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# Environmental hazards, rigid institutions, and transformative change: How drought affects the consideration of water and climate impacts in infrastructure management

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## Abstract

Climate change necessitates major changes in infrastructure siting, design, and operations. Successful adaptation of infrastructure management requires overcoming thorny institutional challenges including path dependency and isomorphic pressures that inhibit major shifts in norms and practices. Hazards have been posited as a potential trigger for changing long-standing institutions because they can upend stable system states. However, research on the ability of hazards to shift norms and practices is still nascent and focuses on rapid-onset disasters like floods, hurricanes, or fires. This paper uses the 2012-2016 California drought to assess the potential for slow-onset hazards to lead to institutional change. We assess whether it yielded a shift in institutional norms, namely agency application of existing regulations toward enhanced socio-ecological resilience in the face of climate change. We focus on the environmental impact assessment process under the National Environmental Policy Act and the Federal Energy Regulatory Commission's process for licensing hydropower dams. Using computational text analysis of Environmental Impact Statements and participant observation of infrastructure licensing negotiations, we assess whether, over the years of the drought, agencies placed more emphasis on drought issues or climate resilience in analyzing infrastructure siting and design. In EIS documents, we observe a short-term spike in consideration of drought-related impacts and a longer-term increase in water security, suggesting some shifts in institutional practice; however, consideration of climate impacts decreased over the time period. In FERC licensing, there was no consideration of future climate impacts, despite managers' recognition that this posed a problem for projects' future operations. Although these results do not preclude the ability of slow-onset hazards to shift institutional norms, they suggest that doing so is challenging.

**Keywords:** drought, climate change, institutional change, adaptive governance, environmental impact analysis, infrastructure management

# 1. Introduction

Around the world, socio-environmental systems are changing rapidly, often in nonlinear and hard to predict ways. In this setting, surprises are common. Scientists recently discovered that Antarctica's ice sheets are melting much faster than predicted (Konrad et al. 2018; Rignot et al. 2019), which could accelerate anticipated sea level rise. Managers of the cod fishery in Eastern Canada were taken by surprise both when the fish stock plummeted in the early 1990s and later when the stock did not recover despite its closure (Filbee-Dexter et al. 2017, 2018). And in western North America, mountain pine beetle has spread far more rapidly than expected, damaging pine trees across the region (Mitton and Ferrenberg 2012; Filbee-Dexter et al. 2018).

Many environmental governance scholars posit the need for institutional change to enable more flexible and adaptive responses to these types of environmental pressures (Chaffin, Gosnell, and Cosens 2014; Folke et al. 2005; Armitage, Berkes, and Doubleday 2010). Institutions are “the humanly devised constraints that structure political, economic, and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct), and formal rules (constitutions, laws, property rights)” (North 1991, 97). Scholars of adaptive governance argue that, in the face of environmental change, our institutions need to be “both flexible enough to address highly contextualized [socio-environmental systems] and dynamic and responsive enough to adjust to complex, unpredictable feedbacks between social and ecological system components” (Chaffin, Gosnell, and Cosens 2014, 1). Essentially, if the environment is changing, the rules we use to govern human interactions with that environment also need to change.

However, many formal institutions are very bureaucratic and hard to change, running in conflict with the need for adaptive governance. As Barbara Cosens and coauthors write, “adaptive environmental governance will require flexibility and action that is currently absent in heavily administrative governments in many Western democracies” (Cosens, Gunderson, and Chaffin 2018, 4). Thus, finding examples of flexibility and change in existing bureaucratic institutions is important for understanding whether there is a possibility of making these institutions more adaptive (Garmestani et al. 2019).

Exogenous shocks--abrupt changes in the setting an institution operates in--are commonly considered drivers of institutional change. In the environmental space, this means things like hurricanes, fires, and disease outbreaks can lead to change, even in particularly rigid institutions. As Carl Folke and colleagues note, “A resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state” (Folke et al. 2005, 441). For instance, following the 2004 Indian Ocean Tsunami, both Indonesia and Sri Lanka created numerous disaster prevention organizations; the tsunami also catalyzed a peace process in conflict-ridden Aceh, Indonesia (Birkmann et al. 2008). A series of large floods in Hungary led to national adoption of a comprehensive flood management program (Albright 2011). Most documented examples of institutional change in the environmental space occur after abrupt shocks: fast moving, high-profile events like hurricanes, floods, or fires. In contrast, many of climate change's anticipated effects--drought, sea-level rise, shifts in precipitation patterns--are *slow onset*, meaning that they aren't perceptible for a long time (Porfiriev 2015). Given the widespread occurrence of slow onset changes, it is important to understand the conditions under which they can lead to institutional change.

In this paper, we explore institutional changes during a recent slow-onset environmental shock: the 2012-2016 California Drought (see figure 1). The drought was the driest five-year period in the historical record (Swain et al. 2014; Robeson 2015; Hanak, Mount, and Chappelle 2016) and had numerous ecological, social, and economic impacts, from widespread tree mortality (Asner et al. 2016; USDA Office of Communications 2016), to wells running dry in rural homes and small communities (Nagourney 2014), to billions of dollars of lost agricultural production (Howitt et al. 2015). Many short- and long-term policy changes have been attributed to the drought, including the state’s first-ever regulation of groundwater (the Sustainable Groundwater Management Act [SGMA] of 2014, see California Water Code 10720-10737.8). We explore the possibility for change in existing administrative institutions, specifically regulatory processes underlying the permitting and operations of water, energy, and other infrastructure. Using a variety of data sources, we assess whether there is evidence of increased consideration of drought or climate impacts between the pre- and post-drought period. We also explore reasons that support or constrain these changes, with the aim of identifying suggestions for enabling institutions to make necessary changes in response to environmental pressures.

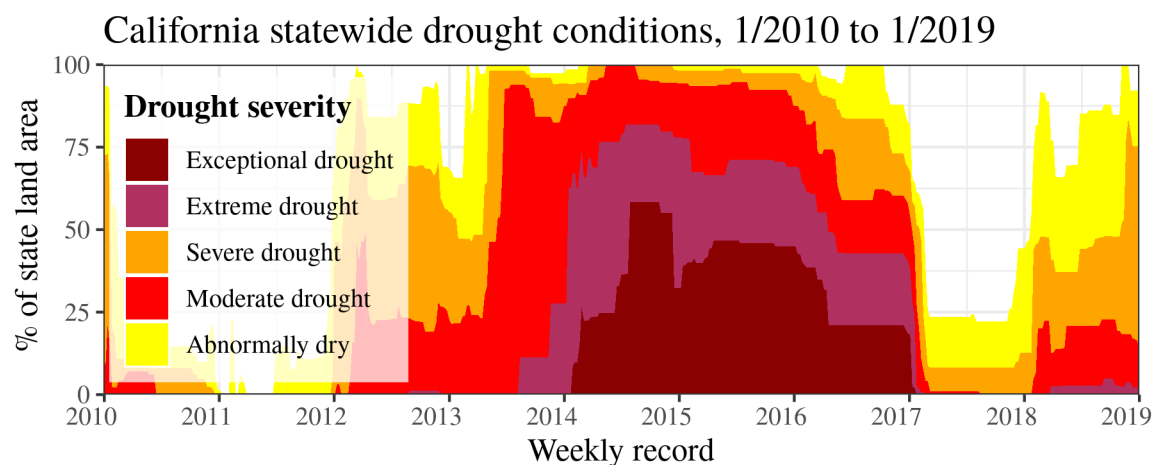


Figure 1. Timeline of the California Drought. Between 2013 and early 2017, 100% of the state was facing some level of drought conditions. On January 17, 2014, Governor Jerry Brown declared a Drought State of Emergency.

