
3.5.2	During operational emergencies, decision-making is most commonly supported through consultations with regulatory agencies and emergency action plans.		✓	✓
3.5.3	Auxiliary, expensive structural tools for environmental flows are relatively uncommon, while basic structural tools are nearly universal.	✓		✓
3.5.3	The structural ability to implement ramping rates largely exists.	✓		✓
3.5.3	Adding tools which enable temperature management are a common structural “upgrade” made to facilities.	✓	✓	✓
3.5.3	Smaller-sized facilities have below average access to the structural tools needed to implement both basic and advanced environmental flows.	✓		✓
3.6.1	Inadequate infrastructural capabilities and regulations are perceived as posing the greatest challenge to environmental flows implementation, more so than inadequate models or information.	✓	✓	✓
3.6.2	Hydropower generation is a major conflicting operational goal with environmental flows, though this has generally not led to the sacrifice of environmental flows in practice.		✓	
3.7.1, 3.7.2	About half of respondents are able to accurately cite a predicted hydroclimatic change and a subsequent management challenge for environmental flows.			✓
3.7.1, 3.7.2	A majority of respondents are favorable towards current environmental flows and believe in climate change; this group of people are more likely to be able to accurately cite predicted hydroclimatic changes and their likely impacts on meeting environmental flows requirements.			✓

4.2 Implications of Results for the Adoption of a Functional Flows Approach

The most direct measure of present-day use of functional flows are the percentages of respondents employing various environmental flows rules and operating for various natural flow components: 67 percent for dry season baseflows, versus 40 percent for spring snowmelt recession, 35 percent for wet season peak flow, and 17 percent for wet season initiation flows. Additionally, 97 percent employ rules for minimum instream flows at least sometimes, as compared with 49 percent for pulse flows. Clearly, functional flow components have not been adopted to the same extent as minimum-level baseflows.

The variations in these percentages may simply reflect the hydrological and ecological diversity of the Western U.S. Or, perhaps there is a systematic reason for this difference. For example, wet season initiation flows may require releasing limited water supplies which have not yet been replenished by the wet season, and the relatively large magnitude of wet season peak flows could significantly deplete stored water. For those operations who are not legally mandated to release functional flow components, or have a limited reservoir size, the operators' interest in preserving water for competing objectives like hydropower could be causing the disparity in responses. There remains some uncertainty on this matter.

There appears to be a good match between the functional flow approach and the dominant regulatory framework of protecting fish and other targeted species. In particular, functional flows are designed around preserving the particular flow metrics and characteristics that sustain important biophysical processes for native assemblages, and rely on the scientific literature, local expertise, and "empirical relationships between a functional flow metric and a biotic response" (Yarnell et al. 2020). Proponents of functional flows may find success in highlighting this compatibility.

Regarding how sufficient current modelling and structural tools are for delivering functional flows, some optimism may also be warranted. It has recently been recommended that the complex process-based modelling used for assessing and prescribing functional flows be distilled into a selection of flow metrics for facilities to follow when implementing releases (Yarnell et al. 2020). This reduces the importance of operators having continuous access to sophisticated modelling capabilities. Also, these selected flow metrics (e.g. "percentile of daily flow within wet season", "percent decrease in flow per day") appear to be simple enough to be implemented using data collection, sensors, release capacity, and fine release controls on flow rates — structural tools which are available at 80 to 90 percent of facilities.

4.3 Implications of Results for the Adoption of an Active Management Approach

Overall, the survey respondents demonstrate a somewhat limited adoption of an active management approach. For example, though high proportions of operators consult with state and federal fish and wildlife agencies regarding environmental flows regulations (about 65 percent each), much less consultation is observed with non-profits (24 percent) other utilities (22 percent), other state and federal agencies (about 10 percent each), or tribal entities (10 percent). This blunts the ability of operators to engage in the truly holistic stakeholder consultation that supports active management. Also, respondents' mandatory communication with regulatory agencies consists mostly of infrequent, reactive communication concerning license deviations and reporting, a far cry from the elaborate institutional mechanisms for active management consultation described in Doolan et al. (2017).

A significant barrier to wider adoption of active management techniques is the need for significant investment of capital and expertise in the areas of environmental water rights, modelling, and regulatory and planning frameworks (Doolan et al. 2017, Stewardson and Guarino 2018). This investment may only be available for a limited number of operators with the needed "power and capacities, scale of operation, and type of environmental water for which they are responsible" (Doolan et al. 2017). Given that the "improved maintenance" and "infrastructural improvements" are respondents' top priorities for additional funding, there appears to be more basic needs that need addressing. Successfully investing in a novel operational management approach may be difficult in this context.

4.4 Implications of Results for Facility Operators' Responsiveness to Hydroclimatic Variability

Among the approximately half of respondents who specify a manifestation of climate change that would impact their environmental flows implementation, the most frequently cited manifestations are reduced snowpack, reduced inflows (particularly during the summer), and increased weather volatility and extremes. The accuracy of these responses indicates there is a significant level of awareness and knowledge of climate change within the hydropower operator community. This has positive implications for the ability of this group to engage with other stakeholders about evolving the implementation of environmental flows.

