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Assessing Historical Extreme Weather Event Impacts

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Overview

Resilience planning, particularly energy and water resilience planning, has been a key priority for the federal government for many years, leading federal agencies to develop processes for identifying and addressing critical resilience gaps at their facilities and sites. Furthermore, recent federal policy[1] is driving agencies to prioritize climate change impacts as a more central component of their resilience planning efforts. To achieve this, federal sites must understand their vulnerability to climate change, which involves identifying climate hazards projected to impact the site (known as *exposure*), as well as understanding the *sensitivity* (the degree to which a site, including its people and the things they value, could be harmed by that exposure), and *adaptive capacity* of the site (the degree to which the site could lessen bathe potential for harm by taking action to reduce exposure and sensitivity). To assess and understand sensitivity and adaptive capacity, it is important to first obtain a baseline and understand how a site has been impacted by past events, in addition to considering the potential for unprecedented impacts based on climate projections.[2] This information paper highlights current limitations for developing event history assessments and suggests a framework for more consistently capturing key data points. The purpose of this paper is to help inform how organizations could begin structuring a comprehensive process for recording the impacts of extreme weather events in order to facilitate climate vulnerability assessments, and thus, resilience planning.

Where to find past event data if you are just beginning the process

While it is a good idea to begin establishing a record of impacts of extreme weather events within the site of interest, when starting, a site will likely rely more heavily on external sources to locate information on past events. Although high-resolution information on extreme weather event impacts may be limited, there are a few notable open-source databases and tools available that can be used to find information on the occurrence of past weather events and outages, which, coupled with staff institutional knowledge can shed light on past impacts for a site. The following is a list of a few authoritative sources that can be used to get started. This is not an exhaustive list.

- The National Oceanic and Atmospheric Administration's (NOAA's) Storm Events Database contains records for states, territories, and other selected areas (e.g., Lake Michigan) in the United States, on the occurrence of storms and other significant weather phenomena with sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption of commerce.

[1] Such as Executive Order (EO) 14008, Tackling the Climate Crisis at Home and Abroad (January 27, 2021).
[2] A site could be sensitive to events that it has never experienced before. Thus, while assessing impacts of past events is essential and is the primary focus of this paper, it is also necessary for a site to consider unprecedented impacts based on climate change projections for the region where the site is located.

- NOAA National Centers for Environmental Information's (NCEI's) "Billion-Dollar Weather and Climate Disasters" is a web resource that contains weather and climate events that have had the greatest economic impact from 1980 to 2024. It is updated on a yearly basis.
- Department of Energy's (DOE's) EAGLE-I is a geographic information system (GIS), data visualization, and situational awareness platform created to monitor electric utility customer outages from data gathered from public sources. It reports electricity service outages at 15-minute intervals for 3,044 out of 3,226 counties and county equivalents by 2022, starting with 2,152 in 2014.

Background

Understanding how past extreme weather events have affected a site is an integral part of site-level resilience planning. For example, the DOE Vulnerability Assessment and Resilience Planning (VARP) Guidance requires sites to evaluate historical weather data along with climate projections to identify possible future climate risks (Department of Energy [DOE] 2022). In the case of the VARP, sites must provide the past event type and date, a description of the event, and the financial impact of the event, such as estimated damage costs to equipment or work/production hours lost. This information is helpful to establish baseline impacts from natural hazards, such as operation and maintenance (O&M) costs. For example, it can be used as a baseline to develop customer damage functions and determine the potential costs of future damages. The information that a site collects on past extreme weather events can serve as inputs to tools such as Federal Energy Management Program's (FEMP's) Customer Damage Function (CDF) Calculator.[3]

Current practice for resilience planning is not standardized and gaps exist in the types of data collected and how the data is tracked and recorded (United States Government Accountability Office [GAO] 2017; Jones et al. 2004). Understanding how a site was impacted by past extreme weather events is usually dependent on the institutional knowledge of the current staff. While many sites collect facility or asset condition information as part of routine O&M procedures, these assessments seldom include information needed to inform decision-makers about a site's resilience to climate change (Department of Defense [DOD] 2016). In a 2016 study focused on assessing the use of event history analyses at the United States Naval Academy (USNA), researchers found that while USNA collected facility condition information such as system age and remaining useful life of an asset, they did not collect information on the root cause behind asset or system failures (e.g., assign responsibility to a specific type and severity of extreme weather event) which is useful for determining resilience gaps (Department of Defense [DOD] 2016). Where impact-related information is available, it is usually focused on monetary and near-term impacts, versus longer-term and harder-to-quantify effects of a disruptive event (e.g., strains on water resources and implications for future water withdrawals at a site).

