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Climate Change Impacts on the Dams Sector

by

Christina Margaret Lazar

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of Christina Lazar find it satisfactory and recommend that it be accepted.

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Climate Change Impacts on the Dams Sector
Thesis Abstract—Idaho State University (2023)

This study examines the existing guidelines, resources, and information easily accessible to emergency management professionals to comprehensively address implications resulting from climate change impacts on the dams sector, including hydroelectric dams. Climate change is furthering the frequency and severity of extreme weather events, which stresses the dams sector's resiliency and efficacy. A review of existing literature was conducted and compared with two case studies. Based on that evaluation, gaps were identified and followed by correlating recommendations. Overall, publications conveniently available to emergency managers are incomplete, failing to address the potential impacts of climate change on the dams sector and how they can stay proactive to safeguard their communities from these hazards.

Key Words: Climate change; dams sector; hydropower; emergency management

Executive Summary

This thesis focuses on the current landscape of available guidelines, resources, and readily accessible information aimed at equipping emergency management professionals with the knowledge and tools needed to effectively address the multifaceted implications arising from climate change's impact on the dams sector, including hydroelectric dams. The intensifying effects of climate change are giving rise to a higher frequency and increased severity of extreme weather events, thereby exerting significant pressure on the resiliency and efficiency of the dams sector.

To conduct a comprehensive literature review, various resources and documentation relevant to the challenges faced by emergency managers dealing with the impacts of climate change on dams and water systems were explored. The aim was to provide a comprehensive and insightful understanding of the existing body of knowledge while making sure that these resources were readily accessible to those involved in emergency management. Most of these attainable resources are housed within the Federal Emergency Management Agency (FEMA) publications and are also provided by similar federal agencies. The focus was on gathering information related to the effects of climate change on dams and water systems, emergency management strategies, and best practices. The gathered resources were evaluated for their reliability, relevance, and accessibility for emergency managers.

In parallel with the literature review, in-depth case studies of Idaho and Japan were conducted to provide practical insights into the real-world challenges posed by climate change on dams and water systems in two distinct regions. Both Idaho and Japan face similar issues concerning their water resources and dam sedimentation due to climate change. However, they differ significantly in terms of their geographical locations, susceptibility to natural disasters,

population sizes, water sources, and scale of their water infrastructure. As a result, their responses to climate change vary, with Japan's response contributing to an integrated and holistic strategy, and Idaho's response dependent on collaboration amongst private owners, state, and federal agencies. This analysis indicates a deficiency in the current emergency management literature, particularly in addressing the unique challenges faced by regions such as Idaho. Japan, on the other hand takes a leading role in literature because it is spearheading global engagement and prioritizing actions in the dam sector.

There is a noticeable opportunity to recognize the potential impacts of climate change on the dams sector, especially hydropower, and escalate the priority of the issue for emergency managers. Furthermore, inadequacies are present in the resources accessible to emergency managers that provide specific insights into the impacts of climate change on the dams sector, and the measures they should take to stay proactive. These insufficiencies extend to funding disparities and coordination between the public and private sectors. Based on the identified gaps in existing and accessible literature, and lessons learned from case studies, the following list provides recommendations to improve emergency management preparedness for climate change impacts on the dams sector.

1. **Dedicated resources for emergency managers:** Emergency managers lack access to publications and resources tailored to comprehensively address climate change impacts on the dams sector. The emergency manager's responsibility is often overwhelming, and their time for research is limited. Federal agencies like FEMA have existing websites and other publication platforms that are easily accessible and well-known to emergency managers where this valuable information can be located.

2. **Funding resources:** There is currently inadequate funding for infrastructure improvements and insufficient emergency management funding for local agencies responsible for managing dams, particularly in rural, underprivileged areas. There is a need for an investment in infrastructure improvements to enhance the resiliency of dams systems against climate change by retrofitting existing dams and constructing new ones with climate resilience in mind, as well as additional emergency management funding for local agencies who are responsible for this management.

3. **Collaboration and information sharing:** A lack of active collaboration and information sharing among federal, state, tribal, and local agencies and private dam owners leads to gaps in funding and responsibilities during disaster phases. Collaborating and sharing information actively among agencies, and with private dam owners, will assist in bridging the gaps in communication and responsibilities in the before, during, and after phases of disasters.

4. **Policy interventions:** Existing policies do not sufficiently acknowledge climate change impacts on the dams sector, and regulations for dam owners to assess and mitigate climate-related risks are inadequate. There is an opportunity for policies to explicitly acknowledge climate change impacts on the dams sector with added regulations for dam owners to assess and mitigate climate-related risks.

5. **Comprehensive training and education:** The current emergency manager training and education to address the specific challenges posed by climate change in the dams sector, including recognizing climate change impacts, vulnerabilities, and climate resilience integration in emergency response plans is deficient. There is an opportunity for the federal government to provide training and education for emergency managers

encompassing recognition of climate change impacts and vulnerabilities, integration of climate resilience in emergency response plans, and troubleshooting existing challenges within their communities.

6. **Support for ongoing assessments and adaptations:** Existing policies and practices are not regularly assessed and updated to keep abreast of the evolving challenges of climate change, and this is exacerbated by a lack of federal support. To combat this, assessments and updates to policies, guidelines, and practices based on climate change evolvement should become routine.
7. **Research and data collection:** There is a need for thorough research and data collection to understand climate change implications for dams systems, including hydrological modeling, vulnerability assessments, and risk analyses. Resources catered toward research and data collection will improve understanding of the repercussions of climate change on dam systems.
8. **Improved accessibility:** Most comprehensive resources and reports are not easily accessible to private dam owners, emergency managers, and other dam associated stakeholders. By ameliorating the accessibility of important resources and reports available for private dam owners, emergency managers, and other stakeholders, critical information should be easily accessible, consisting of summaries and guidelines to highlight key findings.
9. **International cooperation:** International approaches to address climate change impacts on dams could be improved to further information sharing and best practice exchange with countries facing similar challenges. By exchanging best practices, research findings,

and policies with other countries that face similar challenges, the entire globe can benefit and alleviate climate change reverberations.

10. **Holistic approach:** There is a gap for a holistic and comprehensive approach to address climate change impacts on dams, including hydropower, which results in incomplete guidance, regulations, and funding mechanisms. A holistic approach will allow for a complete understanding of the intricacies and interdependencies of the systems, and their potential feedback, and expose leverage points to alleviate some adverse effects.
11. **Public awareness and advocacy:** The public is not completely aware of the risks to downstream residences, insurance options and value, and the recovery process after a dam failure. Additionally, there is insufficient advocacy for increased resources and funding in this area. Outreach and education to the public on the risks to their downstream residences can in turn allow them to take proper mitigation steps based on a comprehensive understanding.

As global issues compound and affect local areas, the pressure on emergency managers and related stakeholders will grow. Given the often-overwhelming nature of the emergency management profession, it's crucial to anticipate emerging threats before they result in irreversible consequences. Emergency management professionals should have ample resources to support their efforts in serving communities and overcoming obstacles. By providing them with accessible information about incoming threats, emergency managers can stay prepared and extend this readiness to their jurisdictions. To protect communities, critical infrastructure, the environment, and the economy, it is essential to emphasize further research into addressing the effects of climate change on the dams sector and ultimately enhance resilience in this context.

Chapter 1: Introduction

Due to climate change, reservoirs behind dams are being filled more rapidly than expected with soil, rocks, trees and branches, and other debris. This material is causing significant drawbacks to dam and reservoir designed functions. Climate change may be a key culprit limiting reservoir storage capacity, which reduces the amount of water available to communities and irrigation cropland and increases costs of mitigation projects or community risks. It is critical to consider these climate change impacts on the dams and their associated water systems to ensure that they can function sustainably and prevent disaster to communities. There are lessons emergency managers can draw from case studies of negative impacts of climate change on dams and water systems, including hydropower.

Purpose

The purpose of this thesis is to guide the United States community to become resilient against climate change effects, specifically to dams and their associated water systems by increasing literacy among the emergency management community and empowering risk-informed decision-making. While the consensus that climate change is an issue in this world is apparent, some of the primary effects of climate change have overshadowed the secondary and tertiary ones. Climate change is a complex problem with many interrelationships and interdependencies. This intricate web of systems can experience significant consequences that may not be immediately obvious. One of these consequences in the context of climate change is to the dams sector, which consists of dam projects, navigation locks, levees, hurricane barriers, mine tailings impoundments, and other similar water retention and control facilities (CISA, 2021). The dams sector provides essential functions related to water storage and management, including hydroelectric power generation, supplying water for municipal and industrial use,

facilitating agricultural irrigation, managing sediment and flood control, enabling river navigation for bulk shipping, handling industrial waste, and promoting recreational activities (See Appendix A). These vital services play a pivotal role in supporting critical infrastructure sectors and industries. A critical infrastructure sector encompasses “assets, systems, and networks, whether physical or virtual, [that] are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof” (CISA, n.d.). By recognizing the potential impacts of climate change on the dams sector, emergency management personnel can attempt to mitigate the most debilitating impacts on individuals and assets.

Indeed, emergency personnel have long planned and prepared for potential hazards and disasters in communities. In addition, they are now considering and adopting mitigation projects to lessen the impacts of climate change to maintain resiliency. Such efforts require resources of many kinds, and illustrating how these resources may be most effective with real-world examples may help improve outcomes.

Significance

This thesis of climate change effects on the dams sector identifies the risks and provides a means for emergency managers, emergency planners, infrastructure owners, and field experts to sustain and build preparedness. The study serves as a basis for individuals and organizations focused on building a resilient nation by generating practical information that influences investment strategies, guides planning efforts, facilitates organizational and equipment investments, and supports training and exercise initiatives.

There is an age-old saying in emergency management: disasters always start and end locally. While climate change may be a global problem, consequences will be felt in local communities that will be expected to deal with them. Emergency managers are tasked with coordinating responses and recoveries to disasters and emergencies in their communities. If climate change increases disasters, the cascading impacts will escalate local managers' duties and responsibilities, and potentially overwhelm their local capabilities. Many local emergency management agencies are already inundated with stress and pressure, and under-resourced (Risk and Resilience HUB, 2021). Emergency managers and their communities will benefit from understanding the potential impacts to the dams sector from climate change and recognizing the gaps in this sector in existing disaster management plans, processes, and publications.

Defining Climate Change

According to the National Aeronautics and Space Administration (NASA), climate change is a general phrase referring to the long-term alteration of Earth's average weather patterns (NASA, 2023). Together, these averages define Earth's local, regional, and global climates. Human driven changes to the climate have been observed arguably since late-19th century to the mid-20th century and are characterized by an overarching global warming trend driven by human activities, industrial processes, and natural processes (NASA, 2023). Several researchers have acknowledged climate change constitutes a serious threat to our environment (Goyette et al. 2023; Mann 2009; Temple 2022). In 2021, the U.S. Congress held a hearing before a subcommittee examining the threat of climate change to our homeland, and publicly recognizes climate factors on national security (U.S. Congress, 2021).

Human processes are key drivers of climate change. Some examples of human processes affecting climate may include but are not limited to the burning of fossil fuels, farming livestock,

deforestation, and urbanization. Each one of these processes produces greenhouse gases. As defined by the Environmental Protection Agency (EPA), greenhouse gases are heat-trapping gases in Earth's atmosphere. The main climate drivers include carbon dioxide, methane, nitrous oxide, water vapor, and fluorinated gases (EPA, 2023). Overall, these human processes produce an excess amount of heat-trapping greenhouse gases in the atmosphere, leading to increased average surface temperatures and other indirect effects.

In addition to rising temperatures, expected climate change impacts increased extreme weather severity and frequency and higher sea levels, which in turn cause various secondary and tertiary impacts. The world's communities are already experiencing the effects of climate change such as poverty and displacement, loss of species, harm to agricultural production, starvation, and other health risks (United Nations, n.d.). As temperatures continue to rise, these effects may cause further greenhouse gas emissions, causing temperatures to continue to rise in a feedback loop (NOAA, 2021).

Chapter 2: Literature Review

Rising Temperatures and the Need for Dam Management Strategies

Across the globe, reservoirs are filling with sediment because of climate change. This sedimentation poses significant challenges to the functionality of dams. Climate change is likely responsible for reducing storage capacity, limiting water availability for irrigation cropland and communities, causing blue-green algal blooms, and necessitating more investment in mitigation efforts (Yasarer and Sturm, 2015). It is important to understand these climate change implications on the dams sector to ensure their sustainability and fulfill their intent to prevent hazards instead of exacerbating them.

Many experts accept the reality of climate change, and how its wide range of impacts can affect the environment (e.g., Geethanlakshmi et al. 2023; Cai et al. 2023; Salvador et al. 2023; Shabani et al. 2022; Sharma et al. 2022; Wahlstrom et al. 2022). There is a broad consensus that changes in the climate system can disrupt many other systems. One study utilized historic meteorological and hydrologic timeseries to estimate future water availability in reservoirs with the context of current climate change conditions and changing water demands. Their findings suggest that the near future could experience a loss of 40 percent of monthly water inflows and up to 50 percent in the far future, which will have severe impacts on dams, irrigation, and hydropower (Bekri et al., 2021). Climate Change causes rising temperatures, sea levels, extreme weather, loss in biodiversity, ecosystem and precipitation pattern disruption, agricultural disruptions, and ocean acidification. Recognizing these climate change implications and learning to cope with it is crucial to adapt to changes and plan to respond to any of these disturbances (Branch, 2023).

A study published in Nature Communications revealed satellite data showing a reduction in water stored in 7,245 reservoirs worldwide from 1999 to 2018, despite an annual increase of 28 cubic kilometers in storage capacity. Lead author Huilin Gao of Texas A&M University pointed out that climate change played a critical role in diminishing reservoir efficiency, but the growing water demand also contributed to this issue. Gao noted that even if global temperatures were to stabilize, the rising demand for water and ongoing construction of reservoirs are expected to persist (Li et al., 2023). It is necessary to state that the study did not account for the impact of sedimentation, a persistent issue that has already caused a reduction of original storage capacity, estimated to be between 13% to 19% in approximately 50,000 large dams worldwide. It is projected that these losses will increase to a range of 23% to 28% by the year 2050 (UNU, 2023). Prolonged droughts have raised concerns about the sustainability of large reservoirs, as seen by countries such as China, which experienced a significant drop in hydropower output last summer due to record-high temperatures in the Yangtze basin. The International Hydropower Association emphasized the crucial role of new dams and reservoirs in mitigating the effects of increasing climate extremes, making it easier to manage water flows. The association argued that as climate volatility intensifies, there will be a growing need for additional water infrastructure, which also offers the benefit of generating low-carbon electricity (Stanway, 2023).

Hydrological Changes

A major theme that emerges in hydrologic research is increased reservoir sedimentation. Researchers define the various causes of reservoir sedimentation like extreme flooding (Ghinassi et al. 2019). However, very few sources professionally linked the two entities (climate change and reservoir sedimentation), and further analyzed the cause-and-effect system. Of the many impacts due to climate change acceleration, hydrological changes are crucial because they can

affect the climate: if water from the Earth's surface begins evaporating from increasing temperatures, there will be more water vapor in the atmosphere, which is the most abundant greenhouse gas. The elevated presence of water vapor causes more warming, thus creating a self-reinforcing cycle of heating (NASA, 2023). This is called a positive feedback loop. Feedback loops, in general, are responses to change speeding up or slowing down a particular process. A negative feedback loop reduces the effect of change, while a positive feedback loop accelerates the effects of change and produces instability (NOAA, 2021). Positive feedback loops in the climate system are not necessarily beneficial, contrary to the 'positive' in its name. In this case, positive feedback loops can be dangerous and accelerate changes our society will have to respond to. In a recent comprehensive survey spanning 17 advanced economies, the Pew Research Center investigated public sentiment regarding climate change. Their findings reveal a widespread sense of worry concerning the personal repercussions of climate change, with most respondents expressing a willingness to make sacrifices to mitigate the effects. However, there appears to be a notable lack of confidence in the efficacy of current efforts to resolve the problems (Bell, Poushter, Fagan, and Huang, 2021).