Conversely, the approximately half of respondents who did not demonstrate a substantive understanding of hydroclimatic variability are also more likely to view climate change and environmental flows skeptically. This group of people also has influence over how prominently climate change is considered in operational planning and execution. Assuming that understanding the nature of a challenge is a prerequisite to responding effectively to that challenge, the implications for environmental outcomes are somewhat pessimistic. However, it is important to note that the dependencies linking personal beliefs to personal knowledge and then to personal actions were not rigorously tested by this survey, so any conclusions drawn from this analysis should be treated with caution.

Beyond this particular series of relationships concerning operator attitudes towards climate change and environmental flows, nearly every result in **Table 7** provides some insight into how responsive operators may be to hydroclimatic variability. During a challenging incident (e.g. a major impending atmospheric river event), an operator's ability to run models on the fly, ability to use prior working relationships with upstream operators and regulators to obtain data and advice, access to structural tools, and previous experience with implementing a dynamic environmental flows regime, will all contribute to his or her ability to implement a release schedule that preserves desirable ecosystem outcomes. The outlook on this is mixed, with the survey responses suggesting adequate access to basic structural tools and consultations, but also an overall lack of prior experience with active management and functional flows.

4.5 Recommendations for Future Work: Social Science Methods

Firstly, deploying this and other similar surveys to non-hydropower enabled facilities, other regions of the United States, or other countries would allow for comparative and aggregative analysis.

Also, more guided and dynamic social science research methods such as interviews and participant observation may be pursued. The more powerful analytical capabilities that interviews offer include discovering novel themes using interactive dialogue, allowing participants to organize their own narratives and register their version of reality as legitimate (Bernacchi et al. 2015), and developing a more causative understanding of complex decision-making processes such as the brokering of power and the use of personal intuition (Bennett and Roth 2015, Crandall et al. 2018). The insights from such interviews may be applied to develop more cooperative relations with hydropower facility operators, and help involve them more deeply in the evolution of environmental flows implementation (Bernacchi et al. 2015).

As an example of the insights obtained by interviewing active stakeholders, Null et al. (2015) conducted interviews of 112 professionals about general operational trends in California water management, and discovered areas of agreement, such as the unsatisfactory level of management of the Sacramento-San Joaquin Delta and groundwater resources; barriers to implementation, like ineffective state agencies and inexperienced legislators; and novel suggestions for future outcomes, such as the use of “stewardship fees” by water districts to generate stable revenue for local water projects.

Potential interview topics which build off the results of this survey include:

1. Understanding the reasons for operators’ approval of environmental flows and belief in climate change (or lack thereof), and possible methods of persuasion.
2. Understanding in a more detailed way the perceived barriers to environmental flows implementation caused by inadequate infrastructure and regulatory regimes, as well as recommended remedies.
3. Understanding how environmentally rigorous state regulatory agencies are perceived to be by operators, based on their recall of past interactions. This could reveal, for example, whether this survey’s finding of higher observed usage of environmental flows rule types in California[2] (**Figure 12**) is due in part to more forceful and stringent input from the California State Water Resources Control Board during the FERC hydropower licensing process[3].
4. Understanding the strategic usages of environmental water rights, including how they are leveraged during negotiations over license requirement exemptions, environmental water trading, water transfers, and coordination of multiple storage releases.
5. Understanding the use of adaptive management to iteratively improve procedures, tools, and decision-support systems for environmental flows.
6. Understanding which specific personal experiences inform decisions on environmental flow release schedules.

4.6 Recommendations for Future Work: Modelling Methods

Quantitatively modelling the movement of water through the engineered components of a river system can provide insights complementary to the mostly qualitative approach taken by this survey. Models which account for engineered components, natural resources and their economic values, and climate change scenarios, such as the California Value Integrated Network (CALVIN) optimization model, enable exploration of how various climate conditions and

---

[2] This finding is in line with those of Schramm et al. (2016), who created a comprehensive database of mitigation requirements at over 300 non-federal hydropower plants that were licensed or relicensed from 1998 through 2013. The California HUC-2 region was found to have the highest percentage of plants required to implement biodiversity mitigation, and among the highest mean number of hydrologic mitigation requirements per plant. California was also the only region where a majority of MIFs vary according to season or annual water conditions. (However, California plants lagged behind with respect to fish passage mitigation measures.)

[3] Each state’s water quality regulatory agency is empowered, under the Clean Water Act’s Section 401 water quality certification, to insert environmental flows requirements into FERC licenses (Federal Energy Regulatory Commission 2017).

adaptive financial decision-making affect hydropower generation outcomes (Medellín-Azuara et al. 2007).

However, facility operators' ability to apply lessons from these models is limited unless the models accurately represents realistic institutional and physical constraints placed on hydropower operations (Sood et al. 2020). The survey responses reveal areas of similarity and variability regarding facilities' legal mandates for environmental protection and their usage of structural tools. This information can help inform model setup and execution, for example with regards to what simplifying assumptions and realistic boundaries about operational conditions can be safely applied, and which key environmental flow metrics should be varied.

Also, modelling how the engineered system reacts during adverse hydroclimatic events may be particularly relevant for facility operators' planning activities. One modelling approach is to create and run focused, shorter time-frame "scenario sequences" of these events, for example extended droughts and combinations of wet and dry years (Sood et al. 2020). Input from facility operators can guide the choice of scenario sequences, thus demonstrating the value of the hydroclimatic phenomena relating to future environmental flows management that respondents cited (**Figure 24** and **Figure 25**).

