California State University
Climate Resiliency Framework

Photo Credit – Russell McArthur, Dept. of Earth and Climate Sciences, SFSU. September 2020.

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Foreword

This document is intended to be part of the planning process for any California State University campus undertaking a significant infrastructure project. It is important to note that the document can be used by any of the multidisciplinary partners typically involved in a project, such as the Affinity Groups, including facilities and energy managers, engineers, architects, campus planners, and others. For clarity, from here on out, any employee using this document will be referred to as the "campus". When a CSU campus is evaluating a replacement, repair, or improvement of any infrastructure system, it is the intention that they can review this document to identify specific climate hazards, vulnerabilities, and risks relevant to their campus and then choose particular mitigation strategies in response. Additionally, if a CSU campus or the CSU system is undergoing a capital expense planning process, they can review this framework to identify climate-related vulnerabilities and prioritize the actions needed to increase their resilience.

As the severity of climate change continues to increase and affect campus operations, including this additional step in the planning process is crucial. Evaluating resilience as an engineering consideration has become just as vital a performance indicator as operational energy usage, utility cost, and other more conventional metrics. Critically evaluating systems for resilience improvements will ensure safety for students, faculty, staff, and surrounding communities, and it will improve business continuity during extreme climate events.

For a brief introduction on how to use this document, Chapter 1 identifies climate hazards relevant to different geographies of California and how climate change exacerbates these hazards. Chapter 2 highlights the resilience planning framework that campuses can use when evaluating how to respond to their identified climate hazards from Chapter 1. Chapter 3 briefly describes strategies campuses can execute to mitigate their identified, relevant hazards. A campus can progress through the document to identify specific climate hazards (Chapter 1), how the hazards affect the campus and its critical operations (Chapter 2), and what actions the campus can take to increase the resilience of its infrastructure systems (Chapter 3).

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CHAPTER 1: Introduction and Climate Hazards

1.1 Introduction

Climate change is expected to increase the frequency and intensity of extreme weather events and natural disasters in California. The California State University system, with its diverse campuses spread across the state, finds itself at the forefront of this evolving landscape of hazards. What were once considered exceptional and isolated events are now more common and severe, expanding beyond historical boundaries and challenging the resilience of the CSU system. The seven climate hazards to the right are currently the most threatening to California campus populations, communities, and infrastructure. The hazards, in order, are extreme heat, flooding, wildfires, poor air quality, power quality and capacity, energy demands, and water supply. This chapter will investigate each of these hazards, with the following chapters addressing planning and mitigation strategies for avoiding the worst effects of climate change on CSU campuses and communities.

It is critical to evaluate the most prominent climate hazards for a specific geographical area and how their impact risks may increase over time. This chapter outlines which specific regions are most affected by each risk and the hazard's impact on humans and infrastructure. Each hazard is also rated based on the probability of occurrence to the CSU system, as follows:

- **Highly Likely**: 76%-100% that the hazard would occur annually.
- **Likely**: 50%-75% that the hazard would occur annually.
- **Possible**: 11%-49% that the hazard would occur annually.
- **Unlikely**: 0%-10% that the hazard would occur annually.

A generalized summary showing the probability of the hazards investigated in this report is shown in **Table 1**. However, this summary shows the average risk. The risks vary from campus to campus and should be investigated in detail using the rest of Chapter 1. For more information on these climate hazards, please reference the 2021 Hazard Vulnerability Risk Assessment under the Resources tab, along with information on CSU's Emergency Management policies.

Additionally, the final section of this chapter addresses climate adaptation scenarios and provides resources for predicting future risks. These tools can be used to anticipate more severe conditions using projected future weather files. A campus can use these to update design standards so infrastructure systems will withstand anticipated storms, floods, wildfires, heat waves, and other natural disasters.

Later in this report, each infrastructure system is given its own information subsection. Each subsection contains information about how each hazard specifically impacts that infrastructure system. For example, while flooding is a threat to nearly all campus operations, it will affect an electrical distribution system differently from a stormwater drainage system. These differences are explored more fully in Chapter 3.

***Table 1**: Summary of Probability and Risk Impact by Climate Hazard*

Climate Hazard	Probability	Risk Impact
Extreme Heat	Highly Likely	Physical harm to humans and infrastructure.
Flooding	Likely	Physical harm to humans, lasting infrastructure damage, and significant disruption in operations.
Wildfires	Highly Likely	Physical harm to humans, lasting infrastructure damage, and significant disruption in operations.
Poor Air Quality	Likely	Causes moderate physical harm to humans.
Power Quality and Capacity	Likely	Disruption in operations and potential light damage to electrical infrastructure.
Energy Demands	Likely	Disruption in operations and potential light damage to electrical infrastructure.
Water Supply	Likely	Potential to disrupt operations.