## 2. Institutional Change and Adaptive Governance

Following Cosens et al. (2018, 4), we define adaptive governance as “environmental governance that allows emergence of collective action capable of facilitating adaptation to change and surprise as well as the capacity to itself evolve” (see also Chaffin, Gosnell, and Cosens 2014). Adaptive governance is a broad concept, encompassing ideas from the literature on resilience (Holling 1973; Folke 2006), adaptive management (Walters 1986; Pahl-Wostl 2006), adaptive capacity (Siders 2019; Brooks, Neil Adger, and Mick Kelly 2005; Folke et al. 2002), and collaborative governance (Emerson and Nabatchi 2015; Wondollock and Yaffee 2000). Key features of adaptive governance are active incorporation of scientific and lay knowledge about the socio-environmental system, learning about change in the system and what is working (or not), integration of actors across scales and perspectives, and the ability to reorganize in the face of sudden change (Pahl-Wostl et al. 2007; Chaffin, Gosnell, and Cosens 2014; Gunderson 1999).

A necessary (though not sufficient) condition for institutions to adapt to new circumstances is capacity to change, which means we need to know how and why institutions change. The literature on institutional change is vast and spans numerous disciplines, so this is not intended to be a comprehensive review. Instead, we highlight key factors driving institutional stability and change.

Broadly speaking, institutions are shaped by their history, by actors interacting with the institution, and by changes in the institution's surrounding environment (Kingston and Caballero 2009; Garud, Kumaraswamy, and Karnøe 2009; Mahoney and Thelen 2010a). With all of these inputs, institutions face a definite tension between being fluid and rigid (Greif and Laitin 2004). Although it is desirable for institutions to be responsive to internal and external pressures, consistency and procedural regularity foster legitimacy and a sense of fairness among stakeholders (Craig et al. 2017) and are important values in public administration (Duit 2016).

Different theoretical traditions tend to emphasize either rigidity or stability. According to the idea of path dependency, institutions are rigid and tend toward a self-reinforcing equilibrium. An institution exists on a historically-determined path whose evolution is shaped primarily by random events (Vergne and Durand 2010). Once on this path, an institution becomes "unable to move to a new state despite all involved preferring to do so" (Garud, Kumaraswamy, and Karnøe 2009, 765). Once such lock-in has occurred, an outside force must intervene to steer the institution toward a new trajectory (Garud, Kumaraswamy, and Karnøe 2009; Vergne and Durand 2010; Kemp, Rip, and Schot 2001).

One such outside force is an exogenous shock, an event or series of events occurring outside the institution that lifts and/or overcomes usual constraints on action. This shock can lead to a critical juncture (Capoccia 2015), "a relatively short [period] of time during which there is a substantially heightened probability that agents' choices will affect the outcome of interest" (Capoccia 2015, 151; see also Mahoney and Thelen 2010a). The critical juncture creates a time of social and political uncertainty, enabling actors more flexibility in their actions than other periods (Capoccia 2015). Although not all institutions will evolve substantially following an exogenous shock (Kingston and Caballero 2009), they are important features in many historical institutional analyses. Finally, an institution need not be in a state of lock-in for an exogenous shock to create the conditions for change (Capoccia 2015).

When critical junctures arise, a common response to environmental pressures is to create new institutions. Two prominent examples from water resource governance are the creation of transboundary organizations (Sternlieb et al. 2013) such as watershed groups (Sabatier et al. 2005; Margerum 2011) that seek to match problem scale, and agencies tasked with specific new mandates such as groundwater basin management (Langridge and Ansell 2018). A potential shortcoming of adaptation through the creation of new institutions is that it may not result in meaningful change unless it "alter[s] the logic of the institution or compromise[s] the stable reproduction of the original core" (Mahoney and Thelen 2010b). Thus, an important outstanding question (which we aim to address) is how and when existing, stable institutions change in response to disruptive events.

### 3. Case background: Infrastructure siting and operations during the California drought

This paper explores whether actors strategically redeployed existing rules or regulations about infrastructure planning and assessment to meet the new circumstances of the drought (Mahoney and Thelen 2010a; Streeck and Thelen 2005). Although the exact start and end points of the drought are debated (as is the case with any drought), starting in December 2011 California entered the driest five-year period since record keeping began in 1895 (Hanak, Mount, and Chappelle 2016). It was also exceptionally warm, leading to increased evapotranspiration and reduced snowpack, in a state heavily reliant on snow for its water supply. Between 2013 and early 2017, 100% of the state was classified as facing drought conditions, with a substantial portion being in “Extreme” or “Exceptional” drought (see figure 1). Because of the drought’s widespread impacts on the state’s environment and society (Lund et al. 2018; Swain et al. 2014), numerous new institutions were created. For instance, the state instructed municipalities to reduce their water use by 20% and enacted its first comprehensive legislation regulating groundwater use (the Sustainable Groundwater Management Act [SGMA]), creating a series of basin-scale institutions and organizations to develop rules for groundwater extraction. While these new measures took shape, Federal and state institutions governing the permitting, construction, and operations of major water and energy infrastructure remained in place. Given the critical role of infrastructure in shaping California’s water resource outcomes specifically (Escriva-Bou et al. 2016) and societal outcomes more generally (Frischmann 2012; DHS 2013), the ability of infrastructure governance institutions to change is a critical element of successful adaptation to environmental change.

We focus specifically on federal rules governing the permitting and operations of large infrastructure projects. In the United States, large infrastructure projects almost always involve review, permitting, and/or assistance by federal agencies. Unlike many areas of resource management, decisions about infrastructure are long-lasting. Once built, a dam or power plant will be in place for decades, and it takes a substantial about-face to decommission or dismantle it (Lejon, Renöfält, and Nilsson 2009). Altering physical infrastructure or adjusting its operations typically increases up-front project costs (political, economic and/or financial), yet benefits accrue over the long term and are highly uncertain. Further, although many environmental and resource management practices are incremental in nature, infrastructure tends to be episodic and punctuated. This disfavors major change because half-measures and hedging are not really feasible, and there is likely a higher threshold for change in infrastructure siting than other water-related policy arenas.

Although there are numerous ways in which one could conceptualize institutional change in this context, *in this paper we ask whether the drought corresponded with changes in the attention decision-makers paid to the impacts of drought and climate change in reviewing the design and operations of infrastructure.* Agencies licensing or reviewing particular infrastructure projects have considerable leeway in how they undertake the review, particularly in what data sources to consider and what resources or impacts to emphasize. By assessing the content of these processes, through written documents and meeting observation, we can understand agencies’ policy priorities and whether, during the drought, actors conducting these reviews began to consider the effects of drought and climate change in novel ways. Although attention and focus are not perfect proxies for institutional change writ large, the policy process literature demonstrates that issue definition and focus shapes subsequent policy outcomes

(Baumgartner and Jones 2009; Kingdon 2003; Jenkins-Smith et al. 2014). If drought, for instance, begins to figure more prominently in water project planning, we assume that this is potentially indicative of drought-induced changes in infrastructure planning and operations at a larger scale. Scholars have similarly used content analysis to assess institutional change via congressional speeches (Nowlin 2016), local government budget documents (Anastasopoulos, Moldogaziev, and Scott 2017), and media coverage (Soroka and Wlezien 2019).

Given the infrequency of formal decisions about what infrastructure should be built and how it should be managed, we focus on two institutions that provide explicit space for these considerations. The first is the environmental impact assessment process under the National Environmental Policy Act (NEPA) (42 U.S.C. §4321). Under NEPA, any project built, funded, or approved by a federal agency must undergo an assessment of its potential environmental impacts (EPA 2013a). Many projects start with an Environmental Assessment, which evaluates the likelihood that a project's impacts will be significant (EPA 2013b). If they are found likely to be significant, an Environmental Impact Statement (EIS) must be written for the project (EPA 2013b); the EIS evaluates the projected impacts of the project on a diverse array of environmental resources, including air quality, biological resources, and aesthetics (CEQ 2018). As part of developing the EIS, the lead federal agency must consult with other resource agencies and provide opportunities for public input.

