The Press and Pulse of Climate Change: Extreme Events in the Colorado River Basin

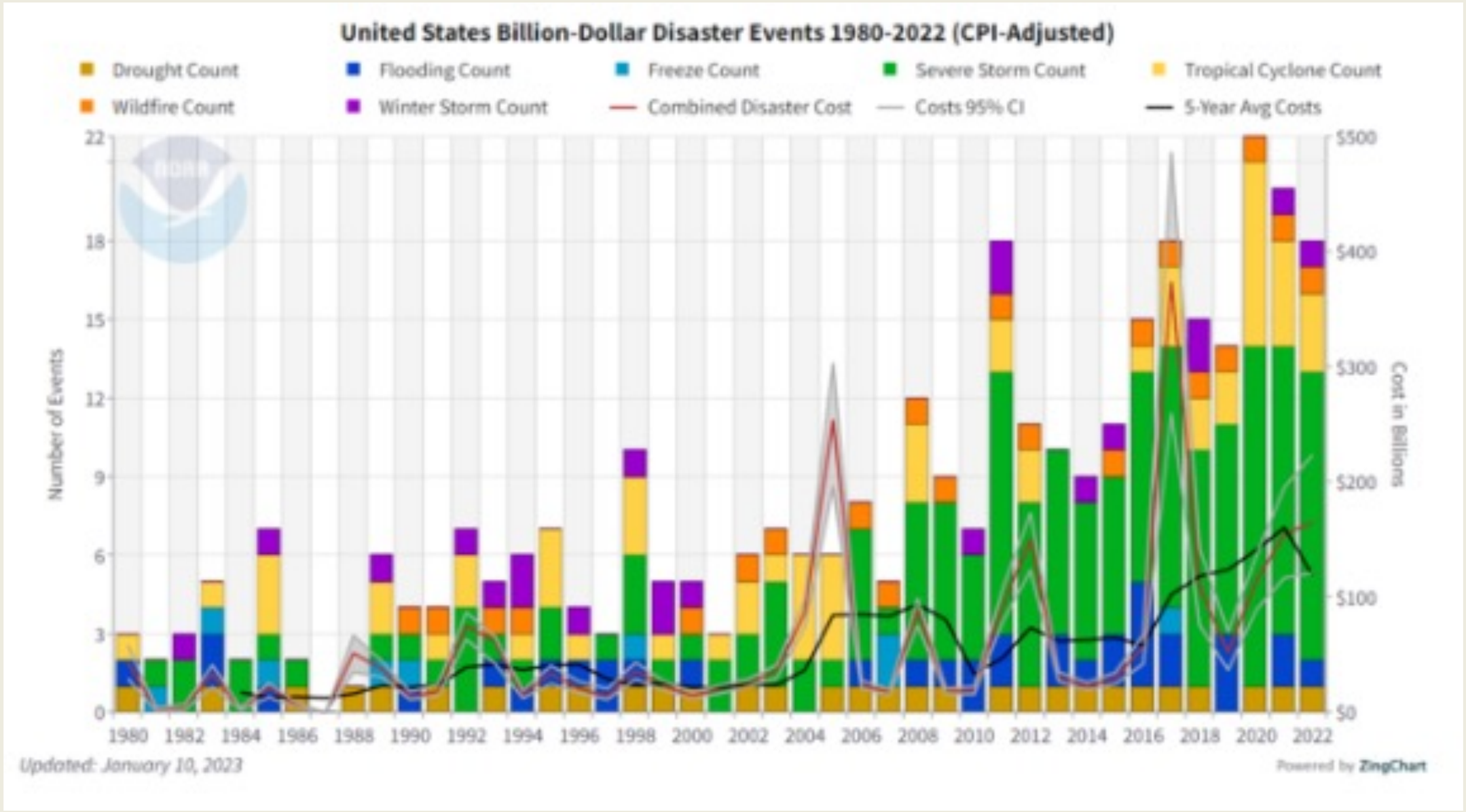
Amy L. McCoy (AMP Insights), Katharine L. Jacobs (University of Arizona), Julie A. Vano (Aspen Global Change Institute), J. Keaton Wilson (Virga Labs), Season Martin (Virga Labs), Angeline G. Pendergrass (Cornell University), Rob Cifelli (NOAA/ESRL/Physical Sciences Laboratory)

Kathy Jacobs

Center for Climate Adaptation Science and Solutions
Arizona Institute for Resilience
Department of Environmental Science
University of Arizona

Extreme events are the "wake-up call" for climate change

and they are becoming increasingly expensive both in economic, social and environmental terms.