Thus, potential modelling exercises which build off the results of this survey include:

1. Comparing modelled operations at a facility which adheres to the general findings in **Table 7** (e.g. overall lack of active management, no sacrifice of environmental flows in favor of hydropower revenue, favorable operator attitudes towards environmental flows), versus a facility that deviates from them along one or more dimensions. This approach can also be used to compare scenarios that have varying degrees of optimization (non-, semi-, and fully optimized) for environmental outcomes, and varying levels of environmental legal restrictions (Sood et al. 2020).
2. Modelling climatic "scenario sequences" cited by respondents (e.g. reduced summertime flows, reduced snowpack due to shift to rainfall) and evaluating the system's response in terms of the operational criteria cited by respondents (e.g. insufficient water storage capacity, negative impacts to hydropower generation).
3. Modelling the financial costs and environmental benefits of upgrading facilities' structural tools for environmental flows deliveries. This can provide a financial justification for installing basic structural tools at smaller-sized facilities for environmental flows (**Figure 18**).

Just as this study sought input from facility operators through a survey, the development and interpretation of models should involve consultation with facility operators and utilities, thus contributing to a two-way knowledge transfer (Sood et al. 2020).

4.7 Recommendations for Hydropower Facility Operators

Without systematic guidance and investment from a central regulatory authority (recommendation 1), it is recognized that any suggested actions for hydropower facility operators should be feasible for each organization to individually undertake using modest resources (recommendations 2 and 3):

1. To move towards the use of adaptive management: Consider directing additional responsibilities and funding to basin-scale entities such as the Columbia Basin Water Transactions Program, which coordinates the voluntary transfer of legal water rights for use as environmental flows, and whose inter-jurisdictional scale is helpful for implementing active management across legal and hydrologic boundaries.

2. To move towards the use of functional flows: Following the procedure recommended by Yarnell et al. (2020), perform a literature review and/or gather local knowledge on the appropriate types of flow components, flow characteristics, and flow metrics for implementing functional flows for a given facility and region. An excellent method for gathering local knowledge, convening a holistic expert panel, is described in Opperman et al. (2018). If past studies have not adequately characterized the target region, then seek out papers exploring other locations with similar ecosystem types. This process can potentially be completed solely through the work of internal staff, and could inform modified environmental flows regimes even if subsequent modelling analyses are not financially feasible.
3. To increase responsiveness to hydroclimatic variability: Provide facility operators with educational materials and workshops regarding climate change. Approximately 22 percent of the 55 respondents included in the analysis of **Figure 28** have greater than neutral-value Likert scale scores for both climate change and environmental flows attitudes, and yet were unable to cite an example for one or both climate change-related topics. Assuming that having “positive attitudes” towards environmental flows and climate change does in fact increase the likelihood of being able to provide a meaningful response, these 22 percent of respondents, and others like them, may be easily informed about the impacts of climate change on environmental flows.

4.8 Study Limitations

Several methodological changes were made between the first and second survey deployments to improve the response rate and the targeting of appropriate respondents. However, there are problems with combining the two resulting datasets, most significantly that they may not have equitably reached the same study population and are thus incompatible to some extent.

Second, the targeting of respondents is best described as expert sampling, since for each organization we sought the most knowledgeable and willing employee’s contact information. Expert sampling is a form of purposive sampling, which poses a challenge to drawing conclusions about the entire population of relevant hydropower project facility employees.

Third, the institutional hierarchies and chains of command for the targeted facilities are sometimes complex and opaque, thus challenging the identification of the proper respondent for some facilities and group of facilities. Follow-up phone conversations did help resolve this issue, and they also reduced the skepticism encountered when asking an unfamiliar person for their personal information and time. Still, there remains a degree of uncertainty over the accuracy of the attempted sample.

Fourth, individuals without a publicly available and functioning email address and/or phone number were completely excluded from the completed sample. Based on feedback during phone conversations, this group included a disproportionate number of individuals operating smaller, “mom and pop” facilities. However, the potential environmental benefits of re-operating this subset of facilities are comparatively minor, so this shortcoming is likely of limited significance.

5 Conclusions

This study sought a better understanding of the decision-making processes and attitudes of Western United States hydropower project facility employees with respect to environmental flows through the use of a survey. The results help establish a baseline-level understanding of current conditions which may inform subsequent goal-setting and planning for adoption of modern environmental flows approaches, and they establish a foundation of prospective research directions and topics which may be pursued through further social science and modelling studies.

Survey results indicate that the regulatory framework and objectives for environmental flows are grounded in the protection of targeted species, especially fish. Respondents report widespread usage of traditional environmental flows techniques that are simple, static, non-collaborative, and reactive. The application of modern advances in environmental flows may be hindered by inadequate stakeholder consultation, infrastructure, and regulatory frameworks, as well as pressure to deliver for competing operational objectives (especially hydropower) after satisfying the minimum environmental regulatory requirements.

Operators indicate general belief in climate change and approval towards current environmental flows regimes, yet a significant minority do not conceptualize climate change as impacting their local region or their ability to implement environmental flows in the future. Lastly, hydrologic basin and facility size may have associative relationships with the extent of environmental flows implementation, though further study is needed regarding these connections.

River infrastructure facilities, including those with hydropower, fall under a variety of regulatory jurisdictions and ownership types, and vary in terms of their visibility within publicly accessible records. Perhaps for these reasons, no authoritative database of United States hydropower facilities existed until 2016, when the first version of the NHPD was released. This removed a large obstacle to addressing this study’s knowledge gaps, given the substantial effort otherwise needed to compile and reconcile facility attributes from disparate sources (Grantham et al. 2014). Thus, a major opportunity now exists to increase the body of knowledge for this topic, thereby helping achieve several recommendations identified within the environmental flows implementation literature.