[3] FEMP's CDF calculator helps determine potential costs of electric grid outages. The publicly available web tool allows organizations to create a baseline of outage risks, quantify the potential benefits of resilience investments, as well as estimate the cost of inaction.

Event History Analysis

An analysis of the impacts from past extreme weather events, or event history analysis, can help gain a better understanding of the existing resilience gaps exist at a site and potential solutions that can help. In general, an event history analysis is a longitudinal record of the timing, severity, and impact of events. Event history analyses can shed light on existing resources that sites have at their disposal to contend with future changes as well as any existing interdependencies. For example, to understand the impacts of drought, Jones et al. (2004) suggest gathering a narrative history of past droughts and the responses to those droughts and matching that with rainfall records. By doing so, they suggest, it is possible to construct a more complete picture of climate-society relationships that can then be assessed under conditions where both climate and society may change. Event history analyses help in painting a picture of potential future impacts under various climate scenarios, as well as help in understanding the costs of those impacts. The findings from the aforementioned 2016 USNA study suggest that information from an event history database can be used to develop damage response curves specific to a site to help estimate the future costs of impacts (Department of Defense [DOD] 2016). Thus, having a consistent process for tracking the impacts of extreme weather events is essential for performing event history analyses. It is also important to note that the longer a site maintains an event history, the more useful that information becomes. For example, some extreme weather events are less frequent but can have a larger impact than events that may have been observed within the past decade. Therefore, it is beneficial to collect and maintain data on all events, regardless of frequency, to better inform future resilience planning.

Challenges

While, conceptually, maintaining an event history is straightforward, there are several challenges to implementing one in practice. Furthermore, there is no consistent guidance published that describes what, when, and how to document extreme weather event impacts. Two of the largest decisions that sites contend with when determining a process for assessing damages from extreme weather events is how to categorize the multitude of potential hazards and impacts, and how to estimate (quantify) those impacts. For example, following a Category 4 hurricane, a site may experience equipment failure at several locations. While the initiating event is a hurricane, a planner responsible for developing resilience solutions to prevent similar impacts in the future would seek detailed data pertaining to the specific causes behind the observed damages and their locations. For instance, the planner will want to know which part of the observed equipment failure was a result of flooding at facilities A and B resulting from heavy rain, and which part of the failure can be attributed to a tree striking a power line near Facility C from heavy winds. Equipped with this information, the planner can then determine that one plausible solution can involve relocating certain equipment from Facility A and Facility B to locations at higher elevation, and another is to remove trees close to the power lines near Facility C. In other words, it is important to identify the exact root causes and locations of the impacts. The more information one knows about the cause(s) of a particular impact, the better one can identify current vulnerabilities and formulate adaptations to prevent similar impacts in the future.

The next two considerations are the various types of impacts and the estimation of the costs of those impacts. Doktycz and Abkowitz (2019) described three types of costs from extreme weather events: *direct tangible costs*, *indirect tangible costs*, and *intangible costs*. Direct tangible costs occur as a direct result of the physical impact of the event, such as damage to infrastructure and property loss. In some cases, organizations include injuries and fatalities under this category, depending on whether the cost of human harm is considered a tangible or intangible cost due to the complexity in quantifying the event. Indirect tangible costs occur because of a direct impact. Examples of indirect tangible costs include business interruption, relocation costs, and disruptions to transportation. Intangible costs are those costs felt by society, but for which the accompanying loss and damage are difficult to value monetarily—examples include cultural impacts or impacts to health or well-being. The differences between each type of cost reflects the differences in the ease of (and subsequently, methods used for) cost estimation. For example, unlike direct cost approaches (e.g., using damage functions), indirect and intangible cost estimations commonly involve the use of surveys. Intangible costs are the most challenging to estimate. Doktycz and Abkowitz (2019) highlight the use of revealed preference methods (e.g., travel costs, cost of illness, and replacement cost) and stated preference methods (e.g., life satisfaction analysis) to estimate intangible costs.