Smith, NCEI 2023 Billion Dollar Disasters by Type

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Overview of “Press and Pulse”

- Extremes in temperature and precipitation are increasing, with increasing damages
- This results from a *combination* of long-term trends and natural variability – along with changes in underlying drivers from anthropogenic forcing
- We explored underlying physical mechanisms of each type of extreme that was of concern to water managers, and what is known about trends in these extremes into the future

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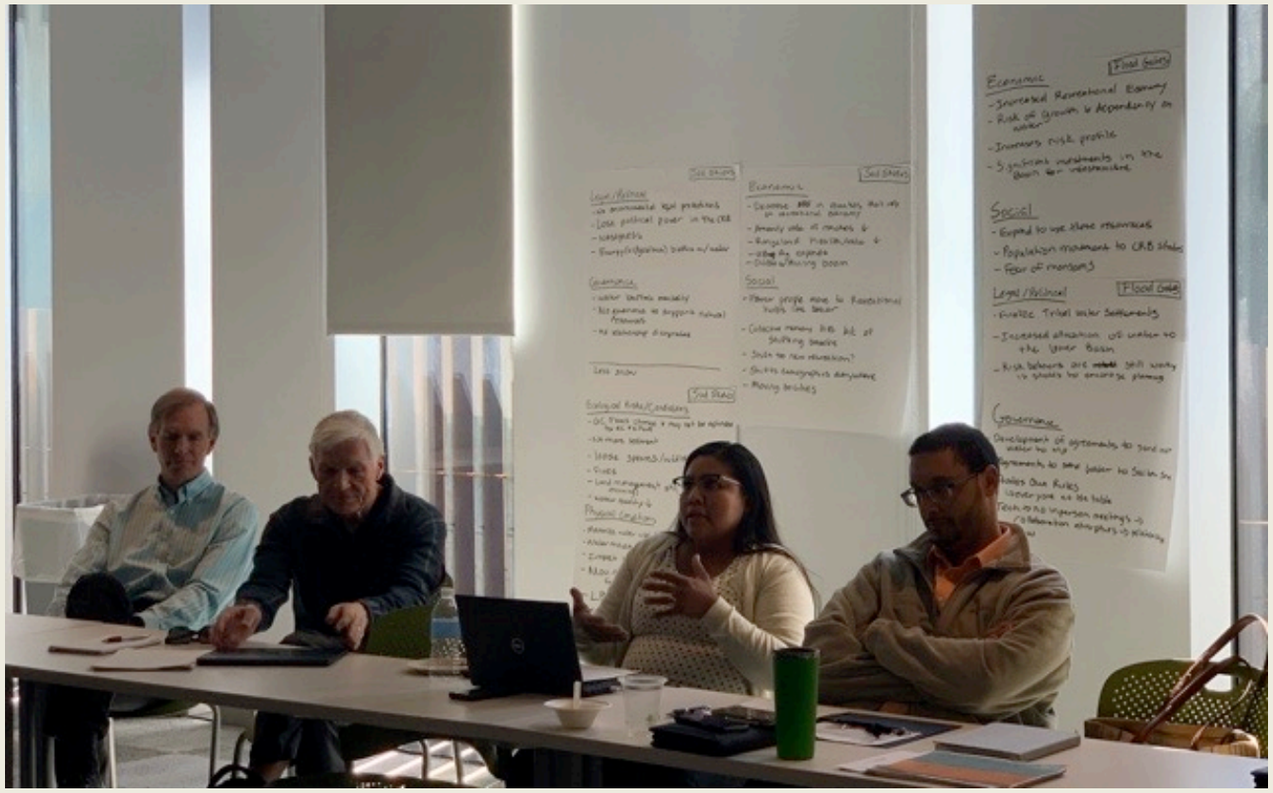
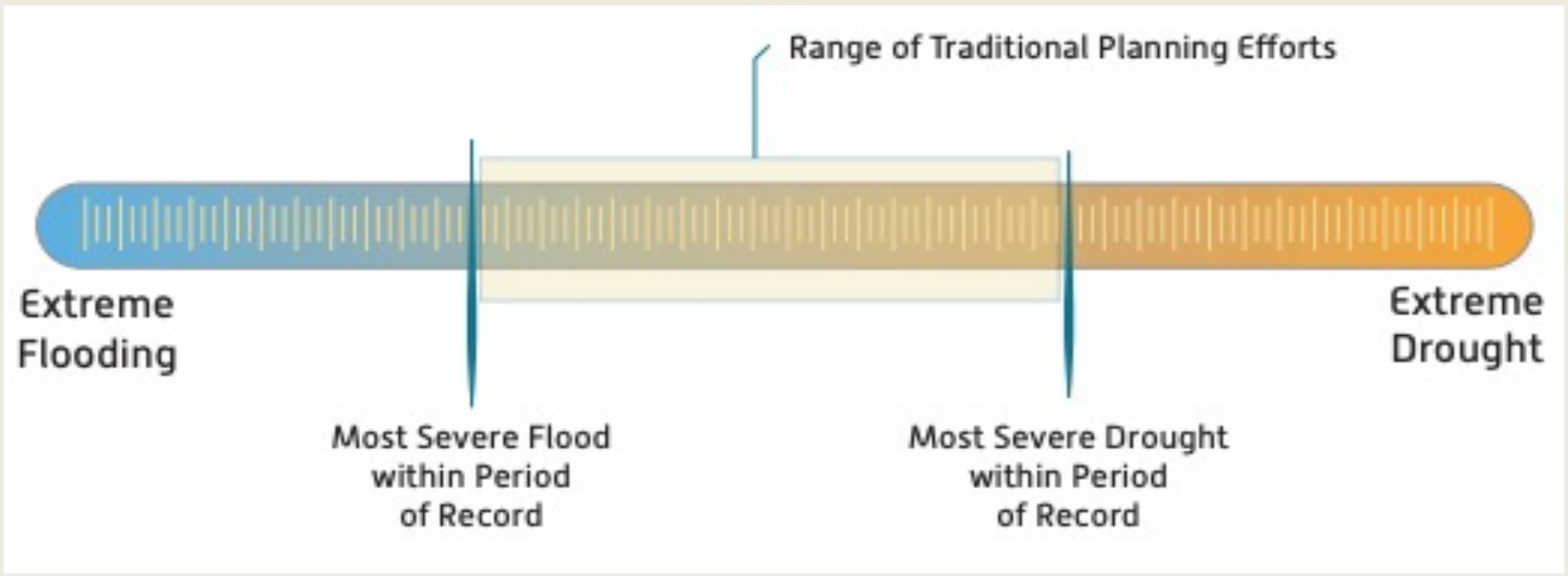
Colorado River Conversations Scenario Planning Workshops