First, learning about the diversity of facility operational methods can inform the development of global network of “living laboratories” where methods can be developed and trialed at a local scale to determine their efficacy (Horne et al. 2017a). Second, greater understanding of facility operator priorities and thought processes can inform strategies to cultivate their legitimacy and social license to operate, in particular by pursuing environmental flows targets for present-day and future water regimes which are mutually desirable among stakeholders (Conallin et al. 2017, Doolan et al. 2017). Third, better understanding the limitations and barriers to environmental flows implementation at existing facilities may inform the siting, construction and operation of new river infrastructure projects, particularly in developing countries (Krchnak et al. 2007, Thomas 2017). Lastly, this knowledge can inform broader changes to the system-level management of electric grids, water supply, and flood control, which will be needed to accommodate reoperation for advanced environmental flows methods (Thomas 2017).

To conclude, the accelerated transfer and scaling up of knowledge and experience is of the utmost importance for the future of environmental flows implementation (O'Donnell and Garrick 2017b). A large majority of environmental flows assessment methodologies have been developed within the ecological and cultural contexts of English-speaking countries (Tharme 2003), and inadequate information exists for large parts of the world. These limitations can be addressed through more effective forums for the transfer and translation of context-specific policies within trusted universal frameworks, such as the U.N. Sustainable Development Agenda 2030 (Horne et al. 2017a). This thesis attempts to offer a number of insights into environmental flows implementation that may be instructive to practitioners operating in different environmental conditions and regulatory frameworks from those explored here.

References

2016 National Inventory of Dams. 2016. . United States Army Corps of Engineers.

Arthington, A. H., A. Bhaduri, S. E. Bunn, S. E. Jackson, R. E. Tharme, D. Tickner, B. Young, M. Acreman, N. Baker, S. Capon, A. C. Horne, E. Kendy, M. E. McClain, N. L. Poff, B. D. Richter, S. Ward, D. Tickner, S. E. Bunn, S. E. Jackson, M. Acreman, A. C. Horne, S. Capon, S. Ward, B. D. Richter, N. Baker, A. H. Arthington, B. Young, M. E. McClain, A. Bhaduri, E. Kendy, and R. E. Tharme. 2018. The Brisbane Declaration and Global Action Agenda on Environmental Flows (2018). Frontiers in Environmental Science 6:1–15.

Bennett, N. J., and R. Roth. 2015. The Conservation Social Sciences: What, How and Why?

Bernacchi, L. A., C. J. Ragland, and T. R. Peterson. 2015. Engaging active stakeholders in implementation of community-based conservation: Whooping crane management in Texas, USA. Wildlife Society Bulletin 39:564–573.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492–507.

California Department of Water Resources. 2017. Hydroclimate Report Water Year 2016. California Department Of Water Resources.

Conallin, J. C., C. Dickens, D. Hearne, and C. Allan. 2017. Chapter 7 - Stakeholder Engagement in Environmental Water Management. Pages 129–150 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Crandall, S. G., J. L. Ohayon, L. A. de Wit, J. E. E. Hammond, K. L. Melanson, M. M. Moritsch, R. Davenport, D. Ruiz, B. Keitt, N. D. Holmes, H. G. Packard, J. Bury, G. S. Gilbert, I. M. Parker, D. Ruiz, H. G. Packard, I. M. Parker, G. S. Gilbert, R. Davenport, J. L. Ohayon, L. A. de Wit, S. G. Crandall, K. L. Melanson, B. Keitt, and N. D. Holmes. 2018. Best practices: social research methods to inform biological conservation. Australasian Journal of Environmental Management 25:6–23.

Das, T., D. W. Pierce, D. R. Cayan, J. A. Vano, and D. P. Lettenmaier. 2011. The importance of warm season warming to western U.S. streamflow changes. Geophysical Research Letters 38:n/a-n/a.

Dillman, D. A., J. D. Smyth, and L. M. Christian. 2014. Internet, phone, mail, and mixed-mode surveys : the tailored design method. 4th edition. Wiley.

Doolan, J. M., B. Ashworth, and J. Swirepik. 2017. Chapter 23 - Planning for the

Active Management of Environmental Water. Pages 539–561 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Drevno, A. 2018. Central Coast growers’ trust in water quality regulatory process needs rebuilding. California Agriculture 72:127–134.

Federal Energy Regulatory Commission. 2017. Hydropower primer A Handbook of Hydropower Basics. Federal Energy Regulatory Commission.

Gotelli, N., and A. Ellison. 2013. A Primer of Ecological Statistics. Second. Sinauer Associates, Sunderland, MA, USA.

Grantham, T. E., J. H. Viers, and P. B. Moyle. 2014. Systematic Screening of Dams for Environmental Flow Assessment and Implementation. Pages 1006–1018 BioScience.

Horne, A. C., S. Kaur, J. M. Szemis, A. M. Costa, R. Nathan, J. Angus Webb, M. J. Stewardson, and N. Boland. 2018. Active Management of Environmental Water to Improve Ecological Outcomes. Journal of Water Resources Planning and Management 144:04018079.

