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A Review of Resilience and Long-Term Planning in Power and Water Systems in the United States

August 2024

Sarah C Reynolds[1]
Yael R Glazer[1]
Konstantinos Oikonomou[2]
Juliet Homer[2]
Michael E Webber[1]

U.S. DEPARTMENT OF ENERGY

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[1] The University of Texas at Austin, Austin, Texas
[2] Pacific Northwest National Laboratory, Richland, Washington

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Richland, Washington 99354

Abstract

There is recognition among power and water utilities that the frequency and magnitude of high consequence and low probability events could increase as a result of climate change. The interconnected nature of energy–water systems raises the possibility of cascading failures, increasing complexity and risks. Building resilience and making long-term plans are important ways of weathering the effects of climate change. First, to understand more about resilience, we reviewed existing literature on resilience definitions, metrics, and modeling, focusing on integrated water–power systems. Second, to understand how resilience and planning are being applied in practice, we interviewed utilities and organized, curated, and synthesized the interview data to arrive at several key findings. We found that there is not a consistent definition for resilience, yet it is something that utilities regularly plan for, often with different names and varying methods/measures. However, there is a tangible shift in the industry towards defining and determining measurable resilience metrics. While the exact metrics are a work in progress, utilities are taking steps forward by (1) putting people and culture at the center of resilience, (2) recognizing their own interdependencies, and (3) pursuing better cross-sector collaboration.

Acknowledgments

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- **Austin Energy (AE)**
  - Thomas J. Pierpoint, VP, Operations at Northern Virginia Electric Cooperative (NOVEC) (Formerly, VP, Electric System Engineering at Austin Energy)
- **Austin Water (AW)**
  - Helen Gerlach, Engineer A
- **City of St. Cloud, MN (St. Cloud)**
  - Liz Kramer, Public Services Analyst
  - Tracy Hodel, Public Services Director
- **City of Stevens Point, WI (Stevens Point)**
  - Joel Lemke, Director of Public Utilities and Transportation
- **Commonwealth Edison (ComEd)**
  - Pat Arns, Engineering and Smart Grid Team Lead
- **CPS Energy**
  - Richard Medina, EVP of Energy Delivery Services
- **Eugene Water and Electric Board (EWEB)**
  - Matthew Schroettnig, Director of Operations & General Counsel at Northwest Requirements Utilities (Formerly, Power Planning Supervisor & Staff Counsel at EWEB)
- **Great Lakes Water Authority (GLWA)**
  - John Norton, Director of Research and Innovation
- **Hawaiian Electric (HECO)**
  - Kahikina Burgess, Supervising Resilience Strategist
- **Las Vegas Valley Water District (LVVWD)**
  - Corey Ross, Emergency Management Coordinator
- **Los Angeles Department of Water and Power (LADWP)**
  - Jonathan Leung, Deputy Director of Water Quality
- **New York Power Authority (NYPA)**

- Adrienne Lotto, Senior Vice President of Grid Security, Technical & Operations Services at American Public Power Association (APPA) (Formerly, Chief Risk and Resiliency Officer at NYPA)
- Andrew O’Neil, Resilience Preparedness Program Manager
- Thomas Savin, Director, Resiliency Programs and Strategy

- **San Antonio Water System (SAWS)**
  - Alissa Lockett, Senior Director, Production & Treatment Operations

Acronyms and Abbreviations

AE	Austin Energy
AW	Austin Water
CAIDI	customer average interruption duration index
CELID	customers experiencing long interruption durations
ComEd	Commonwealth Edison
EWEB	Eugene Water and Electric Board
GLWA	Great Lakes Water Authority
HECO	Hawaiian Electric
ICS	incident command structure
IEEE	Institute of Electrical and Electronics Engineers
IRP	integrated resource plan
IT	information technology
LADWP	Los Angeles Department of Water and Power
LVVWD	Las Vegas Valley Water District
NYPA	New York Power Authority
QCC	qualifying capacity contribution
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SAWS	San Antonio Water System
St. Cloud	City of St. Cloud
Stevens Point	City of Stevens Point
WARN	Water/Wastewater Agency Response Network