June 2019- April 2020



- Three workshops involved 30 Colorado River Basin representatives
- Explored “black swan events” and the areas of uncertainty outside the parameters of most planning discussions



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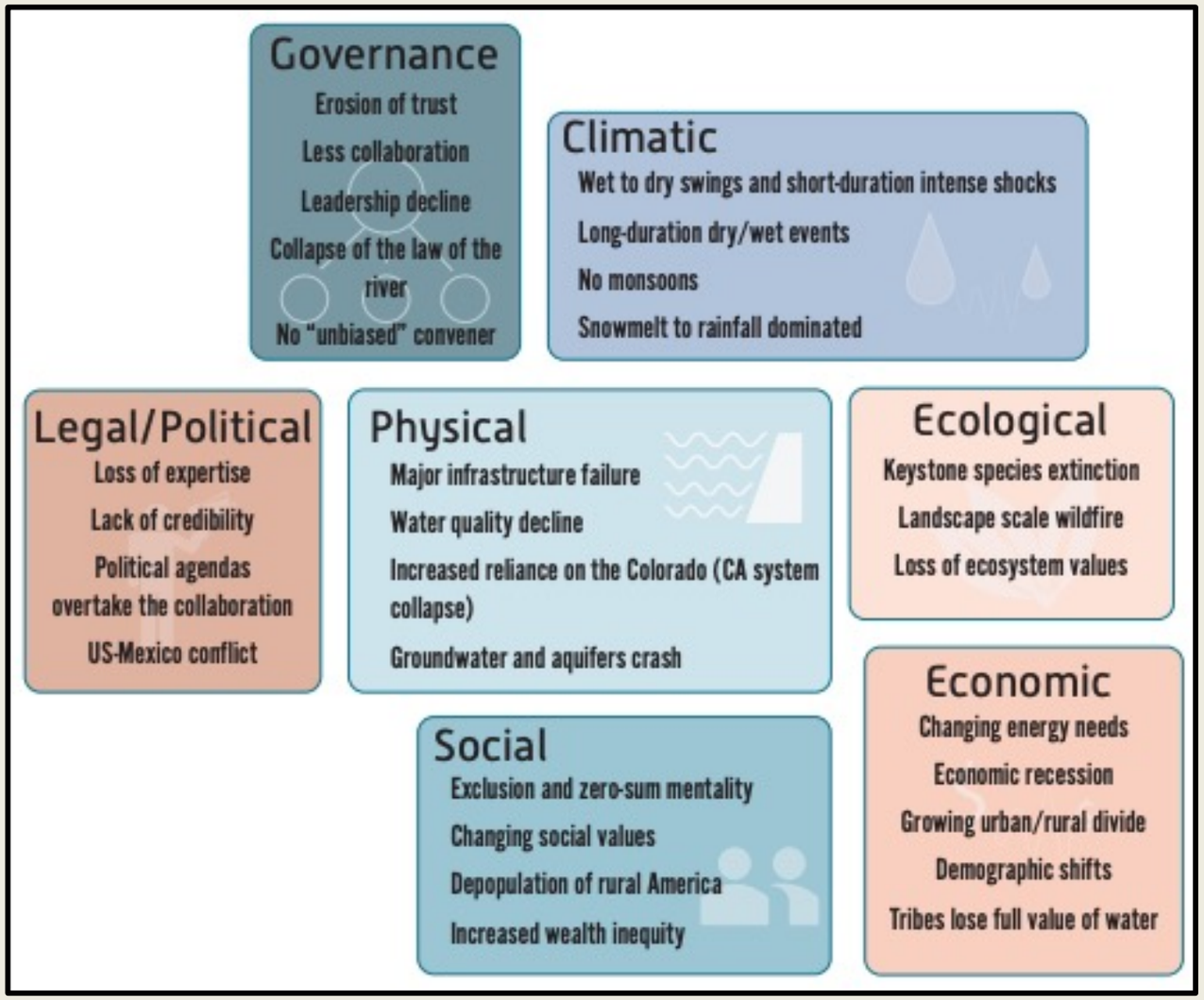
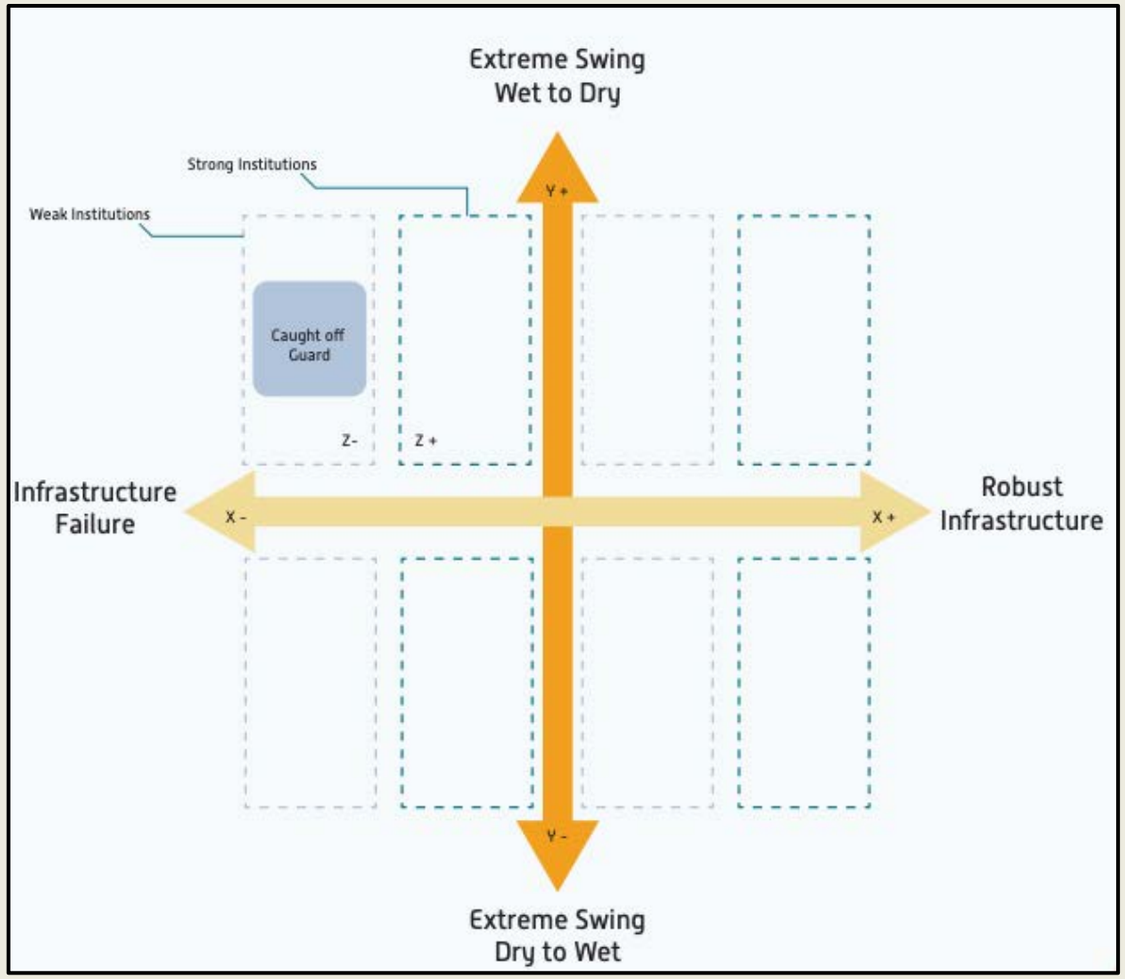
Our process involved: Identifying drivers of change…