Horne, A. C., E. L. O’Donnell, M. Acreman, M. E. McClain, N. L. Poff, J. A. Webb, M. J. Stewardson, N. R. Bond, B. Richter, A. H. Arthington, R. E. Tharme, D. E. Garrick, K. A. Daniell, J. C. Conallin, G. A. Thomas, and B. T. Hart. 2017a. Chapter 27 - Moving Forward: The Implementation Challenge for Environmental Water Management. Pages 649–673 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Horne, A. C., E. L. O’Donnell, and R. E. Tharme. 2017b. Chapter 17 - Mechanisms to Allocate Environmental Water. Pages 361–398 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

King, J., C. Brown, and H. Sabet. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. River Research and Applications 19:619–639.

King, J. M., R. E. Tharme, and M. S. de Villiers. 2008. Environmental Flow Assessments for Rivers : Manual for the Building Block Methodology. WRC Report No TT 354/08. Updated Edition. Water Research Commission, Pretoria, South Africa.

Krchnak, K., B. Richter, and G. A. Thomas. 2007. Integrating Environmental Flows into Hydropower dam Planning, Design, and Operations. Water Working Notes.

Leek, J. 2015. Elements of Data Analytic Style. https://leanpub.com/datastyle.

Lund, J. R. 2015. Integrating social and physical sciences in water management. Water Resources Research 51:5905–5918.

Magilligan, F. J., and K. H. Nislow. 2005. Changes in hydrologic regime by dams. Geomorphology 71:61–78.

Medellín-Azuara, J., J. J. Harou, M. A. Olivares, K. Madani, J. R. Lund, R. E. Howitt, S. K. Tanaka, M. W. Jenkins, and T. Zhu. 2007. Adaptability and adaptations of California's water supply system to dry climate warming. Climatic Change 87:75–90.

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer. 2008. Climate change: Stationarity is dead: Whither water management? Science 319:573–574.

Moyle, P. B., and J. F. Mount. 2007. Homogenous rivers, homogenous faunas. Proceedings of the National Academy of Sciences of the United States of America 104:5711–2.

Naz, B. S., S. C. Kao, M. Ashfaq, D. Rastogi, R. Mei, and L. C. Bowling. 2016. Regional hydrologic response to climate change in the conterminous United States using high-resolution hydroclimate simulations. Global and Planetary Change 143:100–117.

Nover, D. M., J. W. Witt, J. B. Butcher, T. E. Johnson, and C. P. Weaver. 2016. The Effects of Downscaling Method on the Variability of Simulated Watershed Response to Climate Change in Five U.S. Basins. Earth Interactions 20:1–27.

Null, S. E., E. Bartolomeo, J. R. Lund, and E. Hanak. 2015. Managing California's Water: Insights from Interviews with Water Policy Experts. San Francisco Estuary and Watershed Science 10.

Null, S. E., and J. H. Viers. 2013. In bad waters: Water year classification in nonstationary climates. Water Resources Research 49:1137–1148.

O'Donnell, E. L., and D. E. Garrick. 2017a. Chapter 19 - Environmental Water Organizations and Institutional Settings. Pages 421–451 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

O'Donnell, E. L., and D. E. Garrick. 2017b. Chapter 26 - Defining Success: A Multicriteria Approach to Guide Evaluation and Investment. Pages 625–645 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Olden, J. D., and R. J. Naiman. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology 55:86–107.

Opperman, J. J., E. Kendy, R. E. Tharme, A. T. Warner, E. Barrios, B. D. Richter, J. J. Opperman, A. T. Warner, E. Kendy, R. E. Tharme, and E. Barrios. 2018. A Three-Level Framework for Assessing and Implementing Environmental Flows. Frontiers in Environmental Science 6:1–13.

Pahl-Wostl, C., G. Holtz, B. Kastens, and C. Knieper. 2010. Analyzing complex water governance regimes : the Management and Transition Framework 13:571–581.

Poff, L., and J. H. Matthews. 2013. Environmental flows in the Anthropocence: Past progress and future prospects. Current Opinion in Environmental Sustainability 5:667–675.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The Natural Flow Regime. BioScience 47:769–784.

Poff, N. L., J. D. Olden, D. M. Merritt, and D. M. Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Sciences 104:5732–5737.

Poff, N. L., B. D. Richter, A. H. Arthington, S. E. Bunn, R. J. Naiman, E. Kendy, M. Acreman, C. Apse, B. P. Bledsoe, M. C. Freeman, J. Henriksen, R. B. Jacobson, J. G. Kennen, D. M. Merritt, J. H. O'Keeffe, J. D. Olden, K. Rogers, R. E. Tharme, A. Warner, L. Poff, B. D. Richter, A. H. Arthington, S. E. Bunn, R. J. Naiman, E. Kendy, M. Acreman, C. Apse, B. P. Bledsoe, and M. C. Freeman. 2009. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55:147–170.

Poff, N. L., R. E. Tharme, and A. H. Arthington. 2017. Chapter 11 - Evolution of Environmental Flows Assessment Science, Principles, and Methodologies. Pages 203–236 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Rani, D., and M. M. Moreira. 2010. Simulation-optimization modeling: A survey and potential application in reservoir systems operation. Water Resources Management 24:1107–1138.

Rheinheimer, D. E., S. M. Yarnell, and J. H. Viers. 2013. Hydropower Costs of Environmental Flows and Climate Warming in California's Upper Yuba River Watershed. River Research and Applications 29:1291–1305.