As evaporation rates escalate due to climate change, it can also be expected that the frequency and intensity of drought patterns will follow in corresponding escalation. When the average temperatures of Earth rise, evaporation rates will increase, directly affecting the amount of water needed for crops and water supplies. Drought may increase across all seasons, depending on variations in precipitation. Precipitation is usually described by its seasonality, magnitude, duration, frequency, and intensity. In cases of winter droughts, their detrimental effects are often not as immediate as the growing season droughts but can be devastating in parts of the western U.S. that rely on snowpack to sustain water supplies through dry summers. Unlike

most hazards, droughts have the potential to impact most U.S. regions, and can sometimes evade early detection and damage may be difficult to mitigate because short-term droughts affect long-term crop investments. Over the past three decades, the U.S. has allocated approximately $249 billion to address 26 significant drought events, impacting a substantial portion of the continental U.S. (FEMA, 2023).

Impacts from changes in Earth's climate are now being planned for by FEMA in partnership with the National Oceanic and Atmospheric Administration (NOAA) as of July 2023. In FEMA's Response and Recovery Climate Change Planning Guidance, a whole community approach is outlined to achieve climate resilience through increasing climate literacy (NPB, FEMA, 2023). According to FEMA's Response and Recovery Climate Change Planning Guidance, climate experts are anticipating an increase in the occurrence of prolonged heavy rain events as the Earth heats up. The impacts can directly be seen in rivers and streams that experience flooding from precipitation events, and even spring snowmelt. Often, flooding can occur due to a combination of the two referenced as "rain-on-snow events." In areas where the annual runoff is significantly influenced by seasonal snowmelt, elevated temperatures can instigate more rain-on-snow events. This warmer rain accelerates the melting process of existing snow, triggering faster and earlier melting. The interplay between rain and melting snow has the potential to intensify springtime floods, depending on the soil's condition. During spring and winter, the soil is often saturated and sometimes frozen, preventing further capacity to absorb increased runoff. Regions that experience more instances of rain-on-snow events, such as the Northwest, are projected to face higher risks of flooding in the future (NPB, FEMA, 2023).

Increased risks of flooding will lead to higher volumes of sediment transported. Sediment transport is the process of granular particles being carried by water. Floods can carry large

volumes of sediment and particles, which in turn can cause pronounced erosion, deposition, and lead to elevated turbidity levels and cascading impacts to the form and structure of water systems (He et al., 2020).

Dam Infrastructure Vulnerability to Climate Change

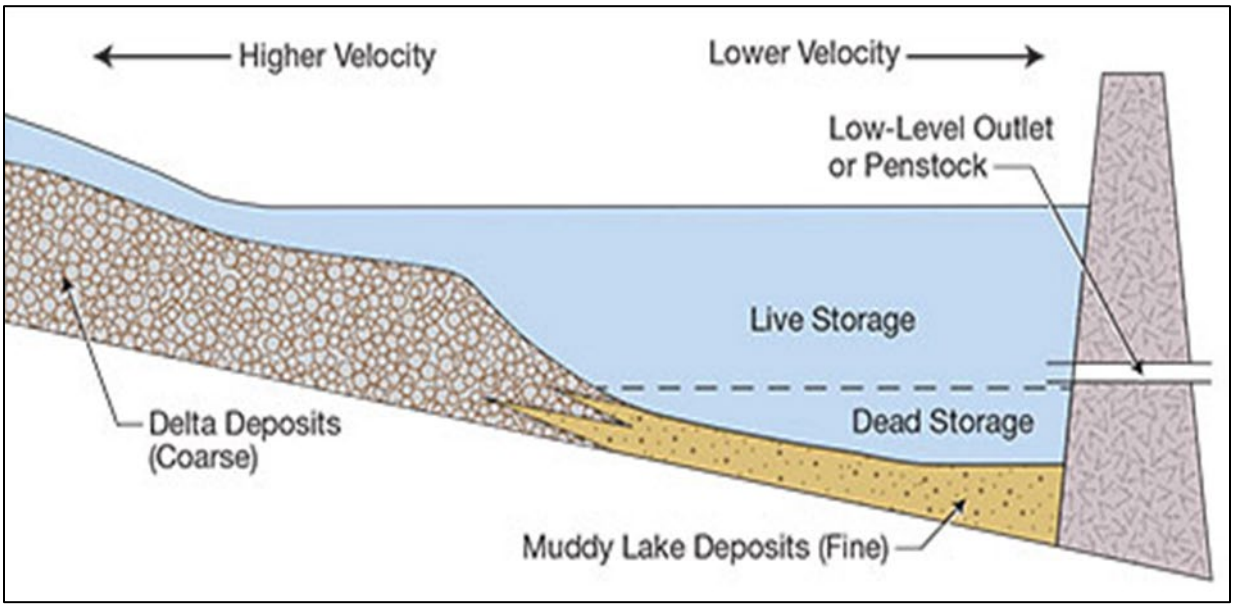
The dams sector is one of sixteen critical infrastructure sectors defined by the U.S. Department of Homeland Security and comprises various hydro-assets including dam projects, reservoirs, levees, and other similar water retention and/or control facilities (DHS, 2011). Critical infrastructure sectors additionally act as supporting entities for many other sectors. Within the U.S., the dams sector includes more than 90,000 dams that aid irrigation to croplands, protect over 43 percent of the U.S. population from flooding. Within the Pacific Northwest, the sector generates more than 60 percent of the electricity (CISA, n.d.).

Dams are already affected by climate change in many regions, mostly through increased sedimentation. Sedimentation refers to the process where particles, such as eroded soil, debris, rocks, and organic matter such as wood, are carried by water. Sediment usually settles at the bottom of a body of water, but can also be suspended in the water column. Sedimentation can occur in rivers, lakes, reservoirs, and estuaries. Storms play a pivotal role in carrying sediment and this is often why bodies of water appear murkier after storms. Evidence suggests that heightened precipitation intensity correlates with elevated rates of erosion, with substantial rain events playing a more prominent role in the overall erosion process. With a rise in severe storms and erosion, sediment transport rates will increase (Yasarer and Sturm, 2015). Many experts are concerned that an increase in dam sector sedimentation can lead to cascading impacts that can affect the dams' efficacy (Tumbare, 2013; Moore et al. 2021; Rodriguez et al. 2020).

Certainly, sedimentation can have positive impacts in some places. For example, it can boost riverbanks and floodplains with mineral-rich sediment making for productive farmland – sedimentation can also damage properties with heavy and foul-smelling mud. Sediment in rivers can also accelerate the aging process of dams and reservoirs. Once a dam has been constructed and the reservoir formed, sediment that once freely flowed is now trapped and deposited within the reservoir. This occurs as the reduced flow velocity within the reservoir fails to keep the sediment suspended, causing it to settle at the reservoir's bottom. Over time, the gradual accumulation of sediment and mud within the reservoir leads to reduced storage capacity, ultimately rendering the reservoir unsuitable for its intended functions (U.S. Geological Survey [USGS], 2018). As shown in Figure 1, the deposited materials pile up against the dam in a predictable way. Typically, the sediments gather in progressively finer deposits as flows encroach the dam gates. Consequently, as sediment deposits continue to accumulate behind the dam, the likelihood of issues increases in tandem (Hydro Review, 2017).

Figure 1

Sediment Effects on Dams and Hydropower Generation. Source: HydroReview, 2017, Adapted from Morris, G.L. and J. Fan, Resevoir Sedimentation Manual, McGraw-Hill, New York, 1998



Fine-material sedimentation may accumulate behind a dam as flows approach it.

Effects on Hydropower

Dams are sometimes utilized to generate electricity through the flowing or falling of water because of gravity. In the U.S., about 2,300 dams produce power, although nonpowered dams have the potential to be converted to hydroelectric dams (Types of Hydropower Plants, n.d.; EIA, 2019). Hydropower dams, also known as hydroelectric dams, are large infrastructure built to harness the kinetic energy of moving water that can power turbines. This movement can then convert the mechanical energy to electrical energy. A renewable energy source, hydropower is heavily utilized in the United States and other regions of the globe. However, hydropower generation depends on predictable water flows to maintain water levels in rivers and reservoirs. With increasingly variable significant weather events, flow predictability and sedimentation in

these rivers and reservoirs directly impacts power generated. Sedimentation behind dams can be quantified using satellite imagery.

Hydropower is an important source of renewable energy (Conde et al. 2019). Many communities rely heavily on hydropower production, especially in the Pacific Northwest and agricultural-dependent communities, and climate change impacts on hydropower may eventually limit this generation (Dozier, 2012; Marshall, 2022).

Different challenges face western U.S. dam and reservoir managers compared to the beginning of large dam construction about six decades ago (East and Grant, 2023). These emerging challenges for dam and reservoir management depend on climate change, growing populations, reservoir sedimentation, aging dam infrastructure, compromised integrity, and environmental approaches to management. Dam removal has recently become more common in the western U.S., especially in cases of excess sedimentation. Dam removal, exceptionally for hydroelectric dams does not come lightly, as removal can be costly and complex. However, the dam and reservoir challenges have caused some of these dams to "become unsafe, obsolete (e.g., due to excessive reservoir sedimentation), and uneconomical" and the only choice is removal (East and Grant, 2023). These determinations reinforce the need for local and regional critical planning and mitigation for emerging climate change impacts on the dams sector.

While an increasing number of dams are being removed after no longer serving their intended purposes, most constructed dams are expected to remain for the foreseeable future (Kondolf and Li, 2022). There is a growing aging population of dams, and once they exceed about 50 years old, they are deemed an 'aging infrastructure.' This implies that an infrastructure is at an increased risk for failure and environmental defiance. There may be increases in repairs

and costs, losses of storage capacity, declines in safety, uneconomical hydroelectric costs, and other valued outcomes. An increase in severe weather events, erosion, and sedimentation can exacerbate the aging process of dams, thus compounding consequences (Kondolf and Li, 2022). With over 91,000 dams in the nation, the American Civil Society of Engineers predicts over 70 percent of dams will reach 50 years or older by 2030, which is the recommended timeframe for rehabilitation to current codes (ASCE, 2021).

Wildfire Effects

Wildfires are becoming more frequent, lasting longer, and intensifying on a global scale (Koudenoukpo, 2023). They can ignite from various sources, with common culprits including lightning strikes and human activities like campfires, fireworks, discarded cigarettes and matches, power line sparks, gas leaks, burning debris, and even acts of arson. These fires are exacerbated by drought conditions, which elevate the risk of wildfire ignition. When moisture levels in trees, shrubs, grasses, and other vegetative debris are low, they become highly susceptible to combustion (NOAA, 2023). Climate change plays a significant role in amplifying fire weather conditions, prolonging drought periods, and desiccating vegetation, thereby providing ample fuel for wildfires.

The impact of climate change on wildfire frequency and severity can vary across the United States, but it often impacts human health, safety, property, and infrastructure. Mitigating fire risk requires understanding the health impacts of wildfire exposure and acknowledging the far-reaching consequences it can have on critical systems (World Health Organization, 2023). Wildfire impacts go beyond the common smoke inhalation, release of toxins into the air, entrapment, and burns (World Health Organization, 2023). According to the Environmental Protection Agency, just as wildfires have implications for air quality, they also exert an influence

on the availability and quality of water resources. The impact on water supplies can be multifaceted, both during the wildfire itself and for some duration after the fire is extinguished. When a wildfire is actively burning, ash and other contaminants float on or are transported by bodies of water, such as streams, lakes, and reservoirs. Also, the vegetation that plays a role in soil retention and water conservation is destroyed by the flames. Following a significant wildfire event, rainstorms can sweep substantial amounts of ash, sediment, nutrients, and pollutants into water bodies. The loss of vegetation in the watershed area promotes erosion, flooding, and the introduction of naturally occurring and human-generated substances that can affect the quality of drinking water, alter the appearance of recreational waters, and potentially contribute to the emergence of deleterious algal blooms. Given the fickle nature of wildfires, drinking water utilities confront a formidable challenge in devising plans and strategies to manage flood events and treat contaminated water. Consequently, there is a pressing need for information and tools to assist water storage and treatment managers in better preparing for the impacts of wildfires (EPA, 2023).

Wildfires can impact watersheds by stripping away groundcover, undermining slopes, and endangering water sources (USGS, 2021). One significant effect on landscapes from wildfires is the heightened sediment levels. Severe wildfires consume vegetation and penetrate deep into the soil, leading to conditions that promote increased erosion. This includes scorched soil that cannot absorb rainwater, causing it to run downhill while collecting sediment, reduced ground cover vegetation that usually stabilizes soil, and a reduced tree canopy that allows rain to directly fall onto the ground. USGS researchers focused on the consequences of the 2018 Carr Fire in northern California, which produced substantial sediment that entered Whiskeytown Lake, a federally managed reservoir within the Whiskeytown National Recreation Area. These

sediments can impair water quality, diminish storage capacity in reservoirs, and occasionally trigger perilous debris flows. In the year following the Carr Fire, the researchers observed a significant increase in sediment flow through the watersheds, in some instances, surpassing pre-fire levels by orders of magnitude, mainly due to higher-than-average precipitation (USGS, 2021).

All large wildfires result in burn scars, which are parts of the ground that had previously burned, charred, and left barren, severely affecting the soil. The burn scars usually have a layer of ash on their surface, which, depending on pre-fire cover and fire intensity, can create a water-repellent coating. The burned regions are at high risk for sudden flash floods and movement of debris, especially in areas with steep terrain. These fast-moving, deadly landslides, debris flows or mudflows can comprise rocks, sticks, mud, trees, and boulders that can damage property, injure, or kill people in their path (NWS, 2022). Deposits from these slope failures usually accumulate in valley bottoms, sometimes affecting the dams sector, filling reservoirs that are naturally located in these downstream valley bottoms.

Emergency Management and Emergency Managers

Emergency management serves as the critical orchestrator of disaster and emergency response efforts. Its primary role is to establish a structured approach to addressing crises, promoting a culture of preparedness, and ensuring readiness. This multifaceted discipline is categorized into five distinct mission areas: prevention, preparedness/protection, mitigation, response, and recovery. According to the Federal Emergency Management Agency (FEMA), emergency management can be succinctly defined as “the managerial function charged with creating the framework within which communities reduce vulnerability to threats/hazards and cope with disasters” (IS-0230-b, FEMA, n.d.). Similarly, emergency managers are responsible

for coordinating the mission areas for their local communities and ultimately enhancing their safety and well-being from disasters. Emergency managers can serve city, county, state, and private companies, and critical systems and infrastructures.

Emergency management policies and procedures in the United States typically follow a hierarchical structure. Federal agencies establish the framework that states, tribes and local jurisdictions use to tailor their responses. Additionally, these federal agencies offer readily available resources, such as documents, training programs, and awareness campaigns, to support emergency management at all levels. This ongoing support is crucial as risks, threats, and hazards continually change and evolve.