Building scenarios…



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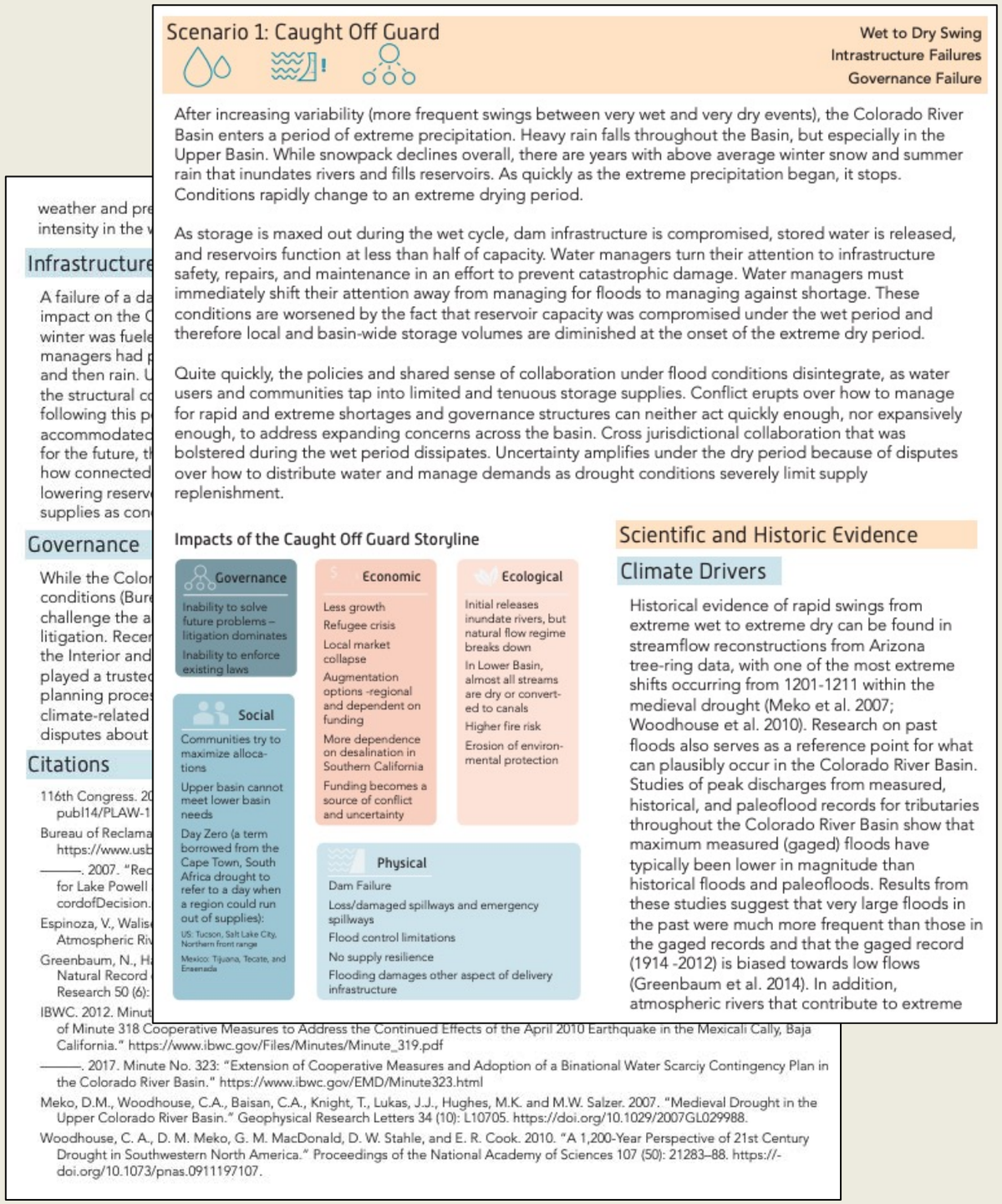
Researching and Writing Storylines…



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Scenario 1: Caught Off Guard

Wet to Dry Swing
Intrastructure Failures
Governance Failure

After increasing variability (more frequent swings between very wet and very dry events), the Colorado River Basin enters a period of extreme precipitation. Heavy rain falls throughout the Basin, but especially in the Upper Basin. While snowpack declines overall, there are years with above average winter snow and summer rain that inundates rivers and fills reservoirs. As quickly as the extreme precipitation began, it stops. Conditions rapidly change to an extreme drying period.