NEPA is a procedural statute: it does not mandate particular policy outcomes but rather places requirements on how agencies must evaluate the environmental impacts of and notify the public about their actions. The lead agency is not required to choose an alternative that minimizes harmful impacts, and NEPA cannot stop particularly damaging projects from being built. The idea of NEPA--and environmental impact assessment more generally--is that by requiring decision-makers to consider the impacts of a project and communicate those impacts to the public, the process will yield better decisions (Rasband et al. 2004; Bazerman, Little, and Chavkin 2003).

The second institution considered in this analysis is the Federal Energy Regulatory Commission's (FERC) process for licensing hydropower facilities. In order to prevent private exploitation of a public resource (rivers), all non-federally-owned hydropower plants must receive operating licenses from FERC; the licenses are issued for 30 to 50 years, so when a license expires the dam must undergo a "relicensing". The relicensing process typically takes 5-10 years, and entails a scoping process to determine what resources might be impacted by the dam, a series of studies to quantify those impacts, and development of management requirements to mitigate those impacts. The proposed management requirements are then submitted to FERC for review; FERC (in coordination with other regulatory agencies) then decides on the final terms of the operating license (Scott, Ulibarri, and Scott 2018; Ulibarri 2017; Chaffin and Gosnell 2017). The FERC review includes preparation of environmental review documents under NEPA.

The two institutions selected bracket two representative facets of infrastructure management: the siting of proposed infrastructure (NEPA) and the re-operation of existing infrastructure (FERC<sup>1</sup> and NEPA). Additionally, by focusing on their application to water and energy infrastructure, NEPA and FERC relicensing represent critical cases (Flyvbjerg 2006), as water and energy infrastructure are more directly

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<sup>1</sup> FERC processes also apply to newly proposed hydropower facilities, but the cases studied here are relicensings.

tied to the impacts of drought than, e.g., transportation or housing developments and therefore it is in their siting and operations that we would expect to see possible changes in practice.

Since this analysis considers how California's drought influenced federal infrastructure permitting, it is worthwhile to consider reasons why federal regulations would be influenced by state-level environmental changes. First, key project actors are often locally focused and most processes have a local or regional orientation despite being managed by federal agencies. Although NEPA applies to actions taken by federal agencies, these actions are often permitting or authorizing of land use by local governments, public utilities, and private firms (Ulibarri, Scott, and Perez-Figueroa 2018); FERC relicensing is explicitly for review of non-federally owned hydropower facilities. Additionally, agency field offices in California such as the Army Corps' Sacramento District office (ACOE 2019) manage and participate in NEPA and FERC processes taking place in the district. Second, California has a state-level environmental impact analysis, the California Environmental Quality Act (CEQA), for state approval or actions (CDFW 2019). NEPA and CEQA encourage a joint review process where state and federal requirements apply (CA OPR 2014) and many of the EIS cases we observe satisfy CEQA as well. For these reasons, we believe it is reasonable to expect that California-specific events like the drought are likely to be reflected in federally-applied infrastructure reviews.

Finally, paying attention to climate change in infrastructure planning is substantively important in its own right. Climate change is expected to alter maintenance and operations costs (e.g., Larsen et al. 2008) and place new physical demands on infrastructure (e.g., Gersonius et al. 2013). Considering the potential effects of drought and climate change in infrastructure design, siting, and operations should make projects more resilient to climate change by improving environmental, physical, and financial viability during future events.

## **4. Material and methods**

Our research employed a mixed method approach, given different data availability for the two institutional cases studied. To study the NEPA process, we used Environmental Impact Statements prepared for each infrastructure project we identified related to water or energy projects in California from 2010-2018. First, we downloaded all available project documents and metadata from the US Environmental Protection Agency's EIS database (EPA 2019). EISs are prepared for a wide array of projects; to filter for water- and energy-related projects, we searched for relevant terms in project metadata (e.g., "hydropower", "wetlands", or "transmission"). We identified 100 water- and/or energy-related EISs (draft, final, and supplementary) for the state of California during the 2010 to 2018 period. Although the EPA database contains a record of all draft and final EISs notified in the US Federal Register, in some cases the actual documents were not available. For the subset of California-based projects identified, we supplemented this database with documents retrieved from other archives, including Federal and state agencies, local governments, and utilities.

Understanding whether California EISs exhibit a unique--and potentially drought-related--shift in attention and focus or reflect a broader trend required comparison to EISs produced in other states. To develop a non-California comparison set, we also relied upon the EPA database. Using the same term-based matching process, we filtered for energy and water related projects. Of the projects identified in this



fashion, we were able to access documentation 362 projects for comparison with projects sited in California.

Text mining offers a means to systematically characterize the content of infrastructure assessment documents. We used a series of natural language processing (NLP) software tools for parsing and extracting relevant information from environmental impact assessment documents, which we describe fully in appendix A.

The initial task was to measure the relative degree to which each assessment emphasized water resources and/or climate change. We converted each PDF file to plain text, and then tokenize the text into sentences (note that although EIS processes involve public comment procedures, we focused on the documents themselves and not comments in this analysis). The most basic way to assess content is to focus on the prevalence of specific words of interest--drought, climate change, etc. *Term frequency-inverse document frequency* (tf-idf) weights each word or phrase (terms) in a document based upon how frequently a term is used in a given document versus the corpus overall. Term  $t$  in document  $d$  will have a high tf-idf weight if it is prevalent in document  $d$  and relatively uncommon in the corpus writ large. By computing tf-idf weights for key terms across documents over time, we tracked how drought and climate change increased or decreased in focus.

However, text may still be about water even when the specific term “water” is not used. Our next step was to build a classification model that estimated the probability that each sentence was related to water and/or climate issues. To quantify sentence content we used a pre-trained word vector model, which positions words and phrases within a multidimensional vector space based upon learned context similarity (Mikolov, Chen, et al. 2013). Word context is learned in one of two ways, fitting a machine learning model to either: (1) predict target words based on surrounding words; or (2) predict surrounding words given the target word (Mikolov, Sutskever, et al. 2013). Individual words are assigned a locational vector; words nearer in location are expected to be more contextually similar than those that are further way. A sentence can then be represented by an aggregate vector of its constituent words.

It is possible to fit a new word vector model based on the text found in EISs, but testing showed that a word vector model fit to our EIS text alone generated noisy results which did not suitably reflect established contextual meanings. Although a single EIS document commonly exceeds 1000 pages in length, in the context of text mining, several hundred documents is not a large number of observations (compared to, e.g., Twitter posts or Wikipedia entries). Accordingly, we used a pre-trained word vector model fit to a much larger corpus. The word vector model we used, Stanford NLP group’s Global Vectors for Word Representation (GloVe) model, has a vocabulary of 2.2M words and phrases measured on 300 context dimensions. These dimensions were fit by modeling the co-occurrence of words in a massive text database (840B tokens).

The GloVe model served to quantitatively represent the content of each sentence token on the 300 context dimensions. To predict whether this content related to concepts of interest, we then trained an artificial neural network classifier to probabilistically assess whether each sentence related to water, climate, drought, or none of these categories based upon where each sentence was located in the word vector space.

The classifier is a type of supervised machine learning model, meaning that it must be trained on pre-labeled data. To label training data, we first built a dictionary of water, climate, and drought related terms. We used glossaries published by organizations such as the United States Geological Survey, US Environmental Protection Agency, news organizations, and universities to generate the list of water-related terms (sources are summarized in appendix A). We identified 12 water glossaries, which we then combined and filtered for terms that occurred in at least 3 different glossaries. After removing a few ambiguous terms, such as “habitat”, “density”, and “mitigation”, the dictionary contained 139 water resource-related terms, ranging from “aquifer” to “zooplankton” (summarized in appendix A). For drought and climate change, we developed a customized dictionary that included not just technical terms but also conditions and status. For instance, “groundwater depletion” relates to hydrological drought, while “groundwater” might not.