Emergencies are most often coordinated locally, from beginning to end. Once a disaster overwhelms the capability of the local jurisdiction, higher levels of government step in to support the management. In the event of a presidential disaster declaration, the federal government, headed by FEMA, initiates a response at the behest of and in support of states, tribes, territories, insular areas, and affected local jurisdictions. The actions taken in response are structured under the *National Response Framework*. FEMA designates a Federal Coordinating Officer (FCO) to establish a Joint Field Office (JFO) and oversee the response effort. The subsequent short- and long-term recovery efforts are coordinated within the framework of the *National Disaster Recovery Framework* (NDRF). FEMA designates a Federal Disaster Recovery Coordinator (FDRC) as a deputy to the FCO, tasked with leading the recovery initiatives emanating from the JFO (Department of Interior, 2018).

Emergency Manager Awareness

Despite the evident vulnerabilities of global systems to the challenges posed by climate change, including those impacting the dams sector and its infrastructure, there is a notable scarcity of empirical research aimed at comprehending how a changing climate will affect dams and even more limited information available to emergency management personnel responsible for protecting those dams.

Emergency managers have access to a wide variety of resources. However, they are often overwhelmed and overworked. The expectation that they have extensive time for research is unrealistic. To better understand the resources available and accessible to emergency managers on this topic, 12 salient resources have been assessed based on their content to determine their relevance concerning the impacts of climate change on the dams sector, while also uncovering gaps in guidance to emergency managers.

While a substantial amount of qualified content exists through scholarly literature like journal articles, this was intentionally excluded because of their limited accessibility to emergency management professionals. The matrix at Table 1 displays a visual representation of the comprehensiveness of various (mostly federal) resources across the following domains:

- Acknowledgment of climate change
- Identification of vulnerabilities in the dams sector
- Clearly addresses climate change impacts on the dams sector, including hydropower
- Impacts to or guidance for emergency management
- Brief descriptor comments based on evaluation.

Table 1

Emergency Management Resources

Resource Title	Recognition of Climate Change	Dams Sector Vulnerabilities	Climate Change Impacts to Dams Sector (Including Hydropower)	Impacts/Guidance for EM	Comments
FEMA-National Dam Safety Program	x	x			Partnership program for states, federal agencies, and other stakeholders to build resiliency for dam safety programs to reduce risk and vulnerabilties.
NOAA-Climate Change Impacts	x			x	The complexity of climate change impacts and various impacts on humans, the environment, and infrastructures, but lacks mention of dams, hydropower, and the dams sector.
FEMA-Climate Essentials for Emergency Managers	x			x	Comprehensive recognition of climate change and educating emergency managers.
FEMA/U.S. Bureau of Reclamation-Incorporating Climate Change into Dam Safety	x	x	x		A technical seminar on how to recognize climate change impacts, and incorporate it into the risk framework. The closest to all-encompassing federal resource, though it lacks specific resiliency education toward EMs. This is also a short PowerPoint, not an official fact sheet or document.
FEMA-Guide to Expanding Mitigation	x		x	x	This short guide offers insight into expanding mitigation across electric power systems. Hydropower is briefly mentioned, and climate change is mentioned once under "solar."
FEMA-Emergency Managers Risk Management Dam Safety		x		x	Includes grant assistance, training programs, information, federal guidelines, advisory committees, and other publications. It is not specifically related to climate change or its impacts on dam safety or hydropower.
Independent Forensic Team-Report Oroville Dam Spillway Incident	x	x	x	x	This report recognizes the role of climate change in the dam spillway failure, the inherent dam vulnerabilities, and the EM process including positives and negatives. Hydropower is not emphasized.
ASCE-Report Card for America's Infrastructure		x			This resource gives America's infrastructure overall a score of C- as of 2021, and offers infrastructure grades by state. Reports that dams are lacking funding.
NOAA-2022 U.S. billion-dollar weather and climate disasters in historical context	x				Shows the increase of billion-dollar disasters over the years, reporting the events and destructiveness. Highlights the escalating trend of costly disasters: exposure, vulnerability, and climate change.
FEMA-Independent Study Course 870 Dams Sector Crisis Management		x		x	Independent online training course that describes the purpose and basic elements of Emergency Action Plans, Recovery Plans, and Continuity Plans. Addresses the basic elements of an effective training program to dam and levee stakeholders (IS-872, FEMA, n.d.).
FEMA-Independent Study Course 872 Dams Sector Protective Measures		x		x	Independent online training course that provides EMs and infrastructure owners on security awareness, protective measures, and crisis management
CISA-Dams Sector-Specific Plan	x	x	x		Addresses climate change and dams sector risks, including hydropower, and accounts for other dams sector vulnerabilities. No direct guidance for emergency managers, but a great resource for education.

Easily accessible resources for emergency managers evaluated based on their inclusion of keywords: climate change; dams sector, hydropower; emergency managers. EM: emergency management; EMs: emergency managers

The resources from various (mostly federal) agencies were selected with their inclusion in the matrix primarily hinging on the content they offer. The assessment reveals that none of the federal resources examined comprehensively addresses all categories. While most of them acknowledge the threats posed by climate change to infrastructure, human lives, property, the environment, and the increasing frequency and severity of weather events, there is a conspicuous absence of resources designed specifically for emergency managers focusing on the impacts of climate change on the dams sector. For instance, the National Dam Safety Program provides valuable training, grant opportunities, and raises awareness of various vulnerabilities to mitigate risks. However, it lacks a dedicated emphasis on the specific impacts of climate change. The only reference to climate change within the program is found in a seminar PowerPoint linked on the program website, which does not include a recorded explanation of the content.

On the other hand, "Climate Essentials for Emergency Managers" is a comprehensive guide designed for emergency managers, offering insights into the risks associated with climate change. This 24-page document aims to equip emergency managers with the knowledge to operationalize climate change information, covering every phase of the disaster lifecycle and detailing the responsibilities from federal to state levels. Nonetheless, it does not directly address the dams sector, including hydropower. Incorporating specific content on the dams sector within the framework of emergency management, similar to what this resource offers for climate change in general, would provide a valuable baseline for emergency managers.

According to the matrix review, one resource is comprehensive in its coverage of all categories. This unusually comprehensive resource stems from an Independent Forensic Team's report on the Oroville Dam Spillway incident. This detailed document not only provides an in-depth account of the disaster across all phases, but also delves into potential factors that might

have contributed to the failure. It notably includes a specific discussion of climate change impacts on the dam, alongside considerations of broader climate change effects on the dams sector. This resource even offers valuable insights for emergency managers by dissecting the entire emergency management response, highlighting both successful and unsuccessful aspects. Despite the wealth of information it contains, this resource remains relatively unrecognized, even though it can serve as a model for future analyses of other vulnerable dams. However, it should be noted that this document is not easily accessible unless one actively searches for it and is aware of the incident report's existence. Furthermore, with a length of nearly 600 pages, it may be unrealistic to expect emergency managers to find the time to digest this resource, especially with the existing inundation of duties for emergency management agencies.

The American Society of Civil Engineers (ASCE) expects a widening gap in funding for dam mitigation as vulnerabilities continue to escalate. Though brief, the ASCE resource provides decent awareness of the current state of America’s infrastructure. Not only is a grade given for the country overall, but individual states can view their independent grade, and dive deeper into the specific infrastructure details supporting the assessment results.

A prevalent and overarching theme emerges from the existing literature within the realm of emergency management – a significant deficit in awareness, emphasis, and funding allocated to the implications that a changing climate brings to the dams sector. Some resources, models, and data have started to explore the intricacies of dams sector systems, and most guidelines, regulations, and funding originate from the federal government. This emphasizes the urgency for a more comprehensive approach from federal resources to bridge these gaps.

Concurrently, the perspective of emergency management professionals regarding the role of dams in disaster preparedness and the growing awareness of climate change risks are evolving. However, there is a need for further research and collaboration to address the complex challenges associated with climate change impacts on dam infrastructure and emergency management efforts. There are significant gaps in acknowledging how climate will impact dams and available resources for emergency managers on this critical topic that also encompasses gaps in funding and the public-private sector coordination.

Chapter 3: Methodology

The research methodology for identifying and analyzing the impacts of climate change on water infrastructure, specifically the dams sector and hydropower, as well as its cascading effects, lessons learned, and implications for proactive emergency management utilizes a synthesis of case studies and critical analysis of literature reviews.

Concepts and Overview

The initial step of the research involves identifying the impacts of climate change across multiple facets, including the frequency and intensity of extreme weather events, evaporation rates, and precipitation patterns. This will be achieved through a focused literature review of scientific studies, reports from climate experts, and relevant data sources. Critical analysis from the literature review will provide a synthesized understanding of the expected changes in climatic patterns and their potential ramifications.

Building upon the impacts of climate change identified in the previous step, this next phase will focus on assessing the specific effects of these influences on the water infrastructure and hydropower sectors. Data related to dam integrity, water storage capacity, and hydropower generation will be collected and analyzed. Additionally, reviews of other reports on dams sector complications will be conducted to gain a deeper understanding of the potential vulnerabilities and challenges that surface in the dams sector and hydropower reliance.

To give context-specific insights and provide lessons learned, case studies will be conducted focusing on two different geographical regions, namely Idaho and Japan. Idaho was chosen due to familiarity gained through existing knowledge and professional experience working for the state's emergency management department, coupled with interactions with local

emergency managers. Conversely, Japan was selected based on its commendable reputation in disaster management, notable technological advancements, and culturally informed practices.

These case studies will lay out the geography and geology of the area to provide context. They will additionally provide site-specific facts that may assist in understanding the topography and hazards in these regions. The goal is to understand how climate change is impacting these regions, how their dams sector is responding to some of these impacts, the extent of the cascading consequences, response strategies employed, and the effectiveness of these mitigations. Both regions rely on hydropower generation for electricity. How this can affect the economy and energy production for these regions will also be reviewed.

A thorough literature review will be performed to identify existing analyses and findings related to climate change outcomes on water infrastructure and emergency management, including global trends and challenges faced by the dams sector and hydropower industry. Comparative analysis allows for the identification of common patterns and differences between areas.

Lessons learned from both case studies and existing literature will be synthesized to identify best practices, successful mitigations and interventions, and areas where challenges remain. The analysis extends to explore the cascading impacts, where climate change effects can go beyond primary and secondary consequences leading to a chain of failures. This principle affects multiple sectors beyond just water infrastructure and hydropower.

Utilizing the insights and trends gathered throughout research, proactive strategies for emergency management in the face of climate change will be proposed. This may involve developing recommendations for personnel to stay proactive, ahead of impending disasters. This

may also include but is not limited to policy changes, recommendations for grant fund usage, infrastructure upgrades and mitigation, staff training, early warning systems, and community outreach and education. The goal is to enhance resilience and preparedness, thus enhancing response capabilities to minimize the negative damage of climate-induced disruptions to people, property, and quality of life.

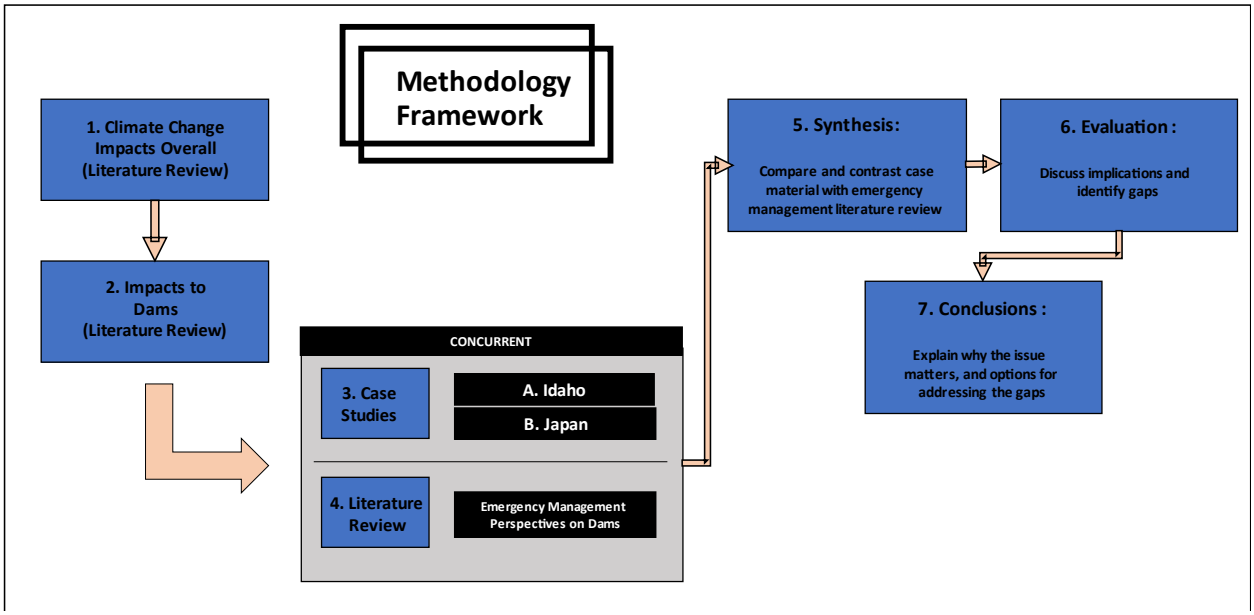
Through the structured methodology process outlined above, this research seeks to comprehensively analyze the multifaceted implications of climate change on the dams sector, identify lessons from case studies and pre-existing studies, and propose strategies for proactive emergency management to mitigate these continuous forthcoming effects.

Approach

The approach phases are visually demonstrated in the flowchart at Figure 2.

Figure 2

Methodology Framework



Phase One: Identifying Climate Change Impacts

Step 1: Literature Review of Climate Change Impacts

This phase conducts a comprehensive literature review of scientific studies, climate expert reports, and relevant data sources. Searches utilize Idaho State University's Library and Google Scholar for verified sources, and then general open-source online data. This widespread intelligence collection instills a foundation of existing knowledge pertaining to climate change impacts, including changes in extreme weather events. The review additionally provides an understanding of anticipated climatic pattern changes and their potential consequences.

Step 2: Assessing Impacts on the Dams Sector

Building upon the identified impacts of climate change, collection and analysis of data related to dam integrity, water storage capacity, hydropower generation, and other alterations to streams, rivers, and reservoirs are reviewed. Reports on dams sector complications to identify vulnerabilities and challenges utilizing an inclusive review of web searches, news articles, and existing journal literature are considered. Relevant information about dam mitigation, aging infrastructure, and dam failures allows for analysis of the potential effects of climate change on water infrastructure and hydropower.

Step 3: Geographical Case Studies

In this phase, two geographical regions are chosen as case studies. For this research, Idaho and Japan have been selected. To set the scene, context-specific insights are provided through the detailing of geography, geology, and topography of these areas. This step includes highlighting the impacts of climate change in these regions with a focus on the dams sector (water infrastructure, hydropower, streams, reservoirs, and levees). Response strategies are then

analyzed, coupled with cascading consequences and economic implications of climate change effects in both regions.

Step 4: Comparative Analysis

A thorough literature review helps to identify existing analyses, perspectives, and available information related to climate change impacts on the dams sector and emergency management. Then, common patterns and differences between different levels of emergency management may be recognized. A highlight of global trends and challenges faced by the dams sector and hydropower industry may become apparent in this step.

Phase Two: Synthesizing Lessons and Proposing Strategies

Step 5: Synthesize Lessons and Best Practices

This step combines insights from case studies and existing literature. Best practices, successful mitigations, and interventions related to climate change impact on the dams sector is identified. Recognizing areas where challenges persist, and lessons can be learned are vital in analyses.

Step 6: Analyze Cascading Impacts

Cascading impacts resulting from climate change effects are explored more deeply. By examining how these impacts extend beyond primary and secondary consequences, the potential cross-sectoral effects of climate change on water infrastructure and other systems is highlighted.

Step 7: Propose Proactive Emergency Management Strategies

Gathered insights and trends from the research assists in the development of proactive strategies for emergency management in the face of climate change. Proposed recommendations for the gaps identified are included in this section. The goal of enhancing resilience and

response capabilities to minimize the negative impacts of climate-induced disruptions are emphasized.