Conceptualizing Hazards and Impacts

To implement a standardized approach for collecting information on extreme weather events, it is first necessary for sites to identify which impacts they would like to collect and prioritize. For example, most sites will want to prioritize collecting information on harm to personnel and infrastructure damages. Additionally, they may also want to explore capturing other information such as impacts to their workforce (e.g., absenteeism and business interruption). Figure 1 helps to illustrate an approach for identifying hazards and the impacts caused by them.

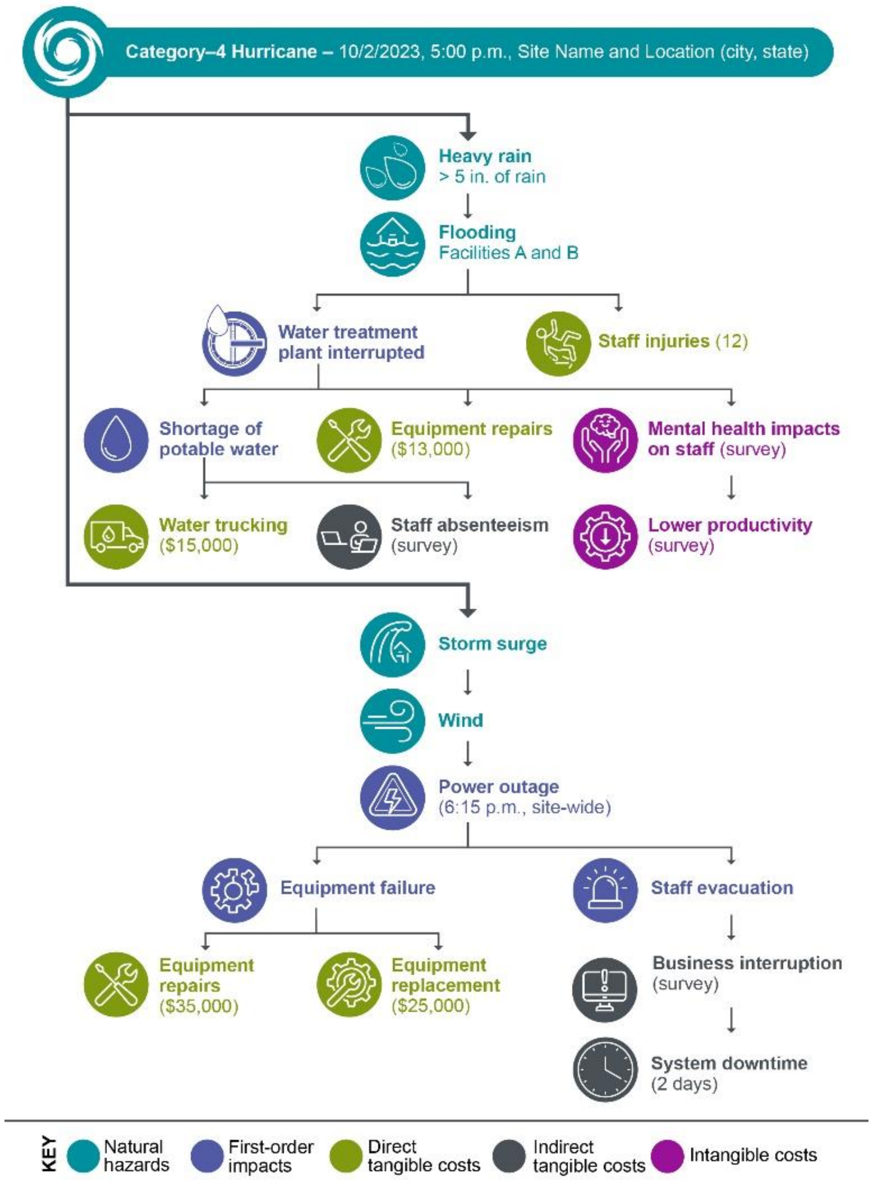

Figure 1. An example event history approach to an extreme weather event.