Since NEPA applies to all Federal environmental actions nationwide, documents for projects outside of California presented an excellent source of domain specific content against which a model could be trained. We converted these documents into tokenized sentences and filtered out tokens of abnormal length (typically representative of non-sentences mistakenly tokenized), yielding a training set of over 500,000 sentence tokens. We then used regular expression matching to identify sentences where one or more of these terms or words occurred and tag such sentences are related to a given topic. The neural network classifier was then trained on the tagged training data. This process resulted in a multilabel, multiclass classifier that took sentence tokens as input and predicted the topical focus. With this technique, a sentence that did not contain a specific concept term, but did contain words that were contextually similar to said term, was also identified as related to the same concept. A fuller discussion of the artificial neural network classification model we deployed is given in appendix A. All coding was done in the R programming language, primarily relying upon the *tidytext* package (Silge and Robinson 2016) for term frequency analysis, the *tokenizers* package (Mullen et al. 2018) for natural language processing, and the *keras* package (Allaire and Chollet 2018) for fitting the neural network classifier.

Lastly, we examined the occurrence of tokenized word pairs (i.e., words that appear in the same sentence) to assess whether different concepts are discussed in concert and the relative prevalence of certain ideas across periods. To focus on prominent word pairs related to climate, we first computed the total frequency of all token pairs found in sentences classified as related to climate and/or drought in California EISs (~3600 sentences). We filtered out all “stop words” (common words such as “the” or “and” that are not of interest) using a stop word dictionary by Silge and Robinson (2016). We then (1) selected the 40 most frequent word pairings across all time periods, which comprised 33 unique words (since one word could be part of multiple pairings); (2) identified all pairings from each time period involving two of these 33 words (1373 unique pairings); and (3) subsetted this list to include only pairings that occurred more frequently than the average pairing in the group (>62.4 times).

Although computational text analysis can reveal much about *what* topics were considered during infrastructure siting, it cannot explore *why* regulators and managers made these choices. Thus, we supplemented the high-level analysis of NEPA documents with an in-depth, four-year ethnographic study of the FERC hydropower relicensing process. The two relicensings studied were for mixed-use (hydropower, flood control, water supply, and recreation) dams in California’s Central Valley and represent the only California relicensings that were in the technical study and application development phase (the phase when local and state stakeholders have control over decisions, as opposed to FERC)

during the drought.<sup>2</sup> Key concerns in these relicensings were similar to other dams in California’s Sierra Nevada foothills, including protecting flows for salmon, providing lake and river based recreation, and ensuring irrigation water for agriculture. Between 2012 and 2016 (the heart of the drought), the lead author observed and recorded fieldnotes capturing conversation topics for over 300 hours of meetings for the two relicensings. Following these observations, interviews were conducted with all major parties in each relicensing, including the hydropower utilities (n=3), scientific consultants and facilitators (n=6), federal agencies (e.g., US Forest Service, National Marine Fisheries Service, n=6), state agencies (e.g., State Water Resources Control Board, California Department of Fish & Wildlife, n=6), and environmental non-governmental organizations (NGOs, n=6). The interviews covered the development and use of scientific information during the process, challenges each participant faced in engaging in the process and in getting their interests met, and overall reflections on the process’s effectiveness. Meeting fieldnotes and interview transcripts were coded using a modified grounded theory approach (Corbin and Strauss 2008) to develop emergent themes and categories about the decision-making process.

## 5. Results and Discussion

### 5.1. NEPA: Mixed trends in consideration of drought and climate change

#### 5.1.1. Term frequency analysis

We first turn to the question of what topics received more or less emphasis in NEPA documents over the years of the drought. Figure 2 shows average term frequency (tf) values and *tf-idf* weights across time for a selection of issues that infrastructure managers are likely to consider. Tf-idf weights are a function of how many times a term was used on a given document (tf) and how many times a term occurred in the corpus overall (idf). In other words, a high tf-idf weight means that a given term is useful for distinguishing a text from other texts. The values shown in figure 2 are only for California water and energy infrastructure EISs, but the tf-idf weights are computed using the entire corpus of California and non-California projects. By computing tf-idf weights across all projects, and then examining weights associated with California-specific projects, we assess the extent to which a given phrase was particularly important in California EISs versus those developed in other states--and thus whether we observe an increase in attention paid to drought and climate change in California relative to the rest of the country.

The left hand panel in figure 2 plots term frequency in EISs over time in order to contextualize the tf-idf weights in terms of how frequently these phrases occur overall. The right hand panel then plots tf-idf weights over time for these same phrases. Trends in both panels are estimated with a locally estimated scatterplot smoother (LOESS) regression across observations and time. The dashed line shows the onset of extreme drought at the start of 2014.

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<sup>2</sup> The names of the hydropower facilities are withheld to protect the anonymity of participants and interviewees.

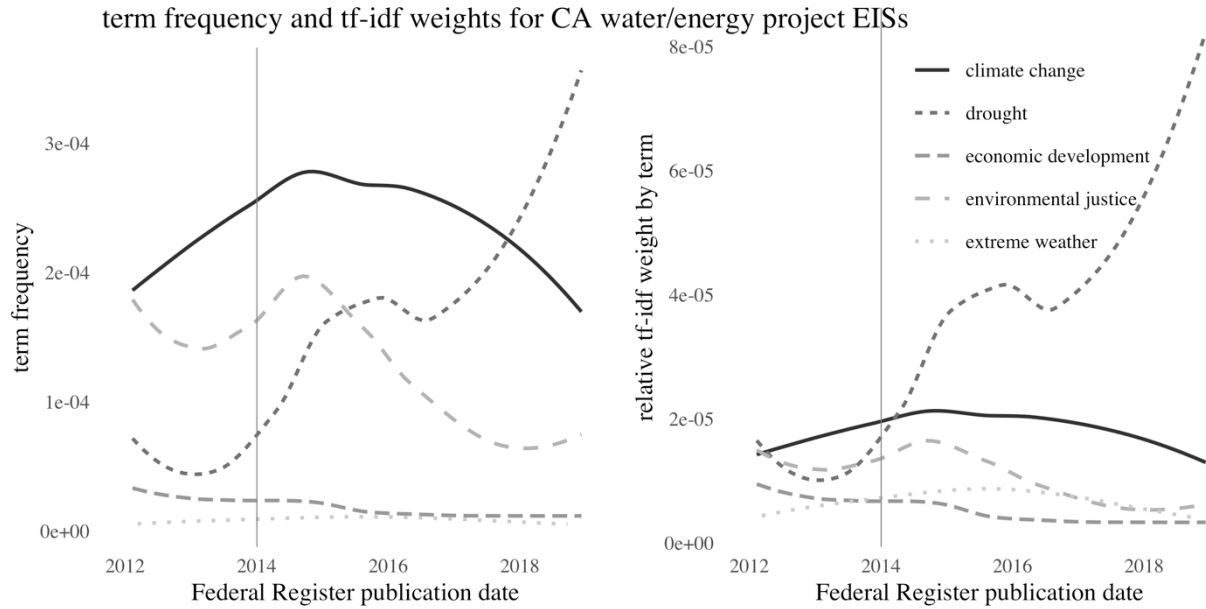


Figure 2: Average term frequency and term frequency-inverse document frequency weights for planning issues in California water/energy EISs

According to figure 2, prior to the onset of severe drought in California, drought was discussed much less than other issues such as climate change and environmental justice, and about on par with economic development. As the drought worsened in 2014, there was a marked uptick in the frequency with which drought was discussed, and a corresponding increase in the average tf-idf weight for drought in California EIS documents. That the idf-weight trajectory for drought closely matched the term frequency trajectory makes sense, because we would not expect drought in California to affect the rate at which drought was discussed in other states.