Step 8: Conclusion and Research Objective Fulfillment

This final step entails a comprehensive analysis of climate change impacts on the dams sector and implications for emergency management. Existing and available information to emergency management is deemed adequate or inadequate. This step features the lessons learned and proposed proactive emergency management strategies. It concludes by demonstrating how the research fulfills the objective of understanding, analyzing, and mitigating climate change's effects on dams sector infrastructure including hydropower.

Chapter 4: Case Studies

Idaho Case Study

Idaho has long enjoyed a reputation for its relatively low occurrence of severe natural disasters (IOEM, 2018). Nestled in the Pacific Northwest, the state boasts diverse landscapes including streams, vast mountains, grasslands, and lush forests. One of its most abundant resources is its network of rivers, which serves as a foundation for renewable electricity generation through hydroelectric plants. With over 140 operational hydroelectric facilities, Idaho hosts the nation’s largest hydroelectric complex: Mountain West Hells Canyon Complex. This environmentally friendly, cost-effective, and dependable energy source plays a pivotal role in sustaining Idahoans' power needs amidst fluctuating demand (IOEMR, 2022).

To comprehend the evolving risks posed by climate change to Idaho's critical hydroelectric infrastructure, it is essential to consider the state's attributes. The geology, hydrography, climatic patterns, and land cover collectively define Idaho's natural hazard environment (IOEM, 2018). According to the State of Idaho Hazard Mitigation Plan (HMP), Idaho has witnessed numerous hazardous events over the last 70 years, resulting in casualties and economic losses totaling millions of dollars. Since 1956, there has been the issuance of 32 federal major disaster declarations, 3 federal emergency declarations, and 19 federal fire management assistance declarations. The breakdown of declarations by incident type is as follows:

- Floods and wildfires were components of 22 declarations each, accounting for 44% of the total declarations.
- Severe storms were associated with 10 declarations, making up 21% of the declarations.

- Landslides and mudslides played a role in four declarations, comprising 8% of the total.
- Severe weather contributed to 2 declarations, representing 4%.
- There were single declarations for earthquake, drought, dam collapse, and evaluation, each accounting for 2 percent.

It is important to recognize that multiple declarations comprised a combination of incident classifications, which may result in some overlap in these percentages (IOEM, 2023). A snapshot of their table is provided as a visual reference, showcasing the last ten years of major events.

Table 2

Major Federal Disaster and Emergency Declarations. Source: Idaho Office of Emergency Management, Idaho State Hazard Mitigation Plan, 2023

Incident Begin Date	Incident Type	Disaster Number	Declaration Type	Counties Affected
September 5, 2022	Ross Fork Fire	5452	Fire Management Assistance	Blaine
August 18, 2022	Four Corners Fire	5449	Fire Management Assistance	Adams, Gem, Valley
August 12, 2021	Bedrock Fire	5407	Fire Management Assistance	Nez Perce, Nez Perce Tribal Nation Land
January 13, 2021	Severe Storm and Straight-line Winds	4589	Major Disaster	Benewah, Bonner, Kootenai, Shoshone
January 20, 2020	COVID-19 Pandemic	4534	Major Disaster	Statewide, Including all tribal nation lands
January 20, 2020	COVID-19 Pandemic	3467	Emergency	Statewide
April 7, 2019	Severe Storms, Landslides, Flooding, Mudslides	4443	Major Disaster	Adams, Idaho, Latah, Lewis, Valley, Nez Perce Tribal Nation Land
July 28, 2018	Grassy Ridge Fire	5263	Fire Management Assistance	Clark
May 6, 2017	Flooding, Landslides and Mudslides	4333	Major Disaster	Blaine, Camas, Custer, Elmore, and Gooding
March 29, 2017	Flooding	4342	Major Disaster	Ada, Canyon
March 6, 2017	Severe Storms, Flooding, Landslides, and Mudslides	4313	Major Disaster	Benewah, Bonner, Boundary, Clearwater, Idaho, Kootenai, Latah, Shoshone, and Valley
February 5, 2017	Severe Winter Storms and Flooding	4310	Major Disaster	Bingham, Cassia, Elmore, Franklin, Gooding, Jefferson, Jerome, Lincoln, Minidoka, Twin Falls, and Washington
August 21, 2016	Henry's Creek Fire	5151	Fire Management Assistance	Bonneville
December 16, 2015	Severe Winter Storms	4252	Major Disaster	Benewah, Bonner, and Kootenai
November 17, 2015	Severe Storm and Straight-line Winds	4246	Major Disaster	Benewah, Bonner, Boundary, Coeur d'Alene Tribal Nation Land, and Kootenai
August 29, 2015	Tepee Springs Fire	5110	Fire Management Assistance	Idaho
August 14, 2015	Municipal Fire	5105	Fire Management Assistance	Clearwater, Nez Perce Tribal Nation
August 10, 2015	Clearwater Lawyer Branch Fire Complex	5099	Fire Management Assistance	Lewis, Idaho, Nez Perce Tribal Nation
July 5, 2015	Cape Horn Fire	5088	Fire Management Assistance	Bonner, Kootenai
August 15, 2013	Beaver Creek Fire	5045	Fire Management Assistance	Blaine, Boise, Camas, Custer, Elmore, and Oneida
August 12, 2013	Elk Fire	5043	Fire Management Assistance	Blaine, Boise, Camas, Custer, Elmore, and Oneida

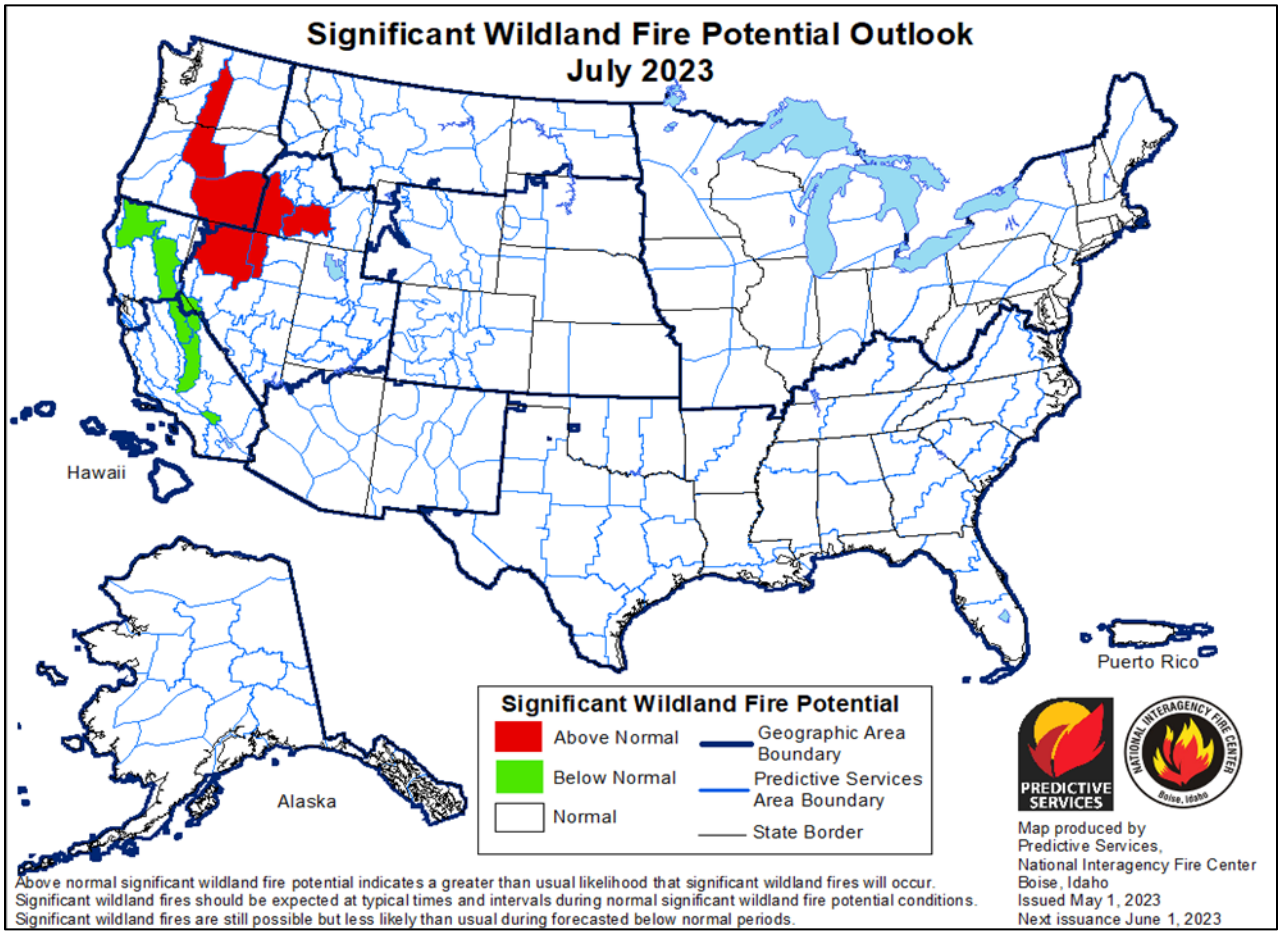
Climate change is exacerbating the severity and frequency of these hazards. Idaho identifies climate change in its HMP, and its goal is to ensure hazard mitigation actions do not further the climate change impacts. One of Idaho's top threats and hazards is wildfires, as identified in both their Threat and Hazard Identification and Risk Assessment (THIRA), and their HMP (IOEM, 2023). As the climate warms, Idaho is expected to experience harsher summers including droughts, and more unpredictable weather may increase winter storms and flooding. In 2021, parts of Idaho experienced a record-breaking heat streak of nine consecutive days of 100 degrees Fahrenheit or hotter (Idaho Statesman, 2021). The following year, temperatures reached 100 degrees Fahrenheit or hotter for 27 total days, these were not consecutive, though they included two periods of six-day streaks of over 100-degree Fahrenheit conditions (Climate Data, NWS, n.d.).

In this time frame, Idaho also experienced severe wildfires raging on the abundant dried-out fuels resulting from the record highs and dry weather. According to the National Interagency Fire Center (NIFC), around 436,733 acres were burned in 2022, ranking fifth overall across the nation that year (Boise State Public Radio, 2022). As of August 2023, the State of Idaho experienced more than 62,000 acres burned due to wildfires. While the State is investigating an apparent increase in human-caused wildfires, there is an elevated fire risk from increasingly hot, dry conditions, the director of the Idaho Department of Lands (IDL) told Governor Brad Little and some other members of the Idaho Stand Board of Land Commissioners (Corbin, 2023). According to IDL's director, the human-caused fires are up by 30 percent, and July of 2023 marked the onset of a swift drying pattern in Idaho, characterized by higher-than-average temperatures and a deficiency in precipitation. These significant wildland fire potential outlooks

are archived by the NIFC. For example, the outlook for July 2023 in Figure 3 demonstrates this higher risk in Idaho.

Figure 3

July 2023 Significant Wildland Fire Potential Outlook. Source: National Interagency Fire Center, 2023



The winter of 2022 leading into the spring of 2023 produced a wealth of water for the state. Flooding occurred in almost every region of Idaho, especially in the southeastern portion. However, flood warnings were heightened in burn scar areas due to the risk of flash flooding and debris flows. A mudslide occurred in Lemhi County on June 4th, 2023. Debris in a burn scar of

the 2022 Moose Fire from that mudslide swept into Panther Creek, requiring the U.S. Forest Service to restore the area.

In early August of 2023, Idaho experienced several storms producing heavy rains. Specifically, heavy rains near Boundary Creek near the Sawtooth Mountain Range underwent intense microburst storms. This initiated numerous landslides and debris flows which obstructed the Middle Fork of the Salmon River. The landslides removed many trees that ended up in the river, causing logjams (Collier, 2023). That same week, thunderstorms triggered two mudslides between Pine Creek and Panther Creek on the Salmon River Road. Some slides were also reported on Panther Creek Road between Beaver Creek and the Salmon River. The slides caused road closures and diversions and led to reports of individuals attempting to hike around the slides to get out of their homes. There were additionally some rafting groups stranded on the water between the slides (Nelson, 2023).

Dustin Aherin, proprietor of Idaho River Adventures, stated that a thunderstorm with concentrated heavy rainfall passed through the region, resulting in several creeks overflowing. Due to significant wildfires affecting the Middle Fork drainage in recent decades, certain creeks have become susceptible to such blowouts. Aherin emphasized that these events are a noticeable indication of the impact of climate change (Barker, 2023). Aherin then recalls that this same region on the Middle Fork experienced a creek blowout and blockage of the river at the same time of year in 2022. With hydrological changes and not enough river flow to flush out the logs causing the blockage, this may lead to multiple jams. Because floods and landslides can occur repeatedly in the same location, local communities will need to invest in mitigating damages (FEMA, 2021). While debris flows occur naturally, they are more common following wildfires (Corbin, 2023). Microbursts on fire scars on steep terrain cause debris flows, and eventually end

up affecting the dams sector by creating blockages, river changes (depth, rapids, direction), potentially endangering communities.

Later, in August of 2023, a rare tropical storm began as a strong category 4 hurricane that formed over the Pacific Ocean. After first tearing through the coast of Mexico, bringing torrential rainfall and gusty winds that resulted in numerous floods and mudslides, it then moved through Southern California weakening into a tropical storm, but it still brought record-breaking rains. For some areas in California, an entire year's supply of precipitation was produced in the single storm. Remnants of this tropical storm carried over into the Pacific Northwest. Traces of the storm brought heavy rain to Idaho, specifically in the eastern portion of the state. Record-setting rainfall was predicted in some areas. According to NBC News, NOAA reported that Idaho was one of the four states that broke some rainfall records due to the tropical storm remnants. As a result, many eastern Idaho counties issued local disaster declarations in response to the forecast. This tropical storm ignited an increase in climate change concerns, emerging just weeks after NASA's cautionary message about the gravity of heat stress, wildfires, and other climate-related perils should global temperatures surpass a 3.6-degree Fahrenheit increase beyond pre-industrial levels (The Hilltop, 2023).

At the end of May 2023, Chesterfield, Idaho faced a flash flood watch triggered by concerns over the potential failure of the Portneuf Dam Spillway at the Chesterfield Reservoir. The spillway, designed to manage high water flows, experienced significant erosion due to an excessive amount of water, as reported by the National Weather Service. The erosion raised concerns about a possible point of failure, posing potential flooding impacts on communities downstream of the reservoir (Nelson, 2023). Despite the availability of up-to-date road conditions and closures communicated to the affected communities, a noteworthy gap was

identified in the absence of a floodplain map for the reservoir. Such a map is essential for delineating flooding risks across different zones within the community. The lack of this resource may be attributed to limitations in resources and funding for local emergency management agencies in Idaho. This may be due to limited resources and funding for local Idaho emergency management agencies.

Currently, the Idaho Department of Water Resources (IDWR) oversees the regulation of nearly 600 water storage dams and over 20 mine tailings impoundment structures dispersed across the state. Mine tailing impoundment structures are essentially earth-filled embankments designed to store liquid, solid, or other fine particles as a byproduct of mining operations. Personnel within IDWR's Dam Safety Program conduct routine examinations of these existing structures, because of the consequences that could arise from a dam failure and a sudden discharge of water downstream, posing risks to life and property. The frequency of individual dam inspections varies based on factors such as the project's physical condition, construction method, maintenance history, age, hazard rating, size, and storage capacity. However, it is mandatory for all dams meeting statutory size criteria to undergo inspections by IDWR at least once every five years (IDWR, 2021). Idaho intends to sustain its mitigation efforts through collaborative initiatives with state and federal agencies, and identification of private owners. Their focus intends to bolster the State Dam Safety Program by enhancing its capacity to secure funding and execute necessary repairs and rehabilitation projects aimed at addressing the deteriorating conditions of dams within the state. (HMP, IOEM, 2018).