Rodriguez, S. L., M. N. Peterson, F. W. Cubbage, E. O. Sills, and H. D. Bondell. 2018. What is private land stewardship? Lessons from agricultural opinion leaders in North Carolina. Sustainability (Switzerland) 10.

Roos-Collins, R. (Natural H. I., and J. (Natural H. I. Gantenbein. 2007. Handbook for Revision of Water Control Plans to Improve Environmental Flows Below

Dams Operated by the U.S. Army Corps of Engineerings and Guide to the Corps Guidance.

Samu, N. M., S.-C. Kao, P. W. O’Connor, M. M. Johnson, R. Uria-Martinez, and R. A. McManamay. 2018. National Hydropower Plant Dataset, Version 2 (FY18Q3). Existing Hydropower Assets [series] FY18Q3. National Hydropower Asset Assessment Program. Oak Ridge National Laboratory, Oak Ridge, TN.

Schramm, M. P., M. S. Bevelhimer, and C. R. DeRolph. 2016. A synthesis of environmental and recreational mitigation requirements at hydropower projects in the United States. Environmental Science and Policy 61:87–96.

Sood, A., D. E. Rheinheimer, A. Cai, A. Rallings, and J. Viers. 2020. Task 2 Project Report: Modeling Hydropower Operations. California Energy Commission.

Soumis, N., É. Duchemin, R. Canuel, and M. Lucotte. 2004. Greenhouse gas emissions from reservoirs of the western United States. Global Biogeochemical Cycles 18:n/a-n/a.

Stalnaker, C., B. L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology - A Primer for IFIM. National Biological Service, U.S. Department of the Interior.

Stewardson, M. J., and F. Guarino. 2018. Basin-scale environmental water delivery in the Murray-Darling, Australia: A hydrological perspective. Freshwater Biology 63:969–985.

Tarlock, D. 2012. Hydro Law and the Future of Hydroelectric Power Generation in the United States. Vanderbilt Law Review 65:1723–1767.

Tharme, R. E. 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19:397–441.

Thomas, G. A. 2017. Chapter 21 - Managing Infrastructure to Maintain Natural Functions in Developed Rivers. Pages 483–518 *in* A. C. Horne, J. A. Webb, M. J. Stewardson, B. Richter, and M. Acreman, editors. Water for the Environment. Academic Press.

Ulibarri, N. 2018. Does collaboration affect the duration of environmental permitting processes? Journal of Environmental Planning and Management 61:617–634.

US Department of Energy. 2016. Hydropower Vision Report: Full Report | Department of Energy.

US Department of Energy. 2017. Effects of Climate Change on Federal Hydropower - The Second Report to Congress January 2017.

Viers, J. H. 2011. Hydropower relicensing and climate change. Journal of the American Water Resources Association 47:655–661.

Vörösmarty, C. J., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R. Liermann, and P. M. Davies. 2010. Global threats to human water security and river biodiversity. Nature 467:555–561.

Warner, A. T., L. B. Bach, and J. T. Hickey. 2014. Restoring environmental flows through adaptive reservoir management: planning, science, and implementation through the Sustainable Rivers Project. Hydrological Sciences Journal 59:770–785.

Whipple, A. A., and J. H. Viers. 2019. Coupling landscapes and river flows to restore highly modified rivers. Water Resources Research 55:2018WR022783.

Yarnell, S. M., G. E. Petts, J. C. Schmidt, A. A. Whipple, E. E. Beller, C. N. Dahm, P. Goodwin, and J. H. Viers. 2015. Functional Flows in Modified Riverscapes: Hydrographs, Habitats and Opportunities. BioScience 65:963–972.

Yarnell, S. M., E. D. Stein, J. A. Webb, T. Grantham, R. A. Lusardi, J. Zimmerman, R. A. Peek, B. A. Lane, J. Howard, and S. Sandoval-Solis. 2020. A functional flows approach to selecting ecologically relevant flow metrics for environmental flow applications. River Research and Applications 36:rra.3575.

Zhou, T., N. Voisin, and T. Fu. 2018. Non-stationary hydropower generation projections constrained by environmental and electricity grid operations over the western United States - IOPscience. Environmental Research Letters 13:074035.

Appendix I – Survey Instrument

Hydropower and Environmental Flows

Research by the University of California, Merced

We are interested in **how decisions for environmental flows are made**.

By environmental flows we mean the quantity (magnitude, duration, frequency, timing, and rate of change) and quality of water needed to sustain ecosystems and the ecosystem services humans depend on.

In this survey, environmental flow is used as an umbrella term for any controlled release that is intended for environmental benefit. Alternative terms include minimum instream flow, pulse flow, down-ramp rates, and functional flows.

By project facility we mean any and all components of a reservoir operation not limited to dams, reservoirs, diversions, penstocks, and powerhouses associated with a particular managed system.

Your information will be maintained in a **confidential** format. Absolute confidentiality cannot be guaranteed since research documents are not protected from subpoena. There are no known risks at this time.

All research has been approved by the Institutional Review Board for Human Subjects Research at the University of California, Merced. Contact the IRB Chair Dr. Ramesh Balasubramaniam with any concerns via phone (209) 385-8655 or email irbchair@ucmerced.edu.

You may contact the researchers at any time at envflow@ucmerced.edu or Leigh Bernacchi, PhD at (209) 355-8229.

We anticipate the survey to take 20 minutes of your time. There are four sections to the survey.