### 5.1.2: Topical focus of EIS content

Figure 2 provides a simple snapshot of how the drought shifted attention in infrastructure planning, but topics like climate and water can be discussed without using those specific terms. Figure 3 summarizes the extent to which EIS textual content, as measured by topic classification, focused on climate-, water-, and drought-related issues over time. For a given EIS, the proportion of text focusing on water, drought, or climate was the number of tokenized sentences predicted as such by the classification model divided by the total number of tokenized sentences. We fit a LOESS regression across publication dates for each sample set and topic to show general trends over the sample period. Note that each panel in figure 3 has a differently scaled y-axis, in order to highlight relative changes in each concept over time. Overall, drought- and climate-specific issues are not a major focus of EIS content, and so changes in these topics over time are not visible when plotted on the same scale as water resource focus in general (a major topic in EISs overall, typically around 10% of the total content). Although the proportions might seem small given the water and/or energy focus of the projects under consideration, this is not unexpected given the comprehensive nature of EIS preparation. Documents cover everything from endangered species present in the area to basic geologic attributes to local social and economic conditions.

## Climate, drought, and water foci in impact assessment

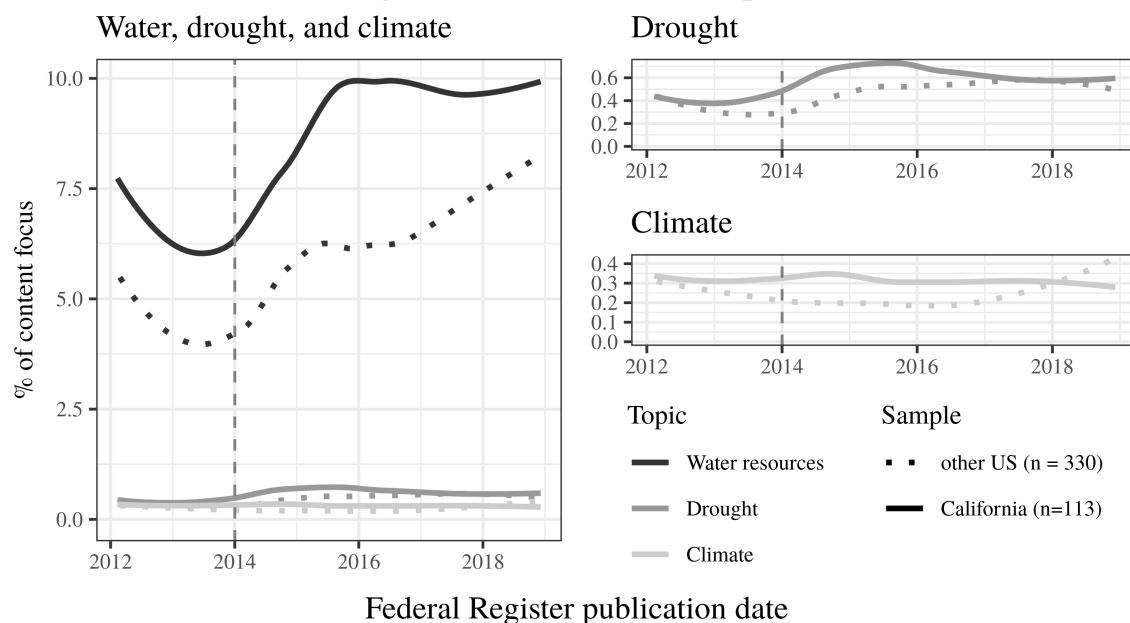


Figure 3: LOESS regression trends on % content focus across water/energy EISs over time

In figure 3, we see that on average, water-related issues were more prominently featured in California infrastructure projects than in the rest of the country. This has many potential causes, including California’s reliance on major water storage and transfer infrastructure such as the Central Valley Project and the California State Water Project, California’s ranking second in hydroelectric power generation (EIA 2018), and the state’s massive, irrigation-reliant agricultural sector (USGS 2018). However, projects both within and outside of California had an increase in water-related content over time, as evidenced by the largely congruent upward trends.

Although overall focus on drought issues within EIS texts was small (less than 1% on average), the temporal trend for California projects indicated a response to the 2014 drought. From 2013 to 2015, California’s drought focus doubled on average (see the upper right panel), from around 0.4% to over 0.8%. As the drought receded in 2017, focus also subsided, but it remained at a higher level than the pre-drought average. That drought focus fluctuated over such a short time period--and in parallel with empirical drought conditions--appears to contradict the goals of comprehensive infrastructure design and review processes. Ideally, infrastructure planning and analysis conducted at any time would consider future drought implications. Instead, it appears that the presence of drought-related discussion only reflected current conditions.

California projects had minimal change in climate change-related topical focus over the sample period. This is particularly noteworthy given the increasing discussion of drought issues in California EISs, as drought risk in California is exacerbated by climate change (Diffenbaugh, Swain, and Touma 2015; AghaKouchak et al. 2014). Additionally, average climate-related focus for projects in other states increased starting in 2016. Although California has been recognized as an agenda setter for climate issues in the US (Schreurs 2008), this perhaps indicates that the rest of the country increasingly recognizes the risks as well.



A few trends emerge in figure 4 with respect to how drought and climate change are discussed. In the pre-drought period (2011-2013), climate change is frequently discussed in the context of global concerns like greenhouse gases and global warming and related issues like renewable energy. During the drought period, the frequency of pairings between “climate” and “greenhouse”, “ghg”, and “gas” decreased, and connections to words like “water”, “groundwater”, “storage”, and “supply” increased. Indeed, drought related terms generally did not appear in the most frequent word pairings pre- and post-drought; only during the drought period (middle panel) was “climate” paired with words such as “drought” and “dry”. Post-drought, climate attention shifted to a different issue--sea level rise; water remained more prominent than in the pre-drought period, but water storage and supply, as well as drought, receded in frequency.

In sum, we see mixed patterns of institutional change in how EIS documents account for water, drought, and climate change. In some instances, there were definite and sustained increases in consideration starting during the drought (and sustaining afterwards), while in others the drought appeared to have no effect.

So why do we see these patterns? Two prominent factors are 1) shifts in presidential administration and 2) agency rules and guidelines. Two administrations are reflected in the data: President Obama from 2012-2016 and President Trump for 2017 and 2018. The long time frame on which EISs--and subsequent legal challenges--play out and the short period observed for the Trump Administration make it difficult to distinguish the influence of the two administrations.<sup>3</sup> However, the left-hand panel of figure 2 indicates an overall decline in agencies using the term “climate change” within EISs after 2017. This decline comports with reported efforts by the Trump Administration to deemphasize climate change in agency planning and assessment documents (Mooney 2018; Gearan, Morello, and Hudson 2019) and a report showing a decline in the use of the phrase “climate change” on government websites (Davenport 2018).

The reader will note that figure 3 does not show a decline in climate-related focus between the two presidential administrations. Although the results in figure 2 pertain to specific phrases, topic coding is based on content, meaning that while “climate change” was used less frequently, there was no decline in climate-related discussion overall. Our research design is focused on pre- and post-drought differences (and thus not particularly suited for addressing differences between the two presidential administrations), but we surmise that the consistency in climate focus combined with decline in actual references to “climate change” likely reflects a confluence of two factors: 1) the political priorities of the Trump Administration, which are generally oppositional to climate change-oriented policymaking (Gearan, Morello, and Hudson 2019; *Reuters* 2019); and 2) a series of legal rulings enforcing that agencies must consider climate impacts under NEPA (Goldfuss, Hardin, and Rehmann 2019). We observe that agencies continue to address climate-related issues in EISs in order to satisfy legal requirements and move projects forward, while also satisfying political preferences to limit discussion of “climate change”.

Regarding agency guidelines, for NEPA, the primary guidance is the Council on Environmental Quality (CEQ)’s “guidance on considering greenhouse gas (GHG) emissions and climate change.” Under President Obama, the guidance was developed in draft form in 2010, with the final version issued in

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<sup>3</sup> For instance, a 2018 ruling found that the US Bureau of Land Management failed to appropriately comply with NEPA because it did not calculate greenhouse gas emissions resulting from the coal leases (*Western Organization of Resource Councils v. U.S. Bureau of Land Management* 2017). However, the EIS Record of Decision was published in 2015 by the Obama Administration and the legal action initiated in March 2016, eight months before Trump took office.