As Idaho continues to experience these recurring weather events in a cyclical fashion, the hydroelectric sector faces mounting challenges. Rivers, streams, levees, and reservoirs become choked with debris (NWS, n.d.). With over 140 existing hydroelectric plants in the state,

hydropower generation is directly affected. Idaho relies on hydropower to produce over half of its electricity (IOEMR, 2018). Winter and spring will bring intense rain events causing flooding and summers will become hotter and longer, instigating droughts. This leads to increased fire fuel availability in the summer and heavy rain events in the winter that cause more flash flooding and debris flows, potentially causing sedimentation in reservoirs. Moreover, Idaho's aging dam infrastructure may struggle to regulate water flows as it grapples with accumulating debris. If left unaddressed, these challenges could escalate into further disasters, underscoring the urgent need for proactive measures from emergency management to safeguard the state's vital hydroelectric resources.

Japan Case Study

Japan is particularly vulnerable to adverse climate change impacts largely due to its complex topography and a heavy reliance on water resources. This case study explores the specific effects of climate change on Japan's water infrastructure, hydropower generation, streams, reservoirs, and levees. It provides an overview of recent climate trends, assesses the impacts on the dams sector, and discusses adaptation measures implemented to address these challenges. The study reinforces the importance of proactive climate resilience strategies in safeguarding Japan's water resources and infrastructure.

The Japanese territory is situated within the geographical area known as Northeast or East Asia. Japan is surrounded by the Pacific Ocean and positioned just east of the Eurasian continent and the Sea of Japan. The island country comprises more than 6,500 islands, with the most significant ones being Honshu, Hokkaido, Kyushu, Okinawa, and Shikoku. Japan boasts a substantial population (123 million) and ranks amongst the world's largest economies (Briney, 2019).

Japan has a landscape of rugged mountains, and is a region characterized by high geological activity, due to being located at the convergence of four tectonic plates and part of the Pacific Ring of Fire. This region is known for its high levels of tectonic activity, including earthquakes and volcanic eruptions. Japan frequently experiences significant earthquakes due to its proximity to the Japan Trench, where the Pacific and North American Plates converge. Earthquakes associated with the subduction of the Pacific Plate beneath the North American Plate off the eastern coast of Japan can also lead to the generation of tsunamis. These large ocean waves have caused loss of life and significant damage in the past. Furthermore, the nation is home to 108 active volcanoes. Japan has an extensive and irregular coastline with many natural harbors and bays, flanked by steep cliffs and rocky shores in some areas, while others have sandy beaches.

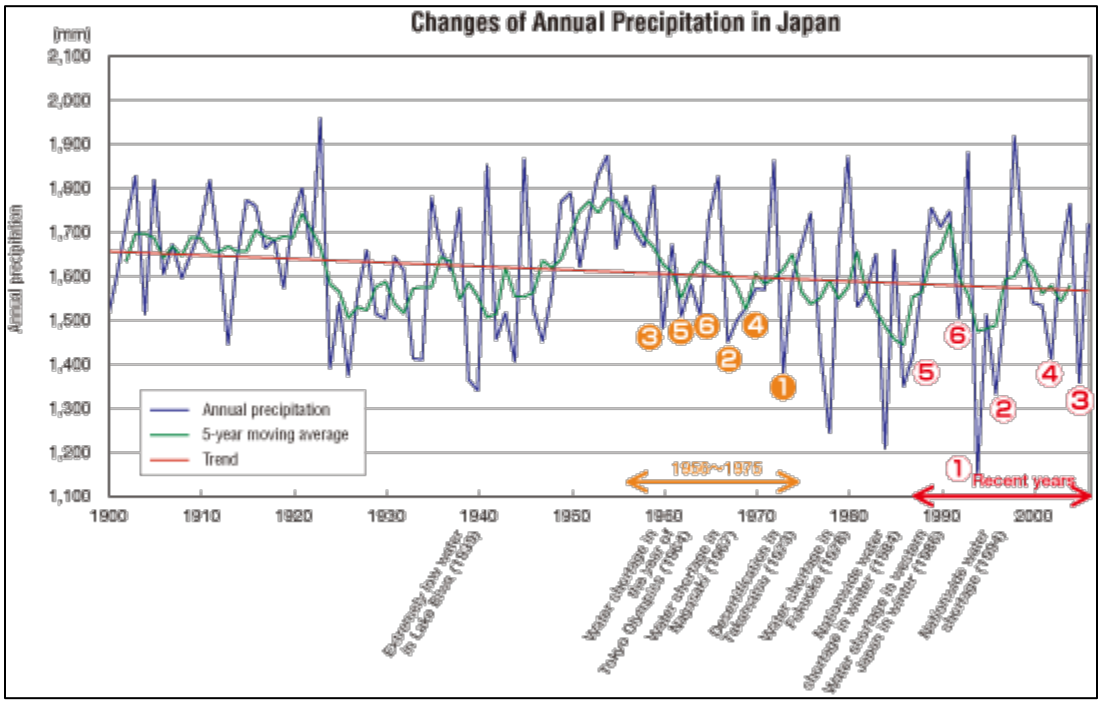
Japan's climate varies based on location; it is tropical in the southern regions and cool-temperate in the north. Tokyo, the capital and largest city located in the northern part of the country, sees an average high temperature of 87 degrees Fahrenheit in August and an average low of 36 degrees Fahrenheit in January. In contrast, Naha, the capital of Okinawa, situated in the southern part of Japan, experiences an average high temperature of 88 degrees in August but an average low temperature of 58 degrees in January (Briney, 2019). This is an interesting aspect to note due to Japan’s significantly smaller size compared to the United States. Japan is nearly double the size of the State of Idaho.

Japan has experienced a harsher rise in average temperatures, registering an increase in average annual temperature of 1.24 degrees Celsius (about 34 degrees Fahrenheit) per century since 1898 (IEA, 2021). This temperature surge has brought about consequential effects. Notably, it has escalated evaporation rates and disrupted the timing of snowmelt, thus impacting

the availability of vital water resources. Concurrently, climate change has brought challenges to Japan's traditional rainfall patterns, ushering in a heightened variability of precipitation. There has been a rise in years characterized by reduced precipitation levels since approximately 1970. Specifically, the years 1973, 1978, 1984, 1994, and 1996 recorded significantly below-average rainfall, leading to water shortages and associated consequences. More recently, there has been an observable trend of heightened fluctuation, swinging between exceptionally low and exceptionally high levels of rainfall (MLIT, 2008). Beyond these diminishing precipitation levels and the frequent occurrence of exceptionally dry years, Japan has also experienced declining snowfall and earlier onset of thawing due to the broader climate change effects associated with global warming (MLIT, 2008). This unpredictability has left Japan more susceptible to both droughts and floods. Moreover, the frequency of extreme rainfall events has surged, leading to amplified runoff and an increased risk of dam overflows as shown in Figure 4.

Figure 4

"Changes of Annual Precipitation in Japan." Source: Ministry of Land, Infrastructure, Transport and Tourism, Water Resources in Japan, 2008



Japan's rugged terrain has long relied on winter snowpack as a fundamental water source. Known to locals in the area as the water mountain, Mount Fuji provides drinkable water to millions of people. Groundwater and surface water in Japan are typically recharged at high elevations (Schilling et al, 2023). Most of their water for domestic use comes from surface water regulated by dams and water infrastructure. However, climate change has led to reduced snowfall and earlier snowmelt, directly affecting the timing and volume of water entering reservoirs. This has caused issues in regulating Japan's water resources (Ohba et al, 2022).

The impacts of climate change have manifested in both direct and indirect consequences for Japan's water infrastructure and dams sector. Diminished snowfall and unpredictable

precipitation patterns have resulted in decreased water availability for reservoir storage (Ohba et al, 2022). This has far-reaching implications for critical sectors like agricultural irrigation, municipal water supply, and hydropower generation. According to the Japan Times synthesizing multiple research papers globally, water reservoir volumes are declining despite a construction boom that increased storage capacity (Stanway, 2023). This finding suggests that the construction of new dams alone may not be sufficient to address the increasing stress on the Japan's water resources.

Another briefly mentioned challenge Japan is currently addressing is the sediment buildup in dams and reservoirs. The surge in erosion due to the increasing extreme weather events has further compounded these challenges, leading to an increased accumulation of sediment within reservoirs (Yasarer and Sturm, 2015; EPA, 2016). This sediment buildup reduces storage capacity and adversely affects the functionality of dams. Japan has been referred to as “a world leader” in various sediment mitigation strategies (Sumi and Kantoush, 2018). Ensuring the prevention of sediment accumulation in multipurpose reservoirs is a vital consideration for their sustainable management of water resources and the protection of aquatic ecosystems. Japan has implemented a range of sediment control methods, including sediment trapping through check dams, dredging, sluicing (allowing sediments to flow freely), flushing, bypassing, and introducing sediments into river channels below dams, such as gravel augmentation or replenishment (Sumi and Kantoush, 2018).

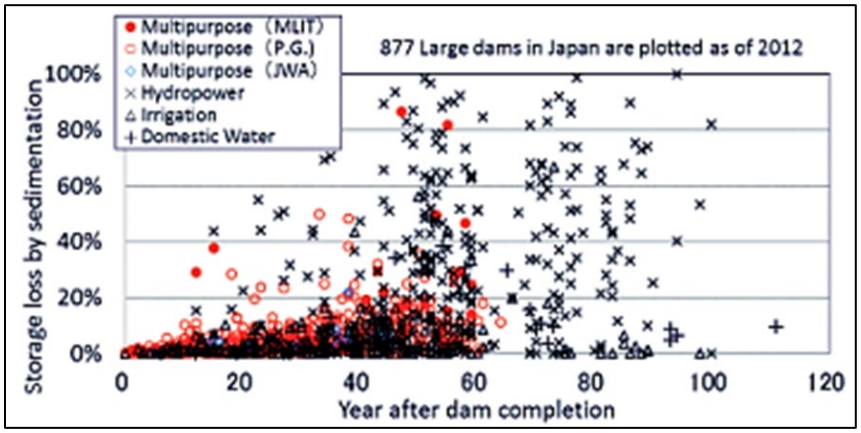
There are over 2,700 functioning large dams in Japan, defined as dams exceeding a height of 15 meters, and these dams have a median age of 61 years. Among this number, 900 dams possess reservoirs with volumes surpassing one million cubic meters. However, the combined storage capacity of these reservoirs remains limited to approximately 23,000 cubic

meters. This constraint can be linked to the elevated sediment yield stemming from the distinctive topographical, geological, and hydrological characteristics within the drainage basins (Sumi and Kantoush, 2018).

Figure 5, as shown in the study illustrates the decline in reservoir capacity due to sedimentation over the lifespan of the dams. It reveals that some hydroelectric reservoirs operating for over 50 years have experienced cumulative storage losses of 0-100 percent due to sedimentation. In contrast, multi-purpose reservoir dams tend to exhibit lower sedimentation losses, generally ranging from 0-85 percent. The graph displays a growing trend of concurrent rise in storage loss (y-axis percentage) with increasing age of the dam (x-axis). As dams age, they become increasingly vulnerable to a reduction in storage capacity due to the accumulation of sediment. But this loss varies dramatically among dams – from 0-5 percent loss within the first 10 years to a rapid increase of storage loss to around 50 percent by 20 years. However, most Japanese dams have maintained at least 80 percent of their capacity for decades.

Figure 5

Changes of sedimentation rate with dam's ages. Source: Sumi, T. and Kantoush, S., Reservoir Sedimentation, *Innovative Strategies For Managing Reservoir Sedimentation In Japan, 2018*



The aging of these dams and the ongoing reduction in water storage capacity due to sedimentation, combined with the increasing environmental demands, pose significant challenges. The intensified frequency and severity of rainfall events have elevated the risk of dam failures and subsequent overflows, posing substantial threats to downstream communities and associated infrastructure. A significant portion of Japan's dams were constructed several decades ago, often without accounting for future climate conditions. Consequently, these aging structures are ill-prepared to withstand the heightened stressors brought about by climate change and require active and regular mitigation.

In response to these pressing challenges, Japan has proactively implemented a suite of adaptive measures within its dams sector. These include adaptive reservoir management strategies designed to optimize the storage, release, and allocation of water resources based on changing climate conditions. Additionally, existing dams are undergoing significant construction upgrades and retrofits to enhance their resilience against these increasing extreme weather

events. These modifications include expanding spillway capacity and implementing advanced monitoring systems (UNDRR, 2023).

The nation has also made it a priority to educate and conduct outreach with their communities. Japan invested in advanced early warning systems, specifically designed to predict, and swiftly respond to potential dam-related emergencies, thereby minimizing the potential consequences of extreme weather events (UNDRR, 2023). To mitigate environmental harm while ensuring a reliable source of renewable energy, Japan is promoting resilient hydropower practices that consider the impacts of altered flow systems on aquatic ecosystems. Furthermore, Japan is integrating green infrastructure solutions such as afforestation and wetland restoration into its approach to reduce flood risks and enhance water retention capacity (Nakamura et. al, 2019).

In conclusion, Japan faces an array of other challenges stemming from climate change, including heatwaves, droughts, wildfires, floods, and severe storms. These threats reverberate across diverse sectors, encompassing agriculture, fisheries, infrastructure, economics, and tourism, among others. In the absence of immediate mitigation actions, Japan could potentially sustain a substantial economic loss equivalent to 3.72% of its GDP by 2050 from a combination of climate change impacts (CMCC, n.d.). What’s more, the implications for Japan's water infrastructure and dams sector are profound, encompassing the criticality of water supply, flood control, and hydropower generation. Acknowledging the gravity of these challenges, Japan has taken proactive measures to enhance the resilience of its dams and water infrastructure. These efforts underscore the imperative of proactive planning and investment in climate resilience, ensuring the safety of Japan's essential water resources and infrastructure, as well as people’s lives and property, amidst a rapidly changing climate.

Chapter 5: Literature Review of Emergency Management Perspectives

Emergency management plays a pivotal role in protecting communities and infrastructure from various hazards, and dams are integral components of this context. Dams serve as critical infrastructure, providing water supply, flood control, and hydropower generation for communities. This literature review dives into what has been discussed concerning dams and their significance in the realm of emergency management, highlighting the perspectives, operations, and mitigation strategies employed by emergency management professionals.

The Federal Perspective

While disasters always start and end locally, the Federal government, led by FEMA, responds to a state, tribe, territory, or local jurisdiction's request for support where actions are organized under the *National Response Framework* (DOI, 2015). FEMA also provides blue-sky (normal, routine day, non-disaster) support and oversight. With this, they offer a section on their website dedicated to supporting the emergency management role of dam safety. According to their website, dams hold a crucial position within the United States' infrastructure, contributing significantly to the country's economic progress and the well-being of its citizens (Guidelines for Dam Safety, FEMA, n.d.).