As storage is maxed out during the wet cycle, dam infrastructure is compromised, stored water is released, and reservoirs function at less than half of capacity. Water managers turn their attention to infrastructure safety, repairs, and maintenance in an effort to prevent catastrophic damage. Water managers must immediately shift their attention away from managing for floods to managing against shortage. These conditions are worsened by the fact that reservoir capacity was compromised under the wet period and therefore local and basin-wide storage volumes are diminished at the onset of the extreme dry period.

Quite quickly, the policies and shared sense of collaboration under flood conditions disintegrate, as water users and communities tap into limited and tenuous storage supplies. Conflict erupts over how to manage for rapid and extreme shortages and governance structures can neither act quickly enough, nor expansively enough, to address expanding concerns across the basin. Cross jurisdictional collaboration that was bolstered during the wet period dissipates. Uncertainty amplifies under the dry period because of disputes over how to distribute water and manage demands as drought conditions severely limit supply replenishment.

Impacts of the Caught Off Guard Storyline

Governance
Inability to solve future problems – litigation dominates
Inability to enforce existing laws

Economic
Less growth
Refugee crisis
Local market collapse
Augmentation options -regional and dependent on funding
More dependence on desalination in Southern California
Funding becomes a source of conflict and uncertainty

Ecological
Initial releases inundate rivers, but natural flow regime breaks down
In Lower Basin, almost all streams are dry or convert-ed to canals
Higher fire risk
Erosion of environ-mental protection

Social
Communities try to maximize alloca-tions
Upper basin cannot meet lower basin needs
Day Zero (a term borrowed from the Cape Town, South Africa drought to refer to a day when a region could run out of supplies):
US: Tucson, Salt Lake City, Northern front range
Mexico: Tijuana, Tecate, and Ensenada

Physical
Dam Failure
Loss/damaged spillways and emergency spillways
Flood control limitations
No supply resilience
Flooding damages other aspect of delivery infrastructure

Scientific and Historic Evidence

Climate Drivers

Historical evidence of rapid swings from extreme wet to extreme dry can be found in streamflow reconstructions from Arizona tree-ring data, with one of the most extreme shifts occurring from 1201-1211 within the medieval drought (Meko et al. 2007; Woodhouse et al. 2010). Research on past floods also serves as a reference point for what can plausibly occur in the Colorado River Basin. Studies of peak discharges from measured, historical, and paleoflood records for tributaries throughout the Colorado River Basin show that maximum measured (gaged) floods have typically been lower in magnitude than historical floods and paleofloods. Results from these studies suggest that very large floods in the past were much more frequent than those in the gaged records and that the gaged record (1914 -2012) is biased towards low flows (Greenbaum et al. 2014). In addition, atmospheric rivers that contribute to extreme