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1.0 Introduction

The Earth is getting warmer; from 1901 to 2022, the global average temperature rose by 1.872°F (1.04°C) (NCEI 2024). Some of this increase is due to natural climactic variation from influences such as volcanic emissions, solar radiation output, and the Earth's orbit, but much of it is due to human influences such as greenhouse gas emissions, aerosols, and land coverage (USGCRP 2018). A warmer world not only brings higher average temperatures but also a change in weather patterns, a relationship that attribution science seeks to elucidate (Clarke et al. 2022). Studies have found that the frequency and intensity of weather events, including precipitation extremes, drought, and tropical cyclones, have generally increased (Clarke et al. 2022; Fischer and Knutti 2015; O'Gorman 2015; USGCRP 2018), and these events can lead to additional impacts such as flooding, landslides, and, in combination with extreme heat waves, wildfires.

Changes in the frequency and severity of weather events have both financial and social equity implications. Since 1980, "the U.S. [in particular] has sustained 310 weather and climate disasters where the overall damage costs reached or exceeded $1 billion. The cumulative cost for these 310 events exceeds $2.15 trillion" (Smith 2022). In 2021 alone, the United States experienced 20 different billion-dollar events totaling $145 billion in damages (Smith 2022), which is consistent with the overall trends of increasing frequency and cost of such events. The number of deaths associated with these events in 2021 was at least 688 (Smith 2022), but not all populations are impacted equally. "Along with poverty, social isolation, and minority ethnicity, age is a characteristic that contributes to being most vulnerable to climate extremes" (Yang et al. 2021). This unequal susceptibility to the impacts of climate change is sometimes referred to as the "green divide" and is further perpetuated by omitting equity considerations from climate action plans or placing them second to economic or environmental considerations (Schrock et al. 2015).

Given the aforementioned impacts of climate change, it is advisable to prepare for the weather of the future rather than the weather of the past and to do so in an economic and socially equitable manner. Though this preparation is critical for many entities, our work focuses exclusively on water and power utilities, who face the dual challenge of aging infrastructure and the need to keep services online. It specifically addresses how these utilities in the United States are using resilience building and long-term planning to weather the effects of climate change.

Previous work on resilience is mostly limited to an academic scope, focusing on theoretical approaches to defining, modeling, and measuring resilience through quantifiable metrics. These definitions, models, and metrics are academic exercises that do not necessarily consider what is done in industry or what is practicable. Our work seeks to address this knowledge gap by drawing on direct input from industry, obtained through interviews that included questions that were informed by a comprehensive literature review. This article is intended to highlight the key findings from these interviews. These findings have particular relevance in the wake of recent weather events such as the 2021 Texas winter storm, 2022 Winter Storm Elliott, and the 2023 Maui wildfires. They are also relevant given the recent passing of the Infrastructure Investment and Jobs Act in the United States, which allots over $50 billion towards infrastructure investments to improve resilience, including the resilience of the grid and water systems (The White House n.d.).

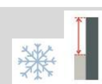
2.0 Methods

Our principal research method was interviewing planners or other experts at utilities in the power and water sectors, whom we contacted via email. Utilities were chosen based on their geographic locations and sizes to gather diverse conditions and viewpoints. The interviewees hold various titles such as director, executive vice president, and strategist, but, across the board, they were people in their organizations who could offer expertise and experience on resilience and long-term planning. In total, we interviewed professionals from 13 utilities across 10 states with customers ranging from 1,000 to 4.2 million and with a similarly broad range of service area sizes. Figure 1 visually depicts the geographic spread of the utilities we interviewed, and Table 1 provides more detailed information about these utilities. Moreover, the last column in Table 1 highlights the main threats that interviewees are worried about and planning for because of climate change.

Figure 1. Map of the United States that depicts the locations of the utilities interviewed.

Table 1. Overview of the information for each utility interviewed. We distinguish between meters and people for "Customers" because there can be more than one person per meter.