August 2016 (post-drought) (Council on Environmental Quality 2016b). The guidance stipulates that NEPA reviews should consider the potential of a project to emit or sequester GHG emissions, as a proxy for understanding the effects of a project on climate change. It also instructs reviews to consider the impact of climate change on the project: “For example, a proposed action may require water from a stream that has diminishing quantities of available water because of decreased snowpack in the mountains, or add heat to a water body that is already warming due to increasing atmospheric temperatures” (Council on Environmental Quality 2016a, 21). Overall, this makes for a fairly comprehensive assessment of climate impacts. However, this guidance was withdrawn in 2017 under President Trump (CEQ 2017). It is unclear to what extent the creation or withdrawal of the guidance had on consideration of climate change impacts, as the only visible trends in figure 3 are a nation-wide uptick starting in 2017. The timing of the uptick coincides with the start of the Trump administration, suggesting that the increase might not be due to better awareness about climate change, but instead an increase oil and gas developments that have more substantial impacts on greenhouse gas emissions.

## **5.2. FERC relicensing: regulatory constraints constrict attention to climate change**

We next turn to FERC relicensing to assess some of the context shaping why infrastructure managers and regulators may choose to pay more or less attention to drought and climate change. During stakeholder meetings in the two FERC relicensings studied, most management decisions were based on a project operations model, which depicted a timeseries of water stocks and flows throughout the project and under different operating scenarios (Ulibarri 2018). The operations models used the historical record as a proxy for future water availability. Given this data source, decision-makers used the most severe drought in the time-series record -- the 1976-77 drought -- as the worst-case scenario of low water availability for all management decisions made. For all proposed management changes, they would run the model, and then assess results for 1976 and 1977 to see how bad things could get: how little water would be available, whether irrigation deliveries would have to be shut off, or whether instream temperatures would become lethally hot for fish. However, the 1970s drought is an imperfect proxy for a worst-case scenario: while it was an extremely dry period, it was only a two-year period, shorter than the 2012-2016 drought and shorter than anticipated droughts under climate change (Diffenbaugh, Swain, and Touma 2015).

This imperfect consideration of drought and climate change during FERC relicensing was not caused by a lack of awareness by resource managers. Stakeholders knew that droughts were likely in this watershed, and in meetings and model runs always wanted to see how a severe drought would affect the management proposals they were developing. During the height of the drought, a number of ongoing studies and decisions were directly affected by the lack of water or heat, and many stakeholder meetings focused on managing around the uncertainty the drought was causing. Lastly, in interviews, many individuals clearly linked the occurrence of drought to climate change: “One of the things that was not contemplated with enough vigor and seriousness, in my opinion, is multi-year dry years... We have a new benchmark, and it’s 2012 to 2015—it’s not ’76-’77. This is the new one. What the climate scientists are saying, this is the new normal. You’re gonna see that mark, and you may see decades-long droughts.”

Instead, the lack of consideration of drought and climate change is directly linked to restrictive guidance from FERC. In 2009, FERC rejected a request to consider the hydrological effects of climate change on project operations for a project in California. In their reasoning, FERC wrote “Although there is consensus that climate change is occurring, we are not aware of any climate change models that are



known to have the accuracy that would be needed to predict the degree of specific resource impacts and serve as the basis for informing license conditions” (Federal Energy Regulatory Commission 2009, 25; Thapaliya 2009). To our knowledge, this ruling has not been reversed in any subsequent decisions. This is despite FERC being fully aware of the potential impacts of climate change on generating capacity, as signaled by a recent report to Congress (US Department of Energy 2017).

Interestingly, a similar discussion took place in the NEPA review of a subsequent California relicensing; in this case, the EPA requested that the hydropower utility follow the CEQ draft guidance on incorporating climate change. The utility, in this case, responded:

“We are unaware of any current climate model that would allow us to predict matters such as water flows in a given basin during the 30 to 50 year term of a typical hydropower license in such a manner as to support reasoned decision making. Attempting to predict future flow scenarios that may occur due to climate change or other conditions would be too speculative given the state of the science at this time.”

This exchange signals tension and uncertainty about whether and how to consider climate impacts for hydropower projects.

The decision not to consider climate change was incredibly frustrating for relicensing participants we interviewed. As one interviewee opined: “I’m scared... all of our work may become moot in the not-too-distant future because of climate change. All this hard negotiated stuff... When you’re talking salmon restoration and putting fish above a rim dam, it’s like, what are you talking about? This habitat’s going away. It’s moot...” In particular, many interviewees recognized the limitations of using the historic record as a proxy for the future:

“People in relicensing meetings have this period of record that they’ve all accepted and you can see exactly what happened to the hydrology, but do you think any of those is ever going to repeat in the future? Never! It’s never gonna’ be exactly the same. It’s tough. There’s a lot of risk involved... It might sound good on paper, but are you really prepared to make that kind of bet that the future is always going to be this cut and dried, that I can always do what this plan says, even in five years of drought. What happens if it’s 500 years of drought?”

Another noted that the group had discussed ways to work around the historical data, but that the group hadn’t opted to do those analyses:

“We have talked about how to approach it with some simulations or something but we’ve never actually gotten to that point yet... Use the water balance model and throw some ten year droughts in there and see what happens, that would be a really interesting and probably helpful exercise to do but we just haven’t ever had the impetus to do it with the licensee. ... just thought exercises for, ‘Let’s look and see what happens if we had a ten year drought what would that do to the reservoir levels and the flows and where would be?’ But we just haven’t ever done that with them.”

Overall, interviewees felt hamstrung by the inability to consider climate change when they knew it was going to make their management decisions less effective.

### **5.3. Evidence of institutional change in NEPA and FERC relicensing**

The prior two sections (5.1 and 5.2) demonstrate mixed evidence of shifts in attention paid to drought and climate change in siting, design, and operations planning for water and energy infrastructure. In the EIS data, there was a long-term increase in consideration of water security impacts associated with infrastructure decisions, although this increase was mirrored by an increase outside of California. There was also a definite spike in consideration of drought impacts on infrastructure function, although this spike appeared to be closely tied to the extent of drought in the state as it occurred during the height of the drought and subsequently declined. At the same time, despite increasing co-occurrence of the terms “drought” and “climate” during the years of drought, there was minimal consideration of climate change writ-large in EIS documents, whether issued before, during, or after the drought. As for FERC hydropower relicensing, project managers were acutely aware of the impact that drought could have on the project’s viability in the future, yet they were limited to using the historical record as a proxy for future weather conditions. There was individual level awareness (perhaps heightened by the ongoing nature of the drought), but no ability to translate it into focused attention in operating plans. The FERC cases represent a best-case scenario, as decision-makers elsewhere in the country may be more reluctant to acknowledge or discuss climate change openly and therefore even less likely to push against the federal rules constraining its consideration in the relicensings.

These results suggest that slow-onset disasters may not enable significant attention shifts in regulatory and planning processes as can occur in high-profile, rapid-onset event like a hurricane, flood, or fire (e.g., Birkland and DeYoung 2012; Birkland 1997). Shifts in attention and focus have long been regarded as a key prerequisite for significant institutional change (Birkland 1997; Kingdon 2003; Baumgartner and Jones 2009), as they upend established policy coalitions (Albright 2011; Jenkins-Smith et al. 2014) and alter how governments process information and adjudicate issues (Jones and Baumgartner 2005, 2012). At a more granular level, it is straightforward to expect that if infrastructure governance institutions are changing in response to climate change and slow-onset environmental pressures, such changes should be reflected in siting and design considerations and long-range planning. That we do not observe strong shifts in attention in our results suggests that Federal infrastructure governance institutions are not changing significantly in the face of shifting climate realities.

At the same time, we chose a particularly rigid case: infrastructure management tends to be highly technical, and these are decisions with long time frames and high risks. Although these characteristics could lead to an increased desire to be as fully aware of future conditions as possible (thus incorporating more knowledge about hazards), they also could induce people to revert to familiar approaches regardless of new information being available. This means that droughts and other slow-onset disasters may create conditions for institutional change in other settings; our results do not preclude that possibility.