Exploring Impacts…

Figure 6. Impacts of the Caught Off Guard Storyline

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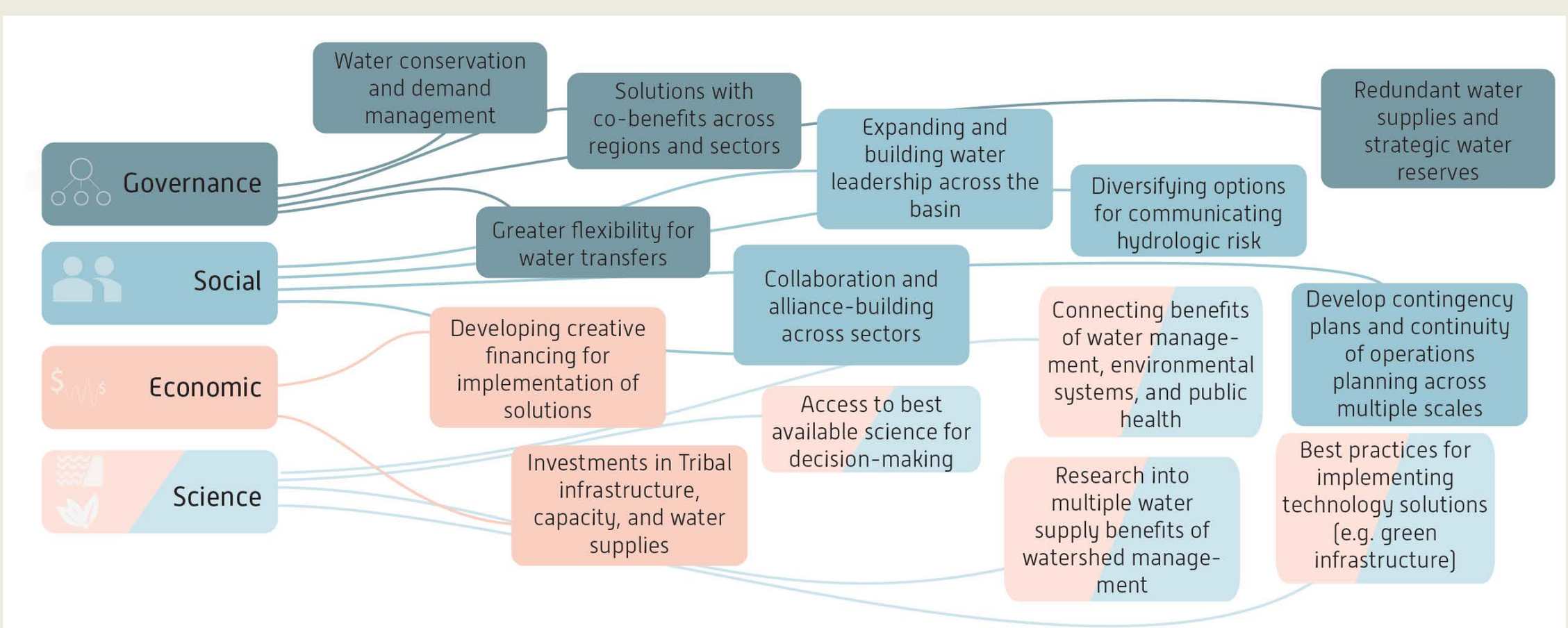
And Identifying Common Solutions

Colorado River Conversations Project
https://ccass.Arizona.edu/Colorado-rver-conservations-project



The Press and Pulse of Climate Change Extreme Events in the Colorado River

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Event of Concern noted by water managers	Climate-change trend defined	Impact of change	Linkage to climate change drivers	Relevant research

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TABLE 1. (continued)

Events of concern noted by water managers	Climate-change trend defined	Impact of change	Linkage to climate change drivers	Relevant research[1]	A recent example (details in text)
The Upper Colorado River Basin in 2020 and 2021 had unexpectedly low run-off volumes					
4. Extensive wildfires	More areas burned	• Public safety threatened • Air quality declines • Water quality declines • Increased erosion	Increased temperatures, increased drying and reducutions in snowpack while lengthening the fire season	*Western US*: Abatzoglou and Kolden (2011); Jenkins et al. (2014); Abatzoglou and Williams (2016); Holden et al. (2018); Kean et al. (2019); Zhang et al. (2020); Brey et al. (2021) *US*: Wehner et al. (2017)	In 2020, Colorado experienced the three largest wildfires in recorded history
5. Short-duration intense wet and dry system shocks	Precipitation intensity increases; each storm brings more water	• Flooding • Increased erosion • Dam safety concerns + Increased groundwater recharge in some locations + Drought relief	A warmer atmosphere holds more water, so when it rains or snows there a greater chance that more precipitation will fall in any given event; additionally, storms are now developing in warmer and more humid environments, ocean surface temperatures drive a worldwide increase in size and number of storms	*Basin specific*: Gutmann et al. (2016); Shamir et al. (2019); Corringham et al. (2019) *Western US*: Zhu and Newell (1994); Corbosiero et al. (2009); Dettinger (2013); Rutz et al. (2015); Alexander et al. (2015); Swales et al. (2016); Demaria et al. (2019); Gershunov et al. (2019); Davenport et al. (2020); Payne et al. (2020); Rhoades et al. (2020) *US*: Easterling et al. (2017); Kossin et al. (2017) *Global*: Trenberth (2011); Pendergrass and Hartmann (2014); Swann et al. (2016); Fischer and Knutti (2016); Simpson et al. (2016); Kossin et al. (2017); Pendergrass et al. (2017); Sippel et al. (2019); Heinze-Deml et al. (2020)	In 2013, the "Front Range Flood" in Colorado resulted from record rainfall and urban runoff volumes
Rapid onset dry year (flash drought)		• Water shortages • Agricultural losses • Recreation limited • Increased fire danger	Large-scale atmospheric circulation changes increase temperatures, modify precipitation, reduce cloud cover, and increase wind speeds	*Great Plains and Eastern US*: Hoell et al. (2020); Ford and Labosier (2017) *US*: Otkin et al. (2018); Christian et al. (2019); Pendergrass et al. (2020) *Global*: Hoffmann et al. (2021)	Recent example not within the Colorado River Basin
			A combination of more moisture and		July 2021 was the wettest month on