Utility Name	Location	System Type(s)	Service Area	Customers M = Meters & P = People	Main Threats[(a)]
Austin Energy (AE)	Austin, TX	Power generation, transmission, and distribution	450 sq. mi.	M: 535,000 P: 1,500,000	
Austin Water (AW)	Austin, TX	Water/wastewater treatment and distribution	548 sq. mi.	P: >1,000,000	

Utility Name	Location	System Type(s)	Service Area	Customers M = Meters & P = People	Main Threats[(a)]
City of St. Cloud (St. Cloud)	St. Cloud, MN	Power, water, gas, and heat systems	41 sq. mi.	P: 60,000 (water) P: 120,000 (wastewater)	
City of Stevens Point (Stevens Point)	Stevens Point, WI	Water and heat systems	8 sq. mi.	P: 40,000	
Commonwealth Edison (ComEd)	Chicago, IL	Power transmission and distribution	11,494 sq. mi.	M: 4,100,000	
CPS Energy	San Antonio, TX	Power generation, transmission, and distribution & natural gas distribution	1,500 sq. mi.	M: 907,526 (electric) M: 373,988 (natural gas)	
Eugene Water and Electric Board (EWEB)	Eugene, OR	Power and water systems	236 sq. mi.	M: 97,192 P: 380,532	
Great Lakes Water Authority (GLWA)	Detroit, MI	Water/wastewater treatment and distribution	1,698 sq. mi.	P: 4,200,000 (water) P: 3,100,000 (wastewater)	
Hawaiian Electric (HECO)	Honolulu, HI	Power generation, transmission, and distribution	3,000 mi. of transmission & distribution lines	M: 470,612	
Las Vegas Valley Water District (LVVWD)	Las Vegas, NV	Water treatment and distribution	500 sq. mi.	P: 2,200,000	
Los Angeles Department of Water and Power (LADWP)	Los Angeles, CA	Power and water systems	462 sq. mi.	P: 4,000,000	
New York Power Authority (NYPA)	White Plains, NY	Power generation and transmission	1,400 mi. of transmission lines	M: >1,000	
San Antonio Water System (SAWS)	San Antonio, TX	Water/wastewater treatment and distribution	929 sq. mi. (water) 854 sq. mi. (wastewater)	M: 600,000 P: 2,000,000	

(a) Legend for the icons: drought, earthquake, wildfire, change in precipitation patterns, climate migration, flooding, insufficient generation to meet demand, hurricane, rising sea level, heat, ice, wind, lightning, tsunami, volcanic eruption

Appendix A gives the questionnaire that was used to conduct the interviews. The questionnaire was subdivided into our two main areas of focus, resilience and long-term planning, with cross-sector integration overlapping both areas. The first questions pertained to the type of system and the size of the service area to ensure reasonable distribution and breadth among interviewees. The remainder of the questions—namely, those in the resilience and long-term planning sections—stemmed from our findings in the literature review. After the interviews, we reviewed, curated, and synthesized our notes into the results discussed in Section 3.0.

Despite the efforts taken to be comprehensive, there are inherent limitations to our method. For one, our scope is still somewhat narrow. Of the utilities we spoke to, more were power only (38.5%) or water only (38.5%) than were both power and water (23%). We also spoke with more large utilities than small ones; for example, 8 out of 13 utilities serve over 1 million people. Additionally, portions of the United States—for instance, the Southeast—were not represented among the interviewees. Interviews are dependent on availability, and as such, we could only interview those who were able and willing to speak with us. We also typically interviewed one person per utility, which meant that the answers reflected the perspective of one person employed at their utility rather than that of a collective. The individual answers may be aligned with those of the collective, but we cannot be certain without interviewing more people from the same utility. Finally, the method of interviewing is itself qualitative, meaning that there is more room for unintentional subjectivity as compared to quantitative, data-driven methods. Nevertheless, the interviews are illuminating, as they provide a window into industry that the literature currently lacks as well as some useful and actionable insights that might be relevant for other utilities.

3.0 Results and Discussion

The interviewees' responses about resilience, long-term planning, and cross-sector integration can be condensed into five key takeaways, which will be elaborated upon in the following subsections.