Evidence from interviews and procedural documents makes it clear that water and energy infrastructure operators in California know that they face long term climate risks and disaster threats. However, the FERC and NEPA processes show the challenge of accounting for broad, uncertain environmental hazards within institutional mechanisms that address more regularized and tightly bounded management problems. Infrastructure planning and assessment processes are generally oriented around efforts to provide one or more public services over a defined scale and term. Managers and operators are expected (by investors, regulators, and the public) to provide regular, safe, and accessible goods and services right

now. The expectation that operators be efficient, consistent, and affordable in the present favors incremental change and makes it hard to design and operate for possible future conditions. Project financing and the fixed asset nature of infrastructure also makes it difficult to take partial measures or adopt a ‘wait and see’ approach. Projects typically require a large upfront investment of funds, with debt repaid over time, constraining redeployment or adjustment. These challenges exist even with respect to management plans for existing resources and already-built structures. For instance, a new operating plan for an existing hydroelectric dam affects how the operator will deploy capital and invest in other assets in order to supply electricity. Together, this means that infrastructure governance processes both (somewhat paradoxically): (1) favor incremental change and (2) require large scale upfront commitments. This combination of factors mean that decisions are likely to reflect an extrapolation of past and current conditions (i.e., an incremental shift in decision-making) and are unlikely to get out ahead of slow-onset disasters.

Slow-onset hazards such as drought also transcend existing institutional systems in ways that are hard to account for within function- and domain-specific regulatory contexts. For acute disasters, there are emergency measures that can be enacted and inter-organizational networks that mobilize to fill institutional gaps and coordinate in response to acute disasters (Comfort et al. 2004; Moynihan 2009). In contrast, slow-onset disasters shift underlying conditions and create new collective action challenges but do not always create a similar locus of response. Issues such as long-term drought and sea-level rise in effect create a new policy issue area, resulting in a “governance gap” (Lubell 2019) where no existing authority or leadership exists to focus on or address the problem. Infrastructure decisions made by agencies and utilities with other existing mandates and priorities are unlikely to reflect the full nature of the hazard.

Studying the conditions for change following different types and sizes of environmental hazards also elucidates barriers to change. One important barrier highlighted by this study is the multi-level nature of change necessary to enable adaptive governance. In the case of FERC, individual and project level awareness about the need to incorporate drought and climate change into decision-making--awareness that was heightened by the ongoing drought--did not translate into changes in how the hydropower projects were managed because the larger regulatory setting did not allow it. Conversely, in NEPA, changes in the regulatory setting (the CEQ guidelines) did not show clear increases in consideration of climate change impacts in individual EIS documents. In other words, this research suggests that you need both individual-level awareness and support from higher level institutions to shift institutional norms (see also Chaffin and Gunderson 2016).

## **6. Conclusion: New Questions and Future Directions**

This paper has explored whether an extreme drought led to increased consideration of drought, water security, or climate change in analyses of infrastructure siting and operations. We observed short term recognition of a pressing problem but limited evidence of systemic adaptation in the case of NEPA, and individual level awareness but no translation to institutional practice in the case of FERC. Given our focus explicitly on institutional change from slow-onset environmental hazards, this work raises a number of important questions. The first relates to identifying thresholds at which a hazard (whether slow or rapid onset) creates uncertain enough conditions to enable institutional change. Identifying the characteristics of a hazard (e.g., duration, magnitude) that affect whether or not it leads to change would enable a better

understanding of when environmental change might lead to more adaptive institutions. Second, how does uncertainty interact with broader socio-environmental conditions to enable institutional change? Third, are there particular focusing events (Tomlinson 2015; Alimi and Maney 2018) that better catalyze public support around institutional change (e.g., a town losing its water supply)? Lastly, what might be the effect of slow and rapid onset hazards interacting? For instance, California has faced two years of severe wildfires catalyzed by the drought; perhaps these wildfires could intensify awareness about the impacts of drought and climate change, creating conditions for institutional adaptation. Similarly, the problems of sea level rise might be more visible or salient following flooding during a particularly large tidal event.

It bears mentioning that this analysis primarily focuses on institutional change at the Federal level (in NEPA practices and FERC relicensings). In California and the rest of the western United States, the Federal agencies such as the Bureau of Land Management, the Bureau of Reclamation, the Western Area Power Administration, and the Army Corps of Engineers are central actors in water and energy infrastructure governance (Davis 2018; Wilkinson 1992). However, as noted previously, NEPA analyses of water and energy projects are often carried out in concert with, or on behalf of, local and regional infrastructure operators, and FERC permitting requirements apply specifically to non-Federal hydropower projects. Thus, future research that incorporates environmental hazard response by state and local institutions is critical for developing a fuller understanding of adaptive governance in a multilayered Federal system.

Finally, it is important to consider different types of change that might be enabled by a particular hazard (Mahoney and Thelen 2010a). We looked specifically at institutional convergence, the reapplication or reinterpretation of existing rules and norms, under the supposition that it might be easier to achieve than wholesale development of new rules. That said, the California drought did lead to the creation of the Sustainable Groundwater Management Act and other new regulations. This suggests that it is perhaps easier for actors to catalyze change around a single large rule rather than smaller scale shifts in norms. At the same time, it is unclear whether SGMA has actually led to shifts in how groundwater is used or in the power dynamics of organizations controlling its use (Kiparsky et al. 2017; Langridge and Ansell 2018), reinforcing the overarching finding that creating more adaptive institutions is challenging.

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## Appendix A: Detailed Methodology

This section describes in detail the methods and tools used for text mining. All data and code are available upon request; analyses were performed using the R statistical language.

NEPA documents are typically stored in pdf format. We first used the *pdftools* package for R (Ooms 2018) to extract text into a machine readable format. After converting each document from pdf to text format, the next step was to tokenize the raw text into words/phrases (for tf-idf analysis) or sentences (for topic classification and sentiment analysis).

We used the *tidytext* package (Silge and Robinson 2016) to tokenize words and “n-grams” (word combinations that represent terms, such as “flood control”). From this point, *tf-idf* weights were computed by calculating term frequency ( $tf = \# \text{ occurrences for term } t \text{ in document } d / \text{total terms in document } d$ ) and inverse document frequency ( $idf = \ln(\# \text{ of EIS documents} / \# \text{ of EIS documents in which term } t \text{ occurs})$ ). The tf-idf weight for term  $t$  in document  $d$  is represented by  $tf_{t,d} * idf_t$ .

Our supervised classification approach involves four basic steps: (1) tokenizing and cleaning sentences; (2) building a training set of pre-labeled sentences on which to train the classifier; that are pre-labeled; (3) fitting and validating the model; and (4) classifying sentences. We used the *tokenizers* package (Mullen et al. 2018) to segment each document into individual sentences. Additionally, we performed a few basic cleaning steps to weed out sentence tokens which are not in fact sentences (e.g., page footers, tables, etc.). We also removed tokenized “sentences” that had a very large or very small number of characters--these cases generally indicated an instances of incorrect tokenization.

We sought to label whether sentences relate to one or more of three topics--water resources, drought, and climate change. This required a supervised learning approach based on predefined, systematic categories against which each text can be classified. In turn, training such a classification model requires developing a pre-coded dataset. As noted above, we used a shortcut in building our training database, relying upon matched terms rather than coding by hand. For the water resource concept, we relied upon a combination of terms found in glossaries published on water/hydrology websites. Table A.1 shows the 12 sites scraped. We filtered out only terms that occur in at least 3 separate glossaries, resulting in 139 terms.