Understanding that dams are susceptible to various challenges, including natural disasters, human-caused risks, and the impact of aging infrastructure compared to available resources, the National Dam Safety Program presents a collaborative effort involving states, federal entities, and interested parties. The program educates the general public, provides guidance to dam owners, and aids decision-makers by utilizing a variety of databases, tools, and supplementary resources. Its primary goal is to foster and endorse the creation and upkeep of robust federal and state dam safety initiatives. These efforts aim to diminish the threats posed by

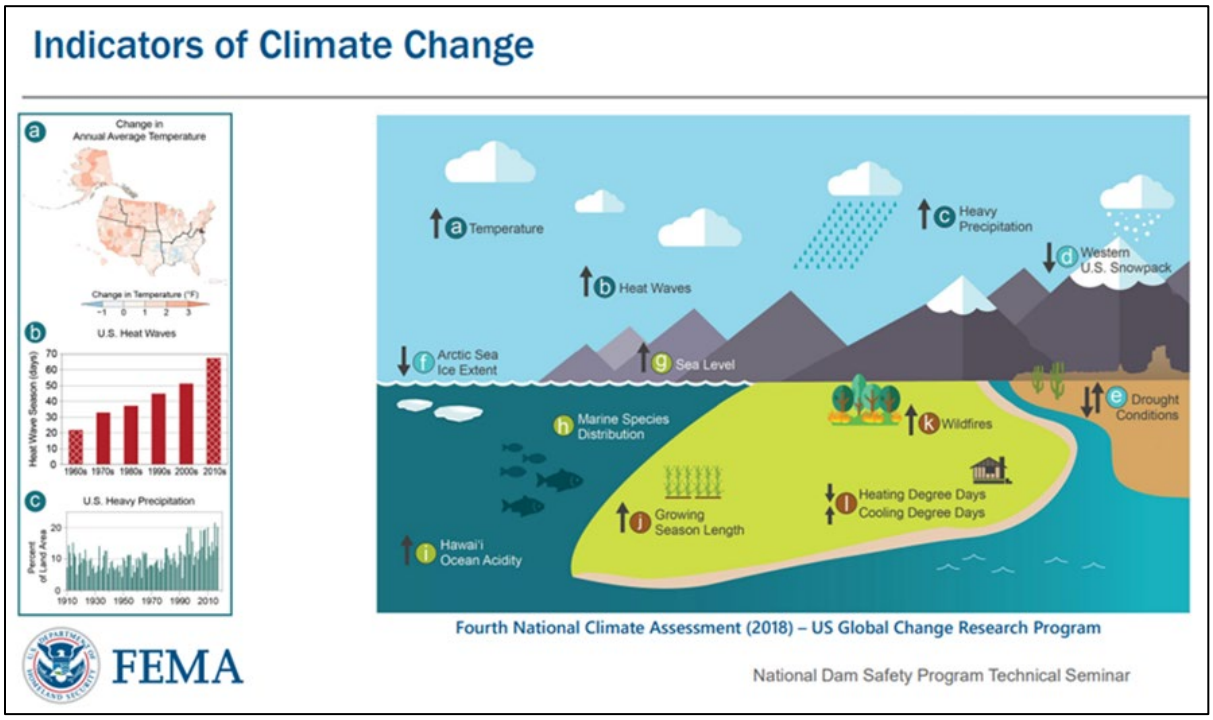
dam-related hazards to human lives, property, and the environment (Guidelines for Dam Safety, FEMA, 2023). With the information and support they provide, it is apparent that the federal government views dams and dam safety as critical components of emergency management.

As a component of FEMA's National Dam Safety Program, seminars play an integral role. In February 2023, a noteworthy collaboration emerged when the U.S. Bureau of Reclamation partnered with FEMA to deliver a briefing titled "Emerging Reclamation Methods for Incorporating Climate Change into Dam Safety" (FEMA, n.d.). This presentation provided insights into various aspects of the existing approaches for estimating flood loads for dam safety studies, the adaptation of these methods to account for climate change impacts, and the application of Forecast-Informed Reservoir Operations (FIRO).

One key highlight of this seminar is its emphasis on acknowledging the influence of climate change on the dam sector. Figure 6 is directly extracted from the seminar material, illustrating climate change indicators and the significant implications for water-related effects. The presentation furthers into the integration of climate change within the risk framework, more specifically on flood hazard analysis. The discussion highlights several notable issues, including the careful selection of climate projections that accurately depict extreme storm drivers, the projection of stream flow patterns, considerable time horizons, reduction and quantification of uncertainty, and the account for population growth factors.

Figure 6

FEMA Indicators of Climate Change. Source: Woolridge, Douglas, National Dam Safety Program Technical Seminar, 2023.



In August of 2023, FEMA announced the dedication of nearly $3 billion in funding selections to drive resilience to climate change and severe weather events (FEMA Press Release, 2023). This climate resilience funding follows President Biden's Investing in America agenda. The selections include $1.8 billion allocated for essential resilience initiatives funded through the national competition known as Building Resilient Infrastructure and Communities (BRIC), along with $642 million designated for community-scale flood mitigation projects under the Flood Mitigation Assistance (FMA) program. According to the statement, these selections expand upon FEMA's earlier announcement in May of 2023, which included $160 million for BRIC and FMA projects aimed at supporting mitigation endeavors, project planning, and the adoption of building

codes designed to withstand hazards (FEMA Press Release, 2023). This funding initiative is consistent with the federal perspective on the importance of building resilience against a changing climate and includes the importance of flood mitigation/dam safety, though overall it lacks an acknowledgment of the implications for hydropower.

However, according to a resource publicly provided by FEMA titled "Guide to Expanding Mitigation: Making the Connection to Electric Power," it emphasizes the threat that extreme weather poses to electric power systems. Additionally, it features the powerful role played by hydroelectric power but omits the connection of climate implications on hydropower.

All in all, through the National Dam Safety Program's offer of grant dollars for the restoration of dams, including those that support hydroelectric facilities, a clear depiction of the federal perspective on the importance of dams, dam safety, hydropower, and recognizing the implications from climate change exists. However, there is still a need for higher importance of this issue as climate change advances through further detailed resources.

The State and Local Perspective

Emergency managers' perspectives are growing in consensus toward accepting global climate change risks and planning for the implications of natural disaster preparedness (Schneider, 2011). Yet, many emergency managers may not understand the full scope of possibilities, including some impacts on the dams sector, and how that may affect their duties to plan for, adapt to, and cope with the effects (Labadie, 2011). Ultimately, it is in their best interest to be educated on these matters because of their obligation to manage the potentially extreme consequences of climate change. Finding where emergency managers fit into this realm of

planning, training, responding, and recovering their communities from climate change-induced natural disasters is often an obscure subject.

Dams are frequently viewed as potential vulnerabilities in the context of local emergency management. Emergency managers are markedly aware of the potential failure of dams due to various factors, including extreme weather events, aging infrastructure, and inadequate maintenance that can result in catastrophic consequences for downstream communities. Researchers have emphasized the need for comprehensive risk assessments and preparedness plans to address these vulnerabilities (Wachtendorf and Kendra, 2004). Recent incidents of dam failures, like the Oroville Dam Spillway Incident, also serve as harsh reminders of the inherent vulnerabilities associated with dam infrastructure. Incidents like this produce "After Action Reports (AARs)" which are lessons learned that are commonly reviewed by other local and state emergency management personnel. In the Oroville Dam Spillway case, one of the primary lessons for other emergency managers is that comprehensive periodic reviews of the original design and construction are foundational for all components of dam projects, especially considering comparison with the current state of practice (Schweiger, 2018).

Erosion and sedimentation control is a rising concern for some regions. As an example, the Wake County, North Carolina Watershed Management division is tasked with providing erosion and sedimentation control, floodplain management, and stormwater management. The department reviews new development plans, ensuring the projects follow guidelines to limit land disturbances that cause sedimentation, affecting Wake County's natural environment. The department is committed to educating its stakeholders and communities, as well as emphasizing the risk of polluted stormwater runoff (Wake County, 2023). While Wake County recognizes the risks of increased stormwater runoff impacts like eroding stream channels, surface water

pollutants, downstream flooding, and groundwater recharge complications, they do not consider climate change impacts on sedimentation. Nonetheless, Wake County is exemplary of other counties around the country taking mitigation measures against threats to their water systems.

Dams are recognized as critical infrastructures that require effective management and protection. Emergency management professionals must ensure the resilience of dams to maintain essential services such as water supply, electricity generation, and flood control for their districts. Investments in dam safety, routine inspections, and maintenance are essential components of emergency management strategies (Flood Risk Management Guidelines, FEMA, 2015). Oftentimes, dams require multi-agency coordination and cooperation to maintain due to the large ownership from the private sector and other regulating agencies. Departments of water resources, bureaus of reclamation, departments of fish and game, departments of environmental quality, and even regulators can all play an active role in this critical infrastructure management. Because of this array of involvement, a significant portion of emergency managers' jobs rely on the ability to build and sustain relationships.

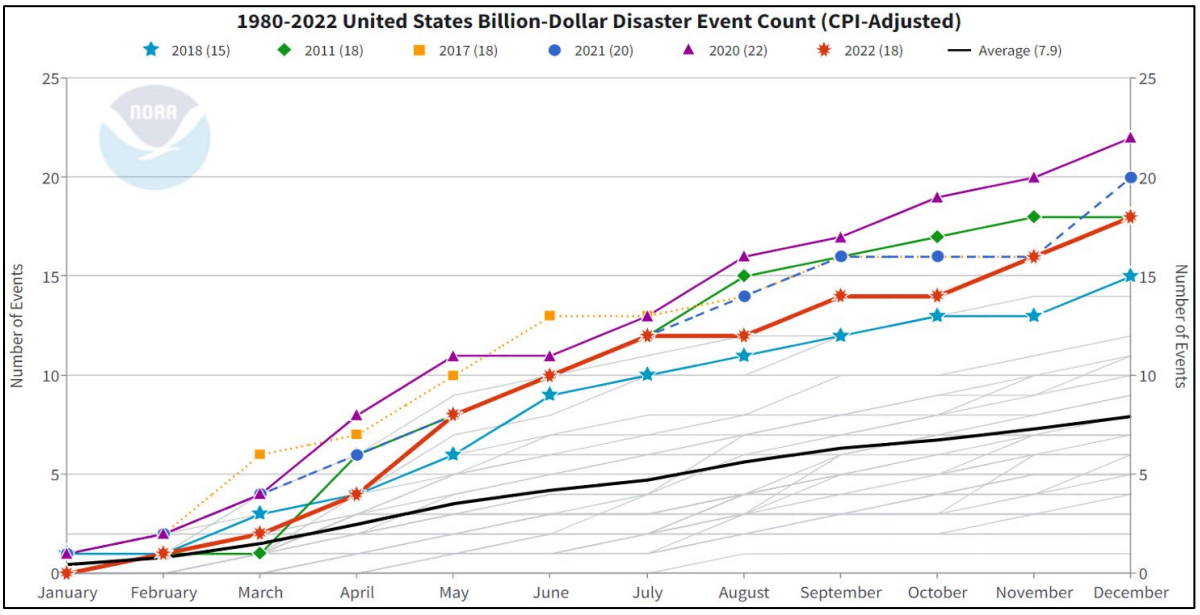
Recognizing the risks associated with dams, emergency management agencies often apply risk assessments to identify potential hazards associated with dams. This process involves evaluating the likelihood and consequences of dam failures or breaches, and the current levels of preparedness for these events. Subsequently, emergency managers develop mitigation strategies, which may include structural improvements, evacuation plans, and early warning systems to increase their capability against a hazard (Dams Sector-Specific Plan, DHS, 2015). In the event of dam-related emergencies, emergency managers begin by coordinating response efforts, including evacuations, emergency notifications, and the mobilization of resources to their affected communities. Effective response measures can lessen the impact of dam failures on

people and infrastructure. Post-event recovery operations involve restoring essential services and implementing measures to prevent future occurrences (DoD, 2013). However, the economic implications of dam failures are substantial. The damage caused by a dam failure can lead to cumbersome financial losses, including property damage, infrastructure repair costs, and potential loss of life. Emergency management professionals recognize that securing dam risks is not only a matter of public safety, but also of economic stability (Preparing for and Responding to Dam Emergencies, FEMA, 2019).

As mentioned, emergency manager's primary role for their communities is to plan and coordinate the response to disasters and emergencies. Part of that role entails assessing risks and mitigating the ones that pose the highest danger. Emergency managers recognize the threat of dams against climate change, specifically due to the increased severity and frequency of expensive natural disasters. The National Centers for Environmental Information (NCEI) provides access for emergency managers to see environmental data and products and helps with preventing unnecessary losses from disasters. To some extent, natural disasters are unavoidable, including incidents that cause significant financial loss (Hannah, 2020). Nonetheless, NCEI is providing emergency managers with data showing climate change is an evolving threat to their landscapes and should be accounted for in emergency planning. According to NCEI, 2022 was a notable year marked by a frequent occurrence of diverse and costly extreme events. The exceptionally high level of activity in recent years suggests a new standard that may need to be understood (NCEI, 2022). A NOAA graph by NCEI at Figure 7 displays the month-over-month compound of billion-dollar disasters for each year, starting in 1980. The colored lines on the image represent the top six years for the most billion-dollar disasters, and the remaining years are left in grey.

Figure 7

"1980-2022 United States Billion-Dollar Disaster Event Count." Source: NCEI, NOAA, Climate.gov Media, 2023



With the knowledge that costly and deadly disasters are on the rise and anticipated to only worsen in both impacts and occurrence, local emergency managers are left wondering who bears the financial burden when future dams fail, given the complexities of external factors (Hannah, 2020). For example, North Carolina emergency management has chosen to engage with their failing dam infrastructure. In the American Society of Civil Engineer's 2021 report card, 1,552 of their dams were considered high hazard (ASCE, 2021). One contributing factor is the aging infrastructure of a significant majority of dams in North Carolina, mirroring the situation prevalent amongst dams across the United States.

Recognizing this vulnerability and having a desire to mitigate it is unfortunately not enough for local emergency managers to be able to act. Dams are predominantly owned by the

private sector in the U.S. This creates a unique obstacle for emergency managers when trying to address the needs of critical infrastructure. Challenges are compounded when it comes to securing funding for maintenance and rehabilitation efforts, mitigating hazards to the public, strategizing, getting ready for potential crises, and instituting regulatory oversight (Hannah, 2020).

Local emergency management often focuses on enhancing community resilience to dam-related hazards. This involves public education, community preparedness programs, and the development of evacuation plans. Ensuring that communities are well-prepared can minimize the impact of dam emergencies (CRED, 2020). However, enhancing public awareness concerning prevailing safety concerns is another challenge local emergency managers face when having to coordinate with private owners (Hannah, 2020). This challenge is not uncommon with emergency management and infrastructure owners. Coordinating with private owners adds layers of complexities, including the willingness to share information. The dams sector infrastructure workforce experiences limited turnover due to the highly technical and specialized positions. Because of this, facilities may lose institutional knowledge as experienced workers retire from their positions and are unable to pass on their specialized and experience-driven insights (CISA, 2015).

Another perspective from local emergency managers associated with dams is how to fund the actual assessments and writing of an emergency plan. According to the Association of State Dam Safety Officials, one of the key factors leading to the lack of Emergency Action Plans (EAPs) for high-risk dams is the financial challenge associated with conducting thorough dam-break assessments. It takes money, time, staff, and resources, all of which are lacking in many

local emergency management agencies. This is a prominent problem for many rural areas, where many of their employees are volunteers.

According to the 2020 Census, 20% of people in the United States reside in a rural region (Census, 2022). While every rural area is different from one another, many of these communities face similar obstacles, especially in disaster management. Some of the challenges identified by the Legal Aid and Disaster Resource Center include but are not limited to lack of funding, longer commutes, longer emergency dispatch times, higher vulnerability to the impact of disasters, poor online access, and potential lack of trust for outside organizational assistance (LADRC, 2023). This nexus of a lack of resources and sufficient staff presents another set of challenges that is particularly acute in Idaho. For example, a local Idaho news outlet reported in 2021 that Idaho faces widespread funding challenges for their emergency medical services and staff, especially in their rural regions. Emergency medical services in Idaho are underfunded due to not being designated as an essential government service. The limited funds create a barrier to expanding capability and staffing. As a result, rural Idaho often staffs many of its emergency personnel with volunteers. The article reports that 69 percent of providers in Idaho are volunteers, and many places are unable to keep up with population growth (Big Country News, 2021).