3.1 In Practice, There Is Not a Standard Definition for Resilience nor Are There Standard Resilience Metrics

There was not a consistent definition for resilience among the interviewees. The general ideas and premises around resilience—for instance, continuity of service and the ability to prepare, adapt, withstand, and recover from challenges—were somewhat consistent across utilities, but the language was not unified. Additionally, the terms reliability, risk, and vulnerability are commonly conflated with resilience. Some utilities said resilience and reliability can mean the same thing depending on the context and perspective, but many agreed that reliability is distinguished from resilience based on timeline and scenario. Reliability is concerned with routine, day-to-day operations and automatic recovery from outages under blue-sky conditions (i.e., not experiencing a weather, cyber, emergency, or other type of event), whereas resilience deals with specific incidents that are of low probability and high consequence. Risk and vulnerability, on the other hand, are lenses used to prioritize resilience.

Without a formal definition for resilience or a resilience event, determining appropriate, quantifiable metrics for resilience is difficult. Consequently, resilience metrics lack formalization and standardization, something that was also found in the literature review. Interviewees described that the metrics are in an awkward period of uncertainty and development as questions arise around what the metrics should be and what metrics are actually important. In the meantime, reliability or other metrics, such as those given in Table 2, are currently used as proxies for resilience metrics, which, as one utility pointed out, poses a challenge for driving investments because of the uncertainty around what to invest in and how much. Moreover, as resilience metrics are developed, they will depend on the event the utility is trying to plan for, an event that is location-dependent and has unknown frequency and severity. Nevertheless, it is clear from the interviews that resilience has always been planned for, albeit indirectly because of the varied definitions and lack of codification.

Table 2. Metrics that interviewees use to quantify resilience in response to question 4.a.ii in Appendix A.

Utility Name	System Type(s)	Metrics
AE	Power generation, transmission, and distribution	Customer average interruption duration index (CAIDI), system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI)
AW	Water/wastewater treatment and distribution	Percentage of volume of water needs met during the worst 12 months of drought under various hydrologic scenarios, percentage of time water needs were met during the period of record for various hydrologic scenarios, unit cost expressed as a present value sum of all costs over the life cycle, social equity and environmental justice score, external funding score, ecosystem impact score, multiple benefits score, local economy score, minimized risk score, maximized local control/local resources score
St. Cloud	Power, water, gas, and heat systems	Flow, production, potential energy growth going into digesters, number of kilowatt-hours purchased in order to complete wastewater treatment, volume of water treated

Utility Name	System Type(s)	Metrics
Stevens Point	Water and heat systems	Flow, production, phosphorus level of water, pH level of water, number of staff, number of staff fully trained
ComEd	Power transmission and distribution	Amount of corrective maintenance, performance of system relative to the size of the storm that affected the system, amount of flexibility in the system, customers experiencing long interruption durations (CELID), CAIDI, SAIDI, SAIFI
CPS Energy	Power generation, transmission, and distribution & natural gas distribution	CAIDI, SAIDI, SAIFI
EWEB	Power and water systems	Qualifying capacity contribution (QCC), SAIDI, SAIFI
GLWA	Water/wastewater treatment and distribution	Number of failures per mile of pipe, number of inspections per mile of pipe, turbidity of water
HECO	Power generation, transmission, and distribution	CAIDI, SAIDI, SAIFI
LVVWD	Water treatment and distribution	Size of outage, number of people affected by outage, number of lives lost due to outage
LADWP	Power and water systems	Percentage of overall infrastructure by category impacted, number of services lost, percentage of customers with interruption of services, amount of financial damage or restoration costs (in dollars)
NYPA	Power generation and transmission	Number of information technology (IT) disaster recovery tests, number of crisis management and business continuity plan exercises, number of risk assessments completed, percentage of business controls linked to risk records, efficiency of risk mitigation through the application of a control or a risk treatment, optimization of a risk management module
SAWS	Water/wastewater treatment and distribution	Number of customers experiencing outages, percentage of service area affected by an emergency