Table A.1: Glossary sources for water terms

<i>Source</i>	<i>URL</i>
<i>USGS “Water basics glossary”</i>	<a href="https://water.usgs.gov/water-basics_glossary.html">https://water.usgs.gov/water-basics_glossary.html</a>
<i>USGS “General introduction glossary”</i>	<a href="https://water.usgs.gov/wsc/glossary.html">https://water.usgs.gov/wsc/glossary.html</a>
<i>USGS “Water science glossary”</i>	<a href="https://water.usgs.gov/edu/dictionary.html">https://water.usgs.gov/edu/dictionary.html</a>
<i>USGS National Water-Quality Assessment Project</i>	<a href="https://water.usgs.gov/nawqa/glos.html">https://water.usgs.gov/nawqa/glos.html</a>
<i>National Water Quality Monitoring Council</i>	<a href="https://acwi.gov/monitoring/glossary.html">https://acwi.gov/monitoring/glossary.html</a>
<i>Global Water Forum</i>	<a href="http://www.globalwaterforum.org/learning-hub/glossary/">http://www.globalwaterforum.org/learning-hub/glossary/</a>
<i>US Bureau of Reclamation</i>	<a href="https://www.usbr.gov/library/glossary/">https://www.usbr.gov/library/glossary/</a>
<i>National Weather Service “Hydrologic terms”</i>	<a href="http://www.nws.noaa.gov/om/hod/SHManual/SHMan014_glossary.htm">http://www.nws.noaa.gov/om/hod/SHManual/SHMan014_glossary.htm</a>
<i>Edwards Aquifer (San Antonio) website</i>	<a href="https://www.edwardsaquifer.net/glossary.html">https://www.edwardsaquifer.net/glossary.html</a>
<i>Minnesota Public Radio</i>	<a href="https://www.mprnews.org/story/2011/09/12/ground-level-water-glossary">https://www.mprnews.org/story/2011/09/12/ground-level-water-glossary</a>
<i>Lenntech LLC</i>	<a href="https://www.lenntech.com/water-glossary.htm">https://www.lenntech.com/water-glossary.htm</a>
<i>Aqua Science LLC</i>	<a href="https://www.aquascience.net/glossary/">https://www.aquascience.net/glossary/</a>

For climate change and drought, found glossaries were less useful because the technical hydrography, weather, and geophysical terms contained are important for understanding each concept but do not necessarily denote that climate change or drought is actually being discussed. For instance, “acre-foot” was found in may drought glossaries (e.g., [https://serc.carleton.edu/eslabs/drought/drought\\_glossary.html](https://serc.carleton.edu/eslabs/drought/drought_glossary.html)), but this term is simply a unit of water quantity. Thus, for drought and climate change we built a customized set of matching terms, shown in table A.2, meant to identify sentences that are were specifically talking about water availability and

climate change issues. Using a simple regular expression search, we identified whether each sentence contains a given word or phrase, and if so labelled it as pertaining to said category.

Table A.2: Words and phrases used to tag training sentences

<b>Water terms (n = 141)</b>	<b>Drought terms (n=33)</b>	<b>Climate terms (n=29)</b>
<i>absorption, acid rain, acre-foot, adsorption, aeration, aerobic, algae, algal bloom, alluvium, anaerobic, aquatic, aqueous, aquifer, attenuation, backflow, bank, bank storage, base flow, bed load, bioaccumulation, biota, brine, channel, channelization, concentration, condensation, confined aquifer, consumptive use, contamination, conveyance loss, crest, cubic foot per second, dam, delta, direct runoff, discharge, dissolved oxygen, dissolved solids, diversion, drainage area, drainage basin, drawdown, drought, ecosystem, effluent, erosion, estuary, eutrophication, evaporation, evapotranspiration, fecal coliform, filtration, flood, flood plain, fluvial, freeboard, gage height, gaging station, gallon, glacier, ground water, groundwater, hard water, hardness, herbicide, hydrograph, hydrologic cycle, hydrology, impermeable, impervious, infiltration, influent, instream use, intermittent stream, irrigation, irrigation efficiency, leachate, leaching, limnology, lysimeter, maximum contaminant level, nitrate, nonpoint source, osmosis, overland flow, percolation, perennial stream, permeability, ph, photosynthesis, phytoplankton, piezometer, plankton, point source, pollutant, pool, potable water, precipitation, reach, recharge, recurrence interval, reservoir, return flow, riffle, riparian, riparian zone, runoff, saturated zone, sediment, sedimentation, soil moisture, solute, solvent, specific conductance, spring, stage, stream, streamflow, subsidence, surface runoff, surface water, suspended solids, tertiary treatment, transpiration, tributary, turbidity, unconfined aquifer, unsaturated zone, water budget, water pollution, water quality, water table, water year, watershed, weir, wetlands, zone of aeration, zone of saturation, zooplankton</i>	<i>aridification, dearth, deficit, depletion, desertification, drought, drouth, dry year, excessive pumping, fallow, groundwater level, hydrological drought, junior rights, overpumping, PDSI, PHDI, precipitation index, pumping restriction, reservoir level, saltwater intrusion, senior rights, severity index, snowpack, SPEI, subsidence, total yield, usage restrictions, vulnerability, water recycling, water shortage, water use, wet year, xeriscaping</i>	<i>adaptive capacity, carbon cycle, carbon dioxide, carbon emissions, carbon sequestration, climate change, climate feedback, climate model, climate projection, climate risk, CO2, desertification, drier, feedback loop, fossil fuels, global temperature, global warming, greenhouse effect, hotter, increased wildfire, IPCC, methane, nighttime temperature, ozone, renewable energy, sea level rise, severe weather, storm surge, wetter</i>

Both term sets and topics can overlap. For instance, “drought” is a water word, a drought word, and a climate word, and a sentence about drought relates to all three focal concepts. Because a sentence can possibly relate to all three categories at once, this is a multi-class, multi-label (one or more types) classification task. In our database of training sentences, about 6.5% of sentences contain a water term, 6% contain a drought term, and 3.5% contain a climate term. A balanced training set is important for training a classification model, because otherwise the a classification model will incorporate proportional representation rather than just content into its classification strategy. Thus, we sampled (with

replacement) 10k sentences of each type, as well as 30k sentences tagged as not relating to climate, drought, or water, at random for use as a training set.

An artificial neural network (ANN) classifier was trained to predict sentence topics. We used the *keras* R package (Allaire and Chollet 2018), which integrates with *Keras*, an API built for neural network models (Chollet 2015) estimated with *TensorFlow* (Abadi et al. 2016) (a graph-based machine learning system built by Google). Our simple ANN was comprised of: (1) an input layer of nodes (a processed representation of the sentences for classification); (2) an output layer of nodes (predicted classification labels); (2) and a “hidden layer” of nodes between the input and output layers that which transmit input information into prediction estimates. An ANN “learns” by adjusting the weights placed upon connective edges between input and hidden nodes, and hidden and output nodes, to determine how and when information is passed between nodes. The ANN classifier iterative trained on subsets of 80% of the training dataset, and then validated on subsets of the remaining 20% of the training data that were not used in estimation. This process was repeated multiple times to develop a model that minimizes the divergence between observed and predicted labels.

Sentence content was quantified with word embeddings. Word embeddings are a type of *vector-space model* (VSM) that map the location of a word within a multidimensional space using continuous dimensions (Mikolov, Chen, et al. 2013). The multidimensional location of a word reflects the fact that words can be similar--or different--in multiple respects (Mikolov, Yih, and Zweig 2013). For instance, the terms “hydropower” and “precipitation index” both relate to water resources, but the latter is typically used in the context of drought when discussing drought conditions. We used the GloVe pre-trained word vector model (Pennington, Socher, and Manning 2014), specifically the large-scale model which encodes 2.2 million words on 300 dimensions, trained on an 840B word data set of scrapped webpage text from the <https://commoncrawl.org/> database (see <https://nlp.stanford.edu/projects/glove/>). Word embeddings enabled viable classification even for sentences that did not contain the exact words or phrases used to make our training data. Because the input layer to the ANN is a representation of the words of a sentence in 300 dimensional vector space, the model learned to predict topics based upon the relative location of these words in context, not the specific words or ordering.