Your responses will help develop environmental flows resources for managers.

Please initial with your consent. You may discontinue this survey at any time without consequence.

____

Initial

I. SYSTEM INFORMATION

1. Please identify your role in your organization.

○ General Manager or Owner
○ Operations Manager
○ Operator
○ Engineer
○ Environmental Scientist
○ Technician
○ Other: ____________________

2. What are the primary tasks in your job? Check all that apply.

☐ Make decisions regarding operations and environmental flows
☐ Run models regarding operations and environmental flows
☐ Implement operational decisions (e.g. control gates to release water)
☐ Verify that infrastructure is functioning properly
☐ Coordinate with other reservoir managers in the system
☐ Supervise staff who generate operation plans or reservoir releases
☐ Ensure compliance with regulatory agencies (federal and state regulators)
☐ Other: ____________________

3. How many reservoirs are you managing?

3a) How many dams are you managing?

3b) How many hydropower plants are you managing?

Project Facility

In this section, please tell us about your project facility. Please respond with the furthest downstream in mind, excluding afterbays, if you manage multiple facilities.

4. Please rank the following priorities for your project facility, which 1 being the top priority? Drag the following options upward or downward to change the rank.

___ Environment
___ Flood Control
___ Hydroelectric Power Generation
___ Navigation
___ Recreation
___ Water Storage and Supply
___ Not listed here

5. Who is the primary owner/operator of your reservoir?

○ Federal agency
○ Non-federal public utility (e.g., municipal, public utility district, county, state)
○ Private utility (i.e., investor-owned utilities)
○ Private non-utility (e.g., independent power producer)
○ Cooperative
○ Other: ____________________

6. In what year was this project facility completed?

7. When were the latest structural updates made?

○ Never
○ In the last 10 years
○ In the last 20 years
○ In the last 30 years
○ More than 30 years ago

8. Were the structural updates made specifically for environmental flows? If so, please describe the updates.

9. What is the reservoir storage capacity?

○ Less than 1,000 acre feet
○ 1,000 - 10,000 acre feet
○ 10,001 - 100,000 acre feet
○ 100,001 - 1,000,000 acre feet
○ More than 1,000,000 acre feet

10. What is the hydroelectric power capacity of the project facility?

○ Less than 1 MW
○ 1 - 10 MW
○ 11 - 30 MW
○ 31 - 100 MW
○ 101 - 300 MW
○ More than 300 MW

11. How much storage variability does your facility have?

○ None (i.e., 100% run-of-river)
○ < 1 day
○ 1 - 7 days
○ 8 - 30 days
○ 31 - 365 days
○ > 365 days

12. What is the length of your bypass reach?

○ N/A (releases are below dam)
○ < 0.1 miles
○ 0.1 - 1 mile
○ 1 - 10 miles
○ 10 - 1000 miles

13. Describe how useful the following structural tools are for providing environmental flows?

	Not useful at all	Somewhat useful	Very useful	Not available on my reservoir
Release capacity (e.g. quantity of water possible to release)				
Fine release controls on flow rates				
Non-selective withdrawal temperature control device				
Fish bypass system				
Data collection/ sensors				
Selective withdrawal for water quality control (e.g. intake gates at different heights for temperature control)				

14. Is your facility licensed by FERC (Federal Energy Regulatory Commission)?

○ Yes
○ No

15. In what major hydrologic region is your facility? The list below is based on USGS mapping of watersheds. See your location on the map: https://water.usgs.gov/GIS/regions.html

○ Region 01 New England
○ Region 02 Mid-Atlantic
○ Region 03 South Atlantic-Gulf
○ Region 04 Great Lakes
○ Region 05 Ohio
○ Region 06 Tennessee
○ Region 07 Upper Mississippi
○ Region 08 Lower Mississippi
○ Region 09 Souris-Red-Rainy
○ Region 10 Missouri
○ Region 11 Arkansas-White-Red
○ Region 12 Texas-Gulf
○ Region 13 Rio Grande
○ Region 14 Upper Colorado
○ Region 15 Lower Colorado
○ Region 16 Great Basin
○ Region 17 Pacific Northwest
○ Region 18 California
○ Region 19 Alaska
○ Region 20 Hawaii
○ Region 21 Caribbean
○ Other:________________

II. TECHNICAL DECISION-MAKING ABOUT ENVIRONMENTAL FLOWS

16. How frequently do you employ the following rules for environmental flows?

	Not at all	Sometimes	Most of the time	All of the time
Minimum in-stream flow (MIF)				
In-stream flow requirement (IFR)				
Pulse flows				
Ramping rate restrictions				
Temperature objectives				

17a. Do you use a runoff forecasting model?

○ No
○ Yes, please specify ___________________________________

17b. If yes, what is your forecast window?

○ < 2 weeks
○ 2-4 weeks
○ 4-6 weeks
○ 6-8 weeks
○ >8 weeks

18. What is the primary tool you use to determine hourly to daily releases?

○ Release rule curves
○ Simulation modeling
○ Optimization modeling
○ Proprietary modeling software (i.e. PLEXOS)
○ Personal experience
○ Other (please specify):__________________________

19. What is the primary tool you use to determine releases over the long-term?

○ Release rule curves
○ Simulation modeling
○ Optimization modeling
○ Proprietary modeling software (i.e. PLEXOS)
○ Personal experience
○ Other (please specify):__________________________

20. With respect to setting environmental flows, how often are decisions about release made?

○ < 1 month
○ 1-3 months
○ 3-6 months
○ 6-12 months
○ 12-36 months
○ > 36 months
○ Other (please specify): ____________________________

21. With respect to environmental flows, with whom do you discuss and plan your allocations? Check all that apply.

☐ Federal fish and wildlife managers (NOAA, FWS)
☐ State fish and wildlife managers
☐ Other utility
☐ Non-profit organizations
☐ Other:___________________________

22. With respect to environmental flows, how often and under what circumstances do you required to communicate with regulatory agencies?