(continued)

Projected Trends in Water-Management Related Extremes

- Heat events are likely to increase in frequency, magnitude and intensity
- Snowpack volumes expected to continue to diminish, timing of melt earlier
- Long-term drying associated with higher temperatures expected to continue
- Large forest fires expected to increase
- Sudden wet/dry transitions – wet system shocks will increase but multiple mechanisms
- Monsoons less reliable, potentially more extreme

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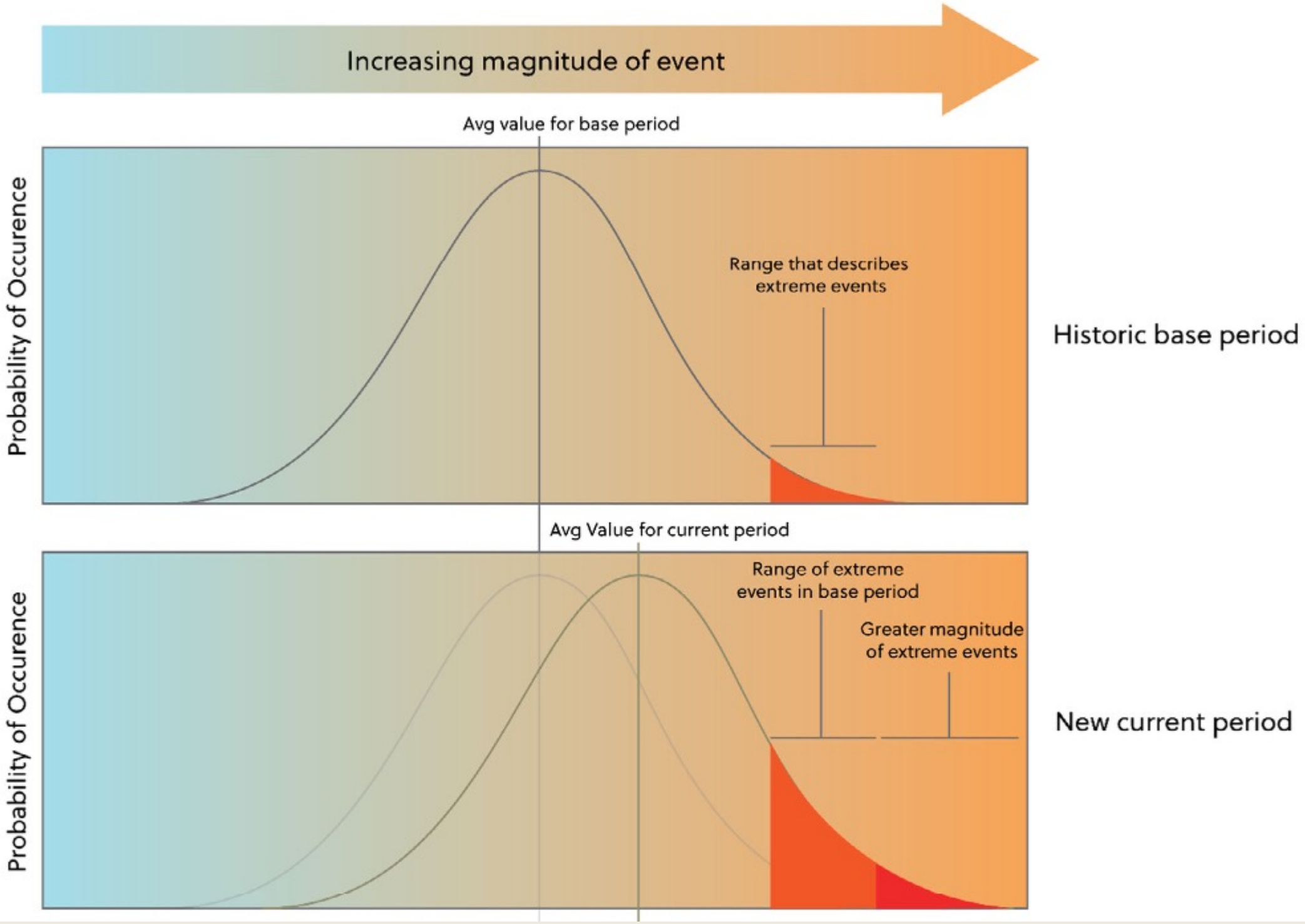

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