3.2 People and Culture Are at the Center of Resilience

If metrics are the hard side of resilience, culture is the soft side. Utilities mentioned that they need their employees and stakeholders to buy into the importance of resilience and investing in resilience while managing the costs to customers. One utility does this through education and outreach in its community, but among the utilities interviewed, the most prevalent way is long-term plans. In one utility's words, these plans socialize what is most important to the utility so that everyone within the organization is working towards the same objective. This socialization also ensures continuity within the workforce via transfer of knowledge during succession, which was stated to be important for organizational resilience. Plans also provide transparency to stakeholders, and many utilities are engaging them in their planning processes via stakeholder input groups. Utilities believe this engagement is important because connecting with the community develops rapport and a culture of trust, which in turn gives the community psychological security about continuity of services. It also provides a platform for populations more susceptible to service outages to be heard. One utility uses this feedback to focus its resilience efforts on more vulnerable communities, and another utility uses it to ensure that the community is positively impacted by its infrastructure—for instance, by an increase in social equity and environmental justice. However, utilities acknowledged that seeking and incorporating stakeholder input can be challenging. They do not want to introduce additional decision-makers, and some utilities ascribe to the belief that they are doing their jobs if the public does not know they are there.

3.3 There Is Poor Integration between Power and Water

Water relies on power, and power relies on water. For example, electricity is required to power the pumps and equipment needed for wastewater treatment, and treated water is required for power plant cooling and for generating steam to produce electricity. This interdependence is the water–energy nexus, but, despite their mutual reliance, utility modeling for the integrated planning of water and power systems is still nascent. Most utilities said that they account for the resilience of other systems when considering the resilience of their own systems, but one utility noted that the dependence may be somewhat unbalanced with water depending more on power than power on water. However, another utility acknowledged that the resilience functioning of their system requires inputs from other systems, and the resilience of their systems impacts the resilience of other systems. This interconnection points to the potential benefits of cross-sector awareness and planning.

From the power perspective, utilities mentioned that they look at water forecasts for hydroelectric power generation and collaborate with water utilities by receiving feedback through stakeholder input groups to feed into their planning. Some ways utilities implement the latter are by placing water infrastructure on circuits protected from load shed, identifying and addressing areas of vulnerability in the power supply for water, and installing backup generation for water infrastructure. From the water perspective, utilities mentioned that having backup generation (e.g., on-site generators, solar panels, biogas from anaerobic digestion, etc.) is critical given that power supply is a vulnerability, and they said that active communication between the water utilities and their corresponding power utilities is critical too.

However, some utilities said they did not account for the water–energy nexus. One utility said the issue is span of control. It is not practical for them to consider the resilience or investments of everyone connecting to their systems, and as such, they focus on what is within their immediate sphere of influence—namely, their own organization. For another utility, the issue is organizational siloing. Even in utilities where water and power are nominally linked, they are, in fact, organizationally separated. Consequently, the utilities noted that the information sharing needed for an integrated approach is lacking, and the managers' foci are on their areas of responsibility. That being said, one utility acknowledged that managers may also lack understanding of the interdependencies that need to be considered and the value of an integrated approach. Nonetheless, in resilience situations, these two systems are both critical for the well-being of communities, and cascading impacts can be significant. This was manifested in the outcomes of the 2021 Texas winter storm where load shed caused power outages for municipal water systems, which were unable to treat and distribute water if they did not have backup power available (Busby et al. 2021; Glazer et al. 2021). Acknowledging the interconnections between power and water is a first step in building cross-sector awareness as well as addressing and overcoming the challenges of integrated planning.

3.4 There Is Greater Collaboration between Utilities Looking to Further Their Shared Interests

There is growing awareness among utilities around acknowledging the signs of change, which point to the expectation that the weather events that they are concerned about and have been planning for, which are given in Table 1, will become more likely and/or frequent as result of climate change. While climate change remains a difficult and controversial topic, one utility noted that people cannot deny what the data show and the potential impacts of extreme weather events on their systems. Another utility stated that, because of this expectation regarding weather, utilities recognize that using historical data to forecast the future is increasingly less helpful and that the situation can get worse than the existing worst-case scenarios. This recognition, as one utility pointed out, is the crucial first step needed to avoid repeated errors. Nevertheless, planning for the weather of the future is inherently challenging because of the uncertainty and frequent inaccuracy of predictions, and in some instances, good predictions do not exist for certain locations and types of events, which was the case for one utility.