While emergency managers are tasked with the planning and response phases in disasters, it has become more evident that numerous dam owners are unaware of their legal responsibilities concerning the potential loss of life and property damage downstream in the event of a dam failure (Olsen and White, 2015). This adds yet another role for emergency managers and creates another obstacle for them with dam-risk management.

Effective coordination among various stakeholders, including government agencies, dam operators, and emergency responders is essential. Dams are integral components of emergency management, serving as both potential vulnerabilities and critical infrastructure. Recognizing the significance of dams in safeguarding public safety and economic stability, emergency management professionals play a crucial role in ensuring the resilience of these vital structures. Local emergency managers are acutely aware of the risks, vulnerabilities, and challenges associated with dams, particularly in the context of climate change. While significant efforts have been made to assess and mitigate these risks, ongoing research and collaboration between emergency management agencies, dam owners, and the public are crucial to enhancing dam safety and resilience in the face of evolving climate conditions. Additionally, emergency managers are not sufficiently aware of the cascading impacts of climate change on the dam infrastructure, including sedimentation, and how that may impact their operations.

Chapter 6: Synthesis

Current emergency management literature provides an overview of climate change and its many impacts, including to the dams sector. The broader understanding includes federal, state, tribal, and local perspectives, emphasizing the critical role of dams in emergency management and the need for proactive strategies to address the associated risks. The case studies offer specific, localized insights into dam-related emergency management challenges and solutions, including potential initiations of climate-induced feedback loops. Both Idaho and Japan experience a significant economic reliance on the dams sector's hydroelectric production, and failure would result in far-reaching systems. Utilizing the case studies from both sites as lenses, available data from the emergency management domain is compared to determine if the information is adequate or if there are gaps.

Relevance of Literature

Emergency management literature increasingly acknowledges the risks posed by climate change, as well as the significance of dams and their infrastructure. Relating to the case studies, emergency managers recognize some of the impacts on the dams sector as a result of climate change, but are more focused on the vulnerabilities due to factors like extreme weather events and aging infrastructure. To combat this, emergency management literature emphasizes the importance of comprehensive risk assessments and preparedness plans. While these are strong components, there is a gap in specific climate-induced consequences as well as opportunities to reduce climate change acceleration. Specifically, there is a lack of needed attention to cascading climate change impacts on dam infrastructure, including sedimentation, and how this will affect emergency management planning and operation. Moreover, a comparison of the literature to the Idaho case study reveals several additional challenges like the complexities of coordinating with

private dam owners, funding assessments and emergency plans, and raising public awareness about safety concerns. These difficulties are intensified in Idaho due to most of the state being rural. Limited emergency management funding and resources available for emergency medical services lead to a heavy reliance on volunteers and inadequate staffing to cope with the growing population. This funding constraint, exacerbated by rural areas' unique navigational impediment, poses significant obstacles to comprehensive disaster management. Idaho exemplifies how financial limitations impact emergency preparedness and response efforts in regions where resources are scarce, emphasizing the need for sustainable funding solutions to enhance community resilience in the face of disasters.

The initiatives taken by Japan to counteract climate change effects on their dams sector seem to take the lead within emergency management literature. Both the experiences of Japan and the global emergency management literature highlight the significance of dams sector complications from climate change, with an emphasis on sedimentation. Emergency management literature recognizes the consequences of sedimentation, but again, is slightly delayed in distinctly recognizing climate change as a compounding element.

Relevance of Case Studies

The Idaho case study provides an overview of the state's dam infrastructure, including the hydroelectric sector, emphasizing its significance in meeting the power needs of Idaho's population as well as disaster mitigation and management. It highlights the state's vulnerability to natural hazards, including floods, wildfires, storms, and landslides with climate change exacerbating the severity and frequency of these events. The case study cites specific examples of recent extreme weather events, such as record-breaking heatwaves and tropical storm remnants, which have led to disasters and the declaration of emergencies in various Idaho

counties. These events, along with the increasing occurrence of debris flows, pose a threat to the state's dam and hydroelectric sector, which heavily relies on consistent flows of rivers and streams. The aging dam infrastructure poses an additional obstacle in regulating water flows and coping with debris, underscoring the need for proactive measures to protect Idaho's vital hydroelectric resources as climate change-related hazards become more common and intense.

Japan’s case study centers on the vulnerability of Japan's water infrastructure, including dams, and the adverse impacts of climate change. Japan's complex topography and heavy reliance on water resources make it particularly susceptible to climate-related trials, something that the nation is well aware of. Japan’s rising temperatures, disrupted snowmelt patterns, and unpredictable precipitation reflect climate change effects. The changes have led to reduced water availability in reservoirs, impacting critical sectors such as agriculture, municipal water supply, and hydropower generation. Sedimentation of dams and reservoirs due to increased erosion exacerbates water supply problems. Japan has responded with proactive measures, including adaptive reservoir management, dam upgrades, early warning systems, and sustainable hydropower practices. By implementing these tactics, the importance of climate resilience strategies to safeguard Japan's water resources and infrastructure in the face of evolving climate conditions is apparent. Japan is executing their response, as their highly variable climate driven by ocean currents with a rising temperature affects their nation’s infrastructure.

The table below describes the main distinctions between Idaho and Japan based on the relevance above.

Table 3

Idaho and Japan Distinctions

Aspect	Idaho	Japan
Natural Hazards	Inland climate-related hazards: droughts, wildfires, and floods.	Higher risk of natural disasters: earthquakes, tsunamis, and volcanic eruptions (Pacific Ring of Fire).
Population and Economy	Sparsely populated, rural state in the U.S.	Densely populated country with a large economy.
Infrastructure Scale	Lower number of large dams and reservoirs.	Larger-scale infrastructure.
Public Education	Response involves a slower approach.	Emphasis on educating the public, reflecting technological and cultural aspects.
Global Engagement	Idaho's response is more focused on regional U.S. challenges.	Japan appears to be at the forefront of literature, global engagement, and priority actions in the dam sector response.
Emergency Management Focus	Literature lacks a detailed focus on climate change feedback loops affecting dams in Idaho.	Japan addresses climate change implications on hydropower with higher priority, incorporating considerations into dam safety efforts.

Key differences between the case studies: Idaho and Japan, developed from emerging aspects in the synthesis.

Overall Analysis

While locations are separated by thousands of miles, both Idaho and Japan encounter weaknesses related to their water resources, and this is due to global climate change. In both

instances, alterations in precipitation patterns, including reduced snowfall and unpredictable precipitation, impact water availability and reservoir storage capacity. The two regions experience sedimentation issues in their dams and reservoirs, which also stresses their hydroelectric capabilities. Climate-caused factors, such as increased erosion, contribute to sediment buildup which reduces the storage capacity of reservoirs over time. This leads to economic risks in both cases. In Idaho, the economic consequences of dam failures due to climate change are a concern, while in Japan, it is estimated that climate-related challenges could result in substantial economic losses. Additionally, Japan's water management is taking proactive measures to enhance the resilience of its water infrastructure. They are investing in upgrades, monitoring systems, and adaptive strategies to mitigate climate-related risks.

Japan and Idaho experience similar water-related challenges, although their disparate geographical locations reveal important distinctions. Japan faces a higher risk of natural disasters such as earthquakes, tsunamis, and volcanic eruptions due to being amongst the Pacific Ring of Fire. On the other hand, Idaho is more prone to inland climate-related hazards like droughts, wildfires, and floods. These hazards affect their populations very differently, as Japan is a densely populated country with a large economy, while Idaho is a sparsely populated, rural U.S. state. Moreover, Japan's response to infrastructure vulnerabilities and climate change involves a broader range of stakeholders and a larger-scale infrastructure. Idaho has a significantly lower number of large dams and reservoirs. This, in turn, results in Japan facing sedimentation and storage capacity issues on a larger scale, and again, affecting more systems and more people. However, even with this broader scope, Japan's response to climate change has a greater emphasis on educating the public. These efforts reflect Japan's technological and cultural

approach to these public education and preparedness efforts. Idaho exhibits a much slower approach.

In summary, both Idaho and Japan share vulnerabilities related to water resources and sedimentation in dams and reservoirs due to climate change. However, their geographical locations, natural disaster risks, population sizes, water sources, and the scale of their water infrastructure differ significantly. Their responses to climate change reflect these differences, with Japan's approach often involving more extensive technological and cultural aspects, while Idaho's response is more focused on regional challenges within the United States. Through these case studies, it appears that emergency management literature is not comprehensive enough to address these challenges, for regions like Idaho. Japan appears to be at the forefront of literature, global engagement, and spearheading priority actions in the dam sector response. Emergency management literature lacks a detailed focus on adverse climate change feedback loops affecting the vulnerable dams sector. The federal perspective offers a preliminary exploration with seminars discussing the incorporation of climate change considerations into dam safety efforts. FEMA has also allocated significant funding for climate resilience initiatives, but there is a notable gap in acknowledging the implications of climate change on hydropower and emphasis on addressing these issues with higher priority.

Chapter 7: Evaluation

There are significant gaps in acknowledging how the changing climate will impact dams. Moreover, gaps reside in the available resources for emergency managers specifically detailing the climate change impacts on the dams sector which also include the large gaps in funding and public-private sector coordination. After a thorough analysis of the available resources, synthesis of case studies providing real world challenges and how they are being combatted and reflection on current emergency management knowledge and perspectives, the following gaps have been discovered. This list of gaps and recommendations is rooted in a solid foundation of existing emergency management knowledge that has been carefully cultivated through the practical experience of the emergency management workforce. Categories emerged utilizing the five mission areas of emergency management (prevention, protection, mitigation, response, recovery). Then, the five solution areas (planning, organization, equipment, training, exercise [POETE]) are used to increase capability and address sustainment needs. POETE is commonly used within emergency management to identify capability gaps and identify areas to approach the gaps. POETE is best known for its role in the Stakeholder Preparedness Review, a risk assessment of a jurisdiction's current capabilities against identified targets. Directly from Comprehensive Planning Guidance 201, POETE elements are defined by Figure 8.

Figure 8

"*POETE Areas*" *Source: FEMA CPG 201*

POETE Areas	
Planning	Development of policies, plans, procedures, mutual aid agreements, strategies, and other publications; also involves the collection and analysis of intelligence and information
Organization	Individual teams, an overall organizational structure, and leadership at each level in the structure
Equipment	Equipment, supplies, and systems that comply with relevant standards
Training	Content and methods of delivery that comply with relevant training standards
Exercises	Exercises and actual incidents that provide an opportunity to demonstrate, evaluate, and improve the ability of core capabilities to perform assigned missions and tasks to standards

All insights are derived from relevant themes within the field of emergency management, ensuring that they are well-informed and applicable to the challenges and priorities faced by professionals in this domain, aligning with several whole community approaches to emergency management (FEMA, 2011). Table 4 displays the recommendations aligning with mission and POETE areas.

Table 4

Recommendations

Recommendation	Mission Area	POETE Area
1. Resources Dedicated to Emergency Managers	Prevention, Mitigation	Planning
2. Funding Resources	Prevention, Protection, Mitigation	Planning
3. Collaboration and Information Sharing	Prevention, Protection	Planning, Organization
4. Policy Interventions	Mitigation, Response	Planning
5. Comprehensive Training and Education	Mitigation	Training, Exercise
6. Support for Ongoing Assessments and Adaptations	Mitigation, Response	Organization, Equipment
7. Research and Data Collection	Response, Recovery	Planning
8. Information Accessibility	Prevention	Planning, Organization
9. International Cooperation	Response, Recovery	Planning
10. Holistic Approach	All	All
11. Public Awareness and Advocacy	Prevention, Protection, Mitigation	Planning, Training, Exercise

Recommendation 1: Resources Dedicated to Emergency Managers

Emergency managers lack access to publications and resources tailored to comprehensively address climate change impacts on the dams sector. The emergency manager's responsibility is often overwhelming, and their time for research is limited. Federal agencies like FEMA have existing platforms that are easily accessible and well-known to emergency managers. Creating resources housed in these well-known and highly trafficked locations on the internet will build awareness in this area, and guide emergency managers through the impacts on their communities. These publications and resources should comprehensively address the impacts of climate change on the dams sector with risk assessments, vulnerabilities, emergency response strategies, and overcoming common obstacles. This recommendation aligns with the prevention and mitigation mission areas, as well as the planning POETE area.

Recommendation 2: Funding Resources

There is currently inadequate funding for infrastructure improvements and insufficient emergency management funding for local agencies responsible for managing dams, particularly in rural, underprivileged areas. Building resilient infrastructure is costly. Similarly, dependable emergency management agencies require access to plentiful resources. There needs to be an investment in infrastructure improvements to enhance the resiliency of dams systems against climate change by retrofitting existing dams and constructing new ones with climate resilience in mind, but also additional emergency management funding for local agencies who are responsible for this management. This is especially true for rural, underprivileged areas that would benefit immensely from allocated funding to bolster their emergency management capabilities. A cross-reference of high-risk dams to these resource-limited emergency management agencies should be considered. There should be a subsequent process to ensure that they are adequately equipped

with the necessary support and personnel to effectively utilize the funding for project completion. This recommendation aligns with the prevention, protection, and mitigation mission areas, as well as the planning POETE area.

Recommendation 3: Collaboration and Information Sharing

A lack of active collaboration and information sharing among federal, state, tribal, and local agencies and private dam owners leads to gaps in funding and responsibilities during disaster phases. Federal, state, and local agencies should collaborate and share information actively with each other, and with private dam owners. Oftentimes, the private sector is not considered to be included in public sector planning and operations. However, the private sector is largely involved with our public, and their ownership of critical infrastructure necessitates their input. The dam owner's understanding of their systems and the requirements for constructing resilient infrastructure will facilitate government agencies in providing them with appropriate support. Furthermore, private dam owners need further education on the various risks associated with their proprietorship. This will assist in bridging the gaps in communication and responsibilities before, during, and after disasters. This recommendation aligns with the prevention and protection mission areas, as well as the planning and organization POETE areas.

Recommendation 4: Policy Interventions

Existing policies do not sufficiently acknowledge climate change impacts on the dams sector, and regulations for dam owners to assess and mitigate climate-related risks are inadequate. Due to the multiple layers of ownership and regulation, as well as the variability of direct cause, accountability is difficult to enforce. There is also uncertainty in the tie to climate change, which can be seen as a case of the “Prisoner’s Dilemma.” In this situation, no person or organization wants to take accountability for the conjoined problem. No entity wants to take the

proper, but inconvenient, actions to combat climate change, nor take the blame. As it directly and indirectly affects the dams sector, further advocacy for the implementation and development of policies should be updated. Policies should distinctly acknowledge the climate change impacts on the dams sector with added regulations for dam owners to assess and mitigate climate-related risks. As climate change alters our threat landscape, policy needs to actively keep pace to equip emergency managers and related stakeholders with the tools to manage them. This recommendation aligns with the mitigation and response mission areas, as well as the planning POETE area.