The tree diagram shows how both causes (hazards) and effects (impacts) can be broken down to provide finer levels of detail that can better inform decision-making for resilience planning. The top tier of the figure represents a hypothetical primary hazard (hurricane) broken down into more specific secondary and tertiary hazards. This exercise helps to pinpoint the exact causes and locations of each impact. The second tier (in purple) provides information on first order impacts, such as power outages and water treatment plant interruptions. These impacts are useful to track, but do not provide information on the actual costs of restoration and repair at the site.[4] The impacts are further broken down into second-order impacts to show direct (in green) or indirect (in gray) tangible costs and intangible costs (in pink).

[4] Note that "costs" is used here to refer to the loss or damage resulting from an impact more broadly—not just monetary costs.

For example, the cost of equipment repairs and the number of injuries are direct tangible costs (in green), while interruption to operations from staff absenteeism and mental health impacts on staff represent indirect tangible costs (in gray) and intangible costs, respectively (in pink). Where applicable, identifying the geographical location in the site (e.g., at Facility A) and severity of the hazard or impact (e.g., more than 5 in. of rain) makes the data comprehensive and useful for future resilience planning endeavors.

Conclusion and Additional Research Opportunities

Federal agencies must understand the vulnerabilities to climate change for each of their facilities, which includes understanding the site-specific sensitivities to extreme hazards and the capacity of the site to cope with any resulting impacts. Assessing the impacts caused by past extreme weather events is essential for site-level resilience planning and a standardized approach, such as an event history database, is recommended as an effective resilience-planning tool. An event history analysis relies on a consistent approach to data collection and recordation to understand how a site has been impacted from past extreme weather events. The process is multifaceted and should capture the timing, severity, and root cause(s) of an event.

While some information on impacts is readily available following an event, other data requires time to assess. For instance, understanding the costs associated with equipment failure, restoration or replacement requires adequate time to conduct sequential activities, such as: (1) an on-site assessment, (2) a repair estimate, (3) procurement, and (4) implementation. Ideally, event histories can be incorporated into existing record keeping systems, such as data sources that the site uses for capital planning and facility condition assessments.

A complete event history analysis records not only the monetary impacts, but also the qualitative and indirect costs from the event. For example, mental health or general health of staff may be indirectly affected by extreme weather events. However, it is difficult to measure the impacts from extreme events on mental health because mental health issues often have existing underlying and unrelated factors, rendering attribution to extreme weather events extremely challenging to assess. One Intergovernmental Panel on Climate Change (IPCC) report concludes that “indirect health impacts are therefore a potentially large but underexamined outcome of extreme weather events that lead to a substantial underestimation of the total health burden” (IPCC 2018). *Compound events*, or the combination of multiple drivers and/or hazards that contributes to societal or environmental risk (IPCC 2023) are not individually considered an extreme event, but together can result in large impacts akin to a single extreme event if occurring simultaneously or successively. As a result of their relative smaller size and severity, compound events are also difficult to track.

Assessing climate hazards accurately is complex and relies on collecting, organizing, and analyzing varying data types to inform decisions for resilience planning. As climate change continues to drive extreme events, the ability to accurately track and record these hazards becomes crucial. Other organizations such as the United Nations Office for Disaster Risk Reduction are starting to develop standardized methods for tracking disaster losses and damages (United Nations Office for Disaster Risk

Reduction [UNDRR] n.d.). These tools may provide value to the federal government in developing its own tracking system. In addition, emerging technologies could assist with addressing some of the challenges associated with tracking impacts from extreme weather events. For example, the evolution of artificial intelligence (AI) may provide a future tool for agencies to consider as AI could allow for automated hazard assessments and event history analyses. A standardized approach to capturing the costs and impacts of extreme weather events is a challenge that many, including groups outside of the federal government, will need to contend with, revealing the benefit of collaboration and knowledge-sharing across different organizations.

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