This challenge lends itself to a pooling together of funds and ideas to respond to potential risks, and utilities mentioned that they do this in multiple ways. Some utilities are looking to give and receive help from their neighbors by joining coalitions—for instance, the Water/Wastewater Agency Response Network (WARN)—that provide mutual aid following an emergency event. Other utilities are looking to partner with neighboring utilities to be assets that can provide water or electricity to bolster each other’s resource supply during an event, particularly if they are not both affected by this event. Neighbors can also motivate improvement via benchmarking. One utility mentioned that they look at utilities who are performing better than them in certain aspects and talk to them to help foster improvement through shared ideas. Performance is frequently judged by metrics, so these conversations offer utilities the opportunity to continue discussion around resilience metrics and exchange ideas on best practices. This information exchange is particularly important between those utilities who have not had a big event challenge their resilience plans, which was the case for most of the utilities interviewed, and those who have had a lot of real-world event experience. One utility mentioned that they collaborate internationally, using these conversations to temper the modeling of their own system.

3.5 Utilities Are Hoping for Standardization

Resilience is far from standardized in industry, and as mentioned in Section 3.1, the lack of a formal definition for resilience or a resilience event only contributes further to a lack of standardization. However, across the interviews, there was a perceived desire from water and power utilities for guidance and standardization around resilience, particularly resilience metrics. For example, power utilities mentioned that they are waiting for top-down guidance on resilience from government and trade organizations such as the Institute of Electrical and Electronics Engineers (IEEE). IEEE is currently working on defining resilience metrics by receiving feedback through working groups, which provide utilities with the opportunity not only to stay abreast of the progress but also to contribute to it. Regardless of its source, this standardization would support utilities’ comfort with innovation, regulatory backing, and cost recovery. It also could potentially enable benchmarking as described in Section 3.4 and ensure consistency across the industry. This consistency is especially important for interconnected systems because, as one utility noted, a discontinuous approach in implementing resilience does not lead to a more resilient system overall.

4.0 Conclusion

As Section 3.0 demonstrates, resilience, long-term planning, and cross-sector integration are not straightforward. There are varied opinions about resilience and differing approaches to addressing resilience even within the same industry (i.e., power or water). This variability means there is much to glean from the interviews, but the results can be condensed to five key takeaways.

1. In practice, there is not a standard definition for resilience nor are there standard resilience metrics.
2. People and culture are at the center of resilience.
3. There is poor integration between power and water.
4. There is greater collaboration between utilities looking to further their shared interests.
5. Utilities are hoping for standardization.

These takeaways reflect a tangible shift in the industry towards defining and determining measurable resilience metrics. However, there is uncertainty around how to establish universal metrics when resilience pertains to particular events and is location dependent. Moreover, if it takes many years to develop resilience metrics, just as it did for reliability metrics, is this time horizon incongruous with the need to take swift action to address the impacts of climate change? We suggest that future work should look at these questions and recommend how to standardize/harmonize resilience across the power and water sectors in a timely fashion and in a way that recognizes the interdependencies between the two sectors. These recommendations will give utilities the guidance they need to evaluate the resilience of their systems and to implement resilient changes to their infrastructure before the weather of the future becomes the weather of the present.

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Appendix A – Interview Questionnaire

This is the questionnaire that we used to conduct each interview.

<u>OTHER QUESTIONS</u>

1. **How do you classify your system?**
   a. Note: multiple-choice question
      i. WDN/WDS = water distribution network/system
      ii. DDS = drainage distribution system (includes water treatment and wastewater treatment plants)
      iii. BPS - PDS = power transmission and distribution systems
      iv. GES = general engineering system (includes water, gas, transportation, etc.)
      v. PWS = power and water systems
      vi. PWGS = power, water, and gas systems
      vii. PWCS = power, water, and communication systems
      viii. PGHS = power, gas, and heat systems
2. **How large is your service area both in terms of area and population?**