Recommendation 5: Comprehensive Training and Education

The current emergency manager training and education to address the specific challenges posed by climate change in the dams sector, including recognizing climate change impacts, vulnerabilities, and climate resilience integration in emergency response plans is deficient. The federal government should provide training and education for emergency managers on the specific challenges posed by climate change in the dams sector. The training should encompass recognition of climate change impacts, and vulnerabilities, integration of climate resilience in emergency response plans, and troubleshooting existing challenges within their communities. This component must include an increased risk to their access and functional needs populations (see Appendix B). Once the training is established, it needs to be hosted in a way that is easily accessible for local emergency managers, given that the local agencies may not have the time, resources, funds, facilities, or sufficient attendees to stage local training. This recommendation aligns with the mitigation mission area, as well as the training and exercise POETE areas.

Recommendation 6: Support for Ongoing Assessments and Adaptations

Existing policies and practices are not regularly assessed and updated to keep abreast with the evolving challenges of climate change, and this is exacerbated by a lack of federal support. Climate change impacts are only furthering consequences, especially due to positive feedback loops reinforcing the system. Negative repercussions will become more prominent and frequent. To combat this, assessments and updates to policies, guidelines, and practices based on climate change evolvement should become routine. Public and private sector partnerships could increase efficiency in this step, though specifically need to be supported federally as this adds a funding and personnel aspect. This recommendation aligns with the mitigation and response mission areas, as well as the organization and equipment POETE areas.

Recommendation 7: Research and Data Collection

There is a need for thorough research and data collection to understand climate change implications for dams systems, including hydrological modeling, vulnerability assessments, and risk analyses. Resources catered toward research and data collection will improve understanding of the repercussions of climate change on dam systems. This can include further hydrological modeling, vulnerability assessments, and risk analyses. Instead of a national approach, this research can begin with local community examinations, and escalate up to states and regions. This recommendation aligns with the response and recovery mission areas, as well as the planning POETE area.

Recommendation 8: Information Accessibility

Most comprehensive resources and reports are not easily accessible to private dam owners, emergency managers, and other correlating stakeholders. There is a lack of empirical research conveniently obtainable, readable, and efficiently displayed which hinders their ability

to access key information and stay up to date on evolving threats. By ameliorating the accessibility of important resources and reports available for private dam owners, emergency managers, and other stakeholders, critical information will be user-friendly, consisting of summaries and/or guidelines to highlight key findings. This recommendation aligns with the prevention mission area, as well as the planning and organization POETE areas.

Recommendation 9: International Cooperation

International approaches to address climate change impacts on dams could be improved to further information sharing and best practice exchange with countries facing similar challenges. Climate change is a global issue, meaning every region is experiencing impacts. Some regions may experience impacts more severely, or before, other regions. By exchanging best practices, research findings, and policies with other countries that face these challenges, the entire globe can benefit and alleviate climate change impacts. Advocacy and promotion of an international approach to address climate change impacts on dams will increase knowledge of successful and unsuccessful mitigating nation's strategies. This recommendation aligns with the response and recovery mission areas, as well as the planning POETE area.

Recommendation 10: Holistic Approach

There is a gap for a holistic and comprehensive approach to address climate change impacts on dams, including hydropower, which results in incomplete guidance, regulations, and funding mechanisms. While critical information on each sub-component may be attainable, there is a need for holistic resources that capture the entire system to understand its complexity. Climate change operates within a complex network, provoking various other systems, such as the heightened frequency and severity of extreme weather events. Although, both climate change and extreme weather are causes for negative impacts to the dams sector system. A holistic

approach will allow for a complete understanding of the intricacies and interdependencies of the systems, and their potential feedback, and expose leverage points to alleviate some adverse effects. This can begin by developing comprehensive essentials for emergency managers on climate change impacts on dams, including hydropower, underscoring the need for holistic guidance, regulations, and funding mechanisms. This recommendation aligns with all mission areas, as well as all POETE areas.

Recommendation 11: Public Awareness and Advocacy

The public is not completely aware of the risks to downstream residences, insurance options and value, and the recovery process after a dam failure. Additionally, there is insufficient advocacy for increased resources and funding in this area. Outreach and education to the public on the risks to their downstream residences can in turn allow them to take proper mitigation steps based on a comprehensive understanding. Furthermore, a cultural approach may prove beneficial to certain communities that resemble significant and similar norms, values, and beliefs. Incorporation of their cultural principles and sensitivities can offer appropriate mitigation and unified community response to challenges. This step should also include education on available insurance and the effectiveness after a dam failure. It is crucial to explain the resources, and lack thereof, available from the federal government after a disaster. After this discussion, advocacy for increased resources and funding in this area can potentially commence. This recommendation aligns with the prevention, protection, and mitigation mission areas, as well as the planning, training, and exercise POETE areas.

Chapter 8: Conclusion

Addressing the significant gaps in our comprehension of how climate change will affect the dams sector and the availability of resources for emergency managers is of paramount importance. The dams sector and its associated infrastructure hold a pivotal role in water resource management, providing essential services such as water supply, flood control, and energy production through hydroelectric dams. It is imperative to grasp and counteract the impact of climate change on this sector to safeguard the communities living downstream and preserve the integrity of infrastructure, given the considerable costs involved. The existing vulnerabilities within the dams sector, such as aging infrastructure and knowledgeable workforces, are further exacerbated by the influence of climate change. Consequently, safety and economic assets are increasingly placed in jeopardy.

Furthermore, the dams sector exerts a profound influence on local ecosystems, and climate change impacts have the potential to disrupt these ecosystems, resulting in cascading effects that can ripple through the environment. These multifaceted challenges place additional strain on local emergency management, which grapples with inadequate funds, personnel, and resources to effectively manage the risks and protect their communities. As more and more local systems succumb to the pressures of these impacts, mounting pressures are transferred to the federal government, potentially overwhelming our collective capacity to respond adequately. To effectively mitigate risks and ensure the resilience of our critical infrastructure, the issue must be proactively addressed. By doing so, we can ultimately protect our people and the environment, creating a more secure and sustainable future.

With the existence of far-reaching resources on climate change, and educating emergency managers, there needs to be a clear linkage and resource dedicated to the dams sector impacts,

including hydropower. Similarly, additional policies should close the gap between the public and private sectors on this issue. As most of the infrastructure in the United States is privately owned, this adds a new layer of complexity for emergency managers.

Based on the identified gaps in existing and accessible literature, and lessons learned from case studies, the following list provides recommendations to improve emergency management preparedness for climate change impacts on the dams sector. In no order of importance:

- Dedicated resources for emergency managers
- Funding resources
- Collaboration and information sharing
- Policy interventions
- Comprehensive training and education
- Support for ongoing assessments and adaptations
- Research and data collection
- Improved accessibility
- International cooperation
- Holistic approach
- Public awareness and advocacy

In conclusion, these gaps in understanding climate change modifications in the dams sector and providing appropriate resources for emergency management must be addressed. As global issues compound and cascade, pressures will first be felt on the local level. Ultimately, this will lead to added stress and pressure on emergency managers and associated stakeholders. The emergency management profession is oftentimes overwhelming, so it is crucial to recognize

potential emerging threats in advance of irreversible consequences. Emergency management professionals deserve accessible, reliable, and targeted resources to guide them to serve their communities and relieve them from as many obstacles as possible.

Similarly, emergency managers and their local communities will experience consequences resulting from a complex issue with numerous contributing factors. At least, support for their daily heroic endeavors through attainable, user-friendly information with incoming threats on the horizon will allow them to stay vigilantly prepared and extend that to their jurisdictions. To safeguard communities, critical infrastructure, the environment and ecosystems, and economic risks, there needs to be an emphasis on further research at addressing the climate change impacts on the dams sector, which will ultimately increase resilience capability.

Appendix A: Definition of Terms

Access and Functional Needs: A person who may be experiencing a disability or function-based need that limits them from executing conventional activities.

Climate Change: The long-term alteration of temperature and weather patterns that alter the climate. The current change of climate shows a rise in global heat due to various contributing factors like the greenhouse effect.

Critical Infrastructure: Infrastructure encompassing both physical and virtual assets, systems, and networks that are of such vital importance that their disruption or destruction would significantly harm national security, economic stability, public health, safety, or any combination of these critical aspects. The United States recognizes 16 critical infrastructure sectors. The Cybersecurity and Infrastructure Security Agency (CISA) oversees all critical infrastructures.

Dam: A structure built to hold back water, creating a reservoir or lake, and is typically utilized for hydroelectric power generation or as a source of water supply.

Dams Sector: Assets, systems, networks, and functions related to dam projects, navigation locks, levees, hurricane barriers, mine tailings impoundments, reservoirs, streams, or other similar water retention and/or control facilities that have a role in providing essential water storage and management services within the United States. These services encompass hydroelectric power production, provision of water for municipal and industrial use, support for agricultural irrigation, management of sediment and flood control, facilitation of river navigation for inland bulk shipping, industrial waste handling, and the promotion of recreational activities.

Disaster: A sudden natural or human-caused incident that results in significant damage, destruction, and/or loss of life.

Emergency Management: The managerial role assigned to establish the structure in which communities minimize their vulnerability to threats, risks, and hazards while effectively handling disasters.

Emergency Manager: A professional responsible for planning, preparing, and coordinating the response and recovery efforts in their specific jurisdiction during disasters.

Feedback Loop: A feedback loop is a dynamic system where the outcomes of a process are reintroduced as inputs, initiating new iterations and cycles. Feedback loops can come in the form of positive or negative. A positive feedback loop reinforces the initial outcome of the original cause, enhancing the change. A negative feedback loop is a normal response to a cause by counteracting its effect, bringing it back to its original state.

Fossil Fuels: A nonrenewable source of energy that is used through the process of burning or combustion and produces a gas. Fossil fuels are hydrocarbon-based sourced from the remains of ancient plants and animals. They include coal, oil (petroleum), and natural gas.

Global Warming: The gradual rise in the global atmospheric temperature, commonly linked to the greenhouse effect resulting from elevated concentrations of carbon dioxide, chlorofluorocarbons, and other pollutants.

Greenhouse Effect: The process through which heat is retained by increasing greenhouse gases in the lower atmosphere driven by the atmosphere's higher transparency to visible sunlight from the sun compared to its transparency to the infrared radiation emitted from the planet's surface.

Greenhouse Gases: A gas that absorbs infrared radiation and contributes to the greenhouse effect.

Hydropower: A term for hydroelectric power, which is a form of renewable energy generated by the flow or fall of water to generate turbines that result in electricity.

Levee: An embankment that prevents the overflow of a river that is built or naturally occurring through the accumulation of sediment deposits.

Reservoir: A large manmade or naturally occurring lake utilized as a water supply.

Sedimentation: The accumulation of deposited sediment through the form of rocks, stones, sand, sticks, or particles in suspension.

Appendix B: Disaster Impacts to the Access and Functional Needs Community

Access and functional needs refer to people who experience a function-based need, related to restriction to decreased ability to perform routine and normal activities (Massachusetts Emergency Management Agency, 2023). This may include, but is not limited to:

- A physical, developmental, and/or intellectual disability
- Persons over the age of 65 (Classified as Elderly)
- Children
- Pregnant women
- People with chronic health conditions
- Limited English Proficiency/Non-English speakers
- Institutionalized-living persons
- People from diverse cultures
- People who are transportation disadvantaged

Incorporating planning for the access and functional needs community has become an overarching theme in recent years for emergency management. Disasters affect the whole community, but episodes in America's history have proven that the access and functional needs community suffer significantly higher challenges before, during, and after disasters (Doyle and Mace, 2017). These individuals with particular healthcare needs have markedly higher mortality and morbidity rates, and various historical disasters have exemplified this phenomenon.

When Hurricane Katrina tormented the Gulf Coast, thousands of people suffered devastation. The storm was responsible for 1,330 deaths and thousands of injuries, not including

pets and animals. Unfortunately, the elderly and people with disabilities bore the heaviest toll. A White House report accounts that 71% of the people who died from the storm in the state of Louisiana alone were over the age of 60 years. Additionally, the National Council on Disabilities reported that the Louisiana community who experienced a disability and/or poverty were disproportionately left behind during Hurricane Katrina (Otte, 2015).

The Northern California region is no stranger to wildfires. Each year, the area is susceptible to wildfire risk, forcing the evacuations of thousands of people. Notable disasters in recent history include the Camp Fire, the Dixie Fire, the Caldor Fire, and the Mosquito Fire. All these wildfires are beginning to burn more rapidly and intense, prompting evacuation and organizational planning to stay vigilant to account for all community members. However, trouble persists with access and functional needs community, especially during wildfires. Their access to necessary special medical care becomes dysfunctional or non-existent, and resources to evacuate these members of the community are strained. A significant amount of people who perished in the Camp Fire were disabled, attributing to their physical or mental state, or even the desire to save themself. Most of the caretakers for these people experience the disaster, too, and may need to evacuate themselves and their families as well. It is important to note that 25% of the residents who lived in the Paradise area were experiencing a disability, according to the U.S. Census Bureau from 2012-2016 (The Sacramento Bee, 2018).

The COVID-19 pandemic disproportionately affected, and still affects, the access and functional needs community. While the pandemic disrupted the medical supply chain and healthcare delivery for the general population, it significantly affected people with access and functional needs. The elderly and people who are immunocompromised are more at risk of COVID-19-caused mortality (CDC MMWR, 2023). This is largely due to a limited or defective

immune response to infection. Moreover, the prominence of a comorbid illness, malnutrition, drugs, and stress can also lead to an increased risk of COVID-19 by declining immune function (Benksim et. al, 2020).

Coastal communities are frequently exposed to flooding, receding coastlines, and environmental degradation that may critically affect the health, safety, and well-being of coastal residents. In particular, those that are inherently vulnerable to natural hazards include those with a disability and the elderly (Bukvic et. al, 2018). The majority of the population of the United States coastlines are people over the age of 60, as it has become a popular retirement destination. However, this is attributed to added difficulties when experiencing accelerated hurricanes, sea-level rise, tidal inundation, and other flooding and extreme weather events. The older community experiences added challenges physically and psychosocially. This may "affect their level of preparedness, ability to cope with, and capacity to respond and recover" from an incident (National Institutes of Health, 2018). In the recent Hurricane Lee, news releases were targeting emergency preparedness for senior communities along the coastline. They emphasized the loss from Hurricane Ian-related deaths in Florida, which took the lives of 149 people, two-thirds of whom were senior citizens (Neely, 2023).

According to the Climate Essentials from the Federal Emergency Management Agency, climate change impacts are also an equity problem. Regardless of socioeconomic status, the natural environment and all its residents are affected. However, it is underscored that the underserved, disadvantaged, and marginalized communities are severely more impacted. Moreover, these populations who are the most at risk of disasters are also the ones who are contributing the least to the problem which leads to an ethical issue. These communities often have limited or complicated influence on political power and decisions. It is also reported that

disasters may exacerbate already existing inequities in society, compounding the risks and vulnerabilities. Declines in health, increase in poverty, and access to resources for preparation, emergency evacuation and/or relocation, hazard mitigation, response, and recovery can all be reduced by these inequities. For example, the Centers for Disease Control and Prevention states some of the human health effects from climate change include "increased respiratory and cardiovascular disease, injuries and premature deaths related to extreme weather events, changes in the prevalence and geographical distribution of food- and water-borne illnesses and other infectious diseases, and threats to mental health" (FEMA, 2023).

It is clear that at-risk communities feel the effects of climate change more severely and long-term. Preparation and resources are extremely limited, and it is recommended that emergency management professionals should give precedence to helping vulnerable communities and strive for equity, under relevant legislation (FEMA, 2021, p.121-131). Whole community initiatives may be led by collaborating with stakeholders to diminish the susceptibility of underserved and disadvantaged populations, integrating environmental justice into all aspects of emergency management activities (FEMA, 2023). With climate change furthering the risks for more frequent and severe extreme weather events, and a nation grappling with an aging critical infrastructure, these considerations should be taken into accord when planning for dams sector-related emergencies.

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