23. What trade-offs do you make in meeting your environmental flows targets?

24. How often do you communicate with dam operators “upstream” or “downstream” from you?

○ Hourly
○ Daily
○ Weekly
○ Monthly
○ Less frequently than monthly
○ Not applicable

25. How often do you have to make changes to a planned release?

○ Hourly
○ Daily
○ Weekly
○ Monthly
○ Less frequently than monthly
○ Not applicable

26. How are decisions about environmental flows changed during an emergency situation? (e.g. 2012-2017 drought or Oroville spillway.)

27. Do you operate your project facility for the following natural flow components? Check all that apply.

☐ Wet season initiation flows (e.g. pre-wetting riverbed)
☐ Wet season peak flow (e.g. sediment mobilization)
☐ Dry season base flow (e.g. minimum in-stream flow)
☐ Spring snowmelt recession (e.g. ramp rate)
☐ Other:______________________________

III. ENVIRONMENTAL FLOWS: CHALLENGES AND OPPORTUNITIES

In this section, please share your personal perspectives on environmental flows and reservoir management.

28. State the degree to which you agree or disagree with the following statements.

	Strongly disagree	Some-what disagree	Some-what agree	Strong-ly agree	Not Appli-cable
Environmental flows requirements are too strict.					
Environmental flows actually accomplish the goal of improving the environment.					
During droughts, I have had to dramatically change my environmental flow release strategy.					
Environmental flows could be improved through better science.					
I often have to sacrifice environmental flows to meet hydropower revenue targets.					
My goal is to maximize hydropower revenue, as long as operational constraints are met.					
I am concerned about legal requirements or lawsuits.					
I would better support ecological targets if I had more information about species' needs.					
I believe my work is effective in balancing the needs of the environment.					
I consider myself an aggressive adopter of new environmental flow practices.					

29. What are your top three objectives for environmental flows? Please select three.

☐ Fish breeding and hatching
☐ Fish passage
☐ Salinity management
☐ Pollutant management
☐ Sediment management
☐ Temperature management
☐ Single species management
☐ Minimum in-stream flows
☐ Aquatic ecosystem/habitat maintenance/improvement
☐ Other:______________________________

30. Which regulations do you consult with respect to environmental flows? Check all that apply.

☐ In-stream flow requirements for ESA-listed species
☐ In-stream flow requirements for non-endangered species
☐ Downstream pollutants (e.g. TMDL)
☐ Downstream salinity requirements
☐ NOAA fisheries regulations
☐ State fish and wildlife regulations
☐ Other:______________________________

31. Which regulations “backfire” or do not serve the intended purpose? And why?

32. How do the following criteria create challenges for your environmental flows?

	Not challenging	Somewhat challenging	Very challenging
Cost of monitoring			
Consumes personnel time			
Infrastructure constraints			
Lack of information for inflows			
Lack of information for outflows			
Regulatory constraints			
Inaccurate models			
Other operating priorities come first			

33. Given more funding, where would you prioritize your allocation of resource? Please select your top priority.

☐ Fund additional staff
☐ Improved maintenance and minor upgrades
☐ Improved science (e.g. sensors for achieving downstream targets)
☐ Improved science (e.g. sensors for managing inflows)
☐ Improved institutional capacity (e.g. convening, training)
☐ Infrastructural improvements
☐ Other (please specify):_____________________________

34. Please state the degree to which you agree or disagree with the following statements on climate change:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Globally climate change is happening.					
In my region, climate change is happening.					
Climate change threatens water quantity locally.					
Climate change threatens local water quality.					

35. What is the biggest challenge you face in meeting environmental flows requirements under climate change?

36. Looking forward, how do you anticipate environmental flows management will change in the future?

IV. DEMOGRAPHICS

37. How long have you been working with your current organization?

38. How long have you been in your current position?

39. Please enter the county and state in which you work?

40. What major river system do you work in? (Major River, e.g. Sacramento, San Joaquin, Columbia, Colorado)

41. What is the highest level of education you have?

○ Junior high school
○ High school graduate or GED
○ Vocational training beyond high school
○ Associate’s degree
○ Bachelor’s Degree
○ Graduate Degree
○ Other:_____________________________

42. In what year were you born?

○ 1920-1929
○ 1930-1939
○ 1940-1949
○ 1950-1959
○ 1960-1969
○ 1970-1979
○ 1980-1989
○ 1990-1999
○ Decline to respond

If you wish, please add any additional information or comments you would like to share. Thank you sincerely for your time.

Would you like a copy of our report? If so, please provide an email address. Your email will be kept confidential and removed from your responses.

Would you be available for your follow up questions? If so, please provide your contact information (Name, email, phone). This data will not be stored with your responses.

Is there anyone else you would recommend we contact for a response to this survey? If so, please provide their name and organization. This data will not be stored with your responses.

Thank you for your time!