<u>RESILIENCE QUESTIONS</u>

3. **How do you define resilience?**
   a. Example: "The ability of a system to maintain and adapt its operational performance in the face of failures and other adverse conditions."
   b. Subquestion
      i. How does resilience differ from or compare to reliability, risk, and vulnerability?
4. **Is resilience something you currently plan for?**
   a. IF SO
      i. What dimensions of resilience do you look at?
         (1) Note: multiple-choice question
            (a) *Technical* = "how well physical systems perform when subjected to events"
               (i) Example Metric: measurement of excess pressure
               (ii) Event = natural disaster, cyber-physical attack, electrical/mechanical/hydraulic failure, etc.
            (b) *Organizational* = "ability of organizations to respond to emergencies and carry out critical functions"
               (i) Example Metric: service disruption
            (c) *Social* = "capacity to reduce the negative societal consequences of loss of critical services in events"

(i) Example Metric: population of community displaced from homes due to water outage

(d) *Economic* = “ability to reduce the direct and indirect economic losses of the community resulting from events”

(i) Example Metric: loss of gross regional product

(2) Subquestion

(a) For technical resilience metrics, do you use surrogate metrics or actual system properties/parameters?

(i) Surrogate metrics = “measures that correlate to physical/hydraulic-based indices of resilience but are not necessarily based on physical indices whose parameters are either unavailable or are difficult to compute”

ii. What metrics do you use to quantify resilience?

(1) Examples: measurement of excess pressure, percent of nominal demand met, etc.

(2) Subquestions

(a) Are the metrics qualitative or quantitative?

(b) What do the metrics measure?

(i) Examples: *days* of interruption, *volume* of water, *cost* of interruption, etc.

(c) How do you apply these metrics to compute the resilience of your system? What inputs do you use?

iii. Do you account for the resilience of other systems (i.e., power or water) when you account for/measure the resilience of your system? Explain.

iv. Is resilience something that you have planned for in the past?

(1) IF SO

(a) When did you start planning for it?

(b) Has your definition of resilience and/or your metrics/indices for quantifying resilience changed over time?

(i) IF SO

1. What are some reasons that you attribute this to?

(ii) IF NOT

1. Do you see them changing in the future?

(c) Are you satisfied with your current methods for defining and measuring resilience?

v. How did a big event challenge your resilience plans?

(1) Examples: natural disaster (Winter Storm Uri, earthquake, hurricane, etc.); cyber-physical attack; electrical/mechanical/hydraulic failure; etc.

(2) Subquestion

(a) **Do you have an incident command structure (ICS) in place for such an event?**

b. IF NOT

i. **Should/will this change in the future?**

(1) Subquestion

(a) **What are some reasons this might change?**

ii. **Did a big event change your perspective on resilience planning?**

(1) Examples: natural disaster (Winter Storm Uri, earthquake, hurricane, etc.); cyber-physical attack; electrical/mechanical/hydraulic failure; etc.

(2) Subquestion

(a) **Do you have an ICS in place for such an event?**

LONG-TERM PLANNING QUESTIONS

5. **Do you have any long-term plans for your system?**

a. Example: integrated resource plans (IRPs)

b. IF SO

i. **Would we be able to look at them or get a high-level summary of their contents if we cannot view them directly?**

ii. **To what extent do you consider the other sector (i.e., power or water) in your long-term plans? More specifically, how far does the integration reach (i.e., within the organization, to external organizations, etc.)?**

iii. **What resources/tools have been the most helpful for constructing and implementing your plans?**

c. IF NOT

i. **What are some reasons that you attribute this to?**

ii. **What resources/tools do you think you would need to implement them?**

iii. **What would be some benefits and challenges you would anticipate having if you were to implement them?**

6. **What value do you see in having long-term plans?**

a. Examples: financial, reputation, etc.

7. **How prevalent do you think long-term planning is throughout the energy/electric utility industry? Explain.**

8. **Generally, in your long-term plans or otherwise, how are you planning for the weather of the future rather than the weather of the past given the effects of climate change?**

CLOSING QUESTION

9. **Is there anything else that you think we should know or should be considering?**

Pacific Northwest
National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

www.pnnl.gov