1.2 Climate Hazards

Extreme Heat

Increasing temperatures pose a threat to human health. Extreme temperatures put people at higher risk for heat-related illnesses, such as dehydration, heat exhaustion, heat stroke, and in severe cases, death. Hazards from extreme heat are made worse when high temperatures are accompanied by high levels of humidity. Vulnerable populations- including youth, adults older than 65, athletes, outdoor workers, low-income households, and individuals with certain chronic medical conditions- are more prone to the effects of extreme heat.

The risk of power shut-offs due to extreme heat is also of concern to the CSU system. Utility alerts are a constant threat to campuses particularly during the summer when there is increased risk of brownouts, rotating outages, and full outages that strain the grid. In the event of a power outage, many campuses rely on inefficient backup diesel generators.

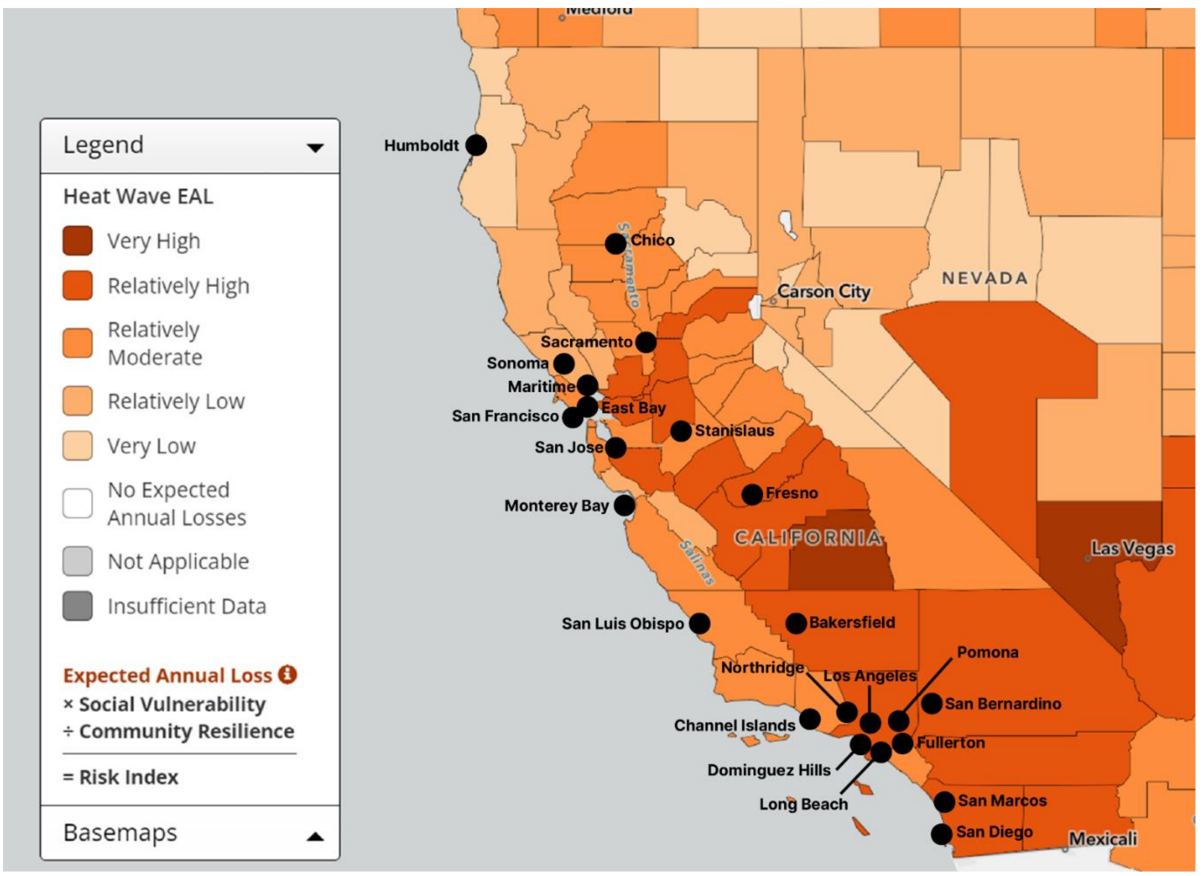

Figure 1: FEMA Heat Wave Risk Map[1]

Risk: Likelihood of extreme heat change causing harm.

Heat waves and extreme heat events are becoming increasingly more common in California. Preparing the CSU infrastructure to withstand the impacts of these extreme temperatures will be vital as they continue to intensify. Southern and urban-area campuses are already experiencing these impacts, while Northern and coastal campuses will be affected in the near future. Across all CSU campuses, extreme heat events have occurred annually for the past several years. Given that more than 26 extreme heat events have occurred over the past 15 years (1.7 events per year), it is **Highly Likely** that the hazard will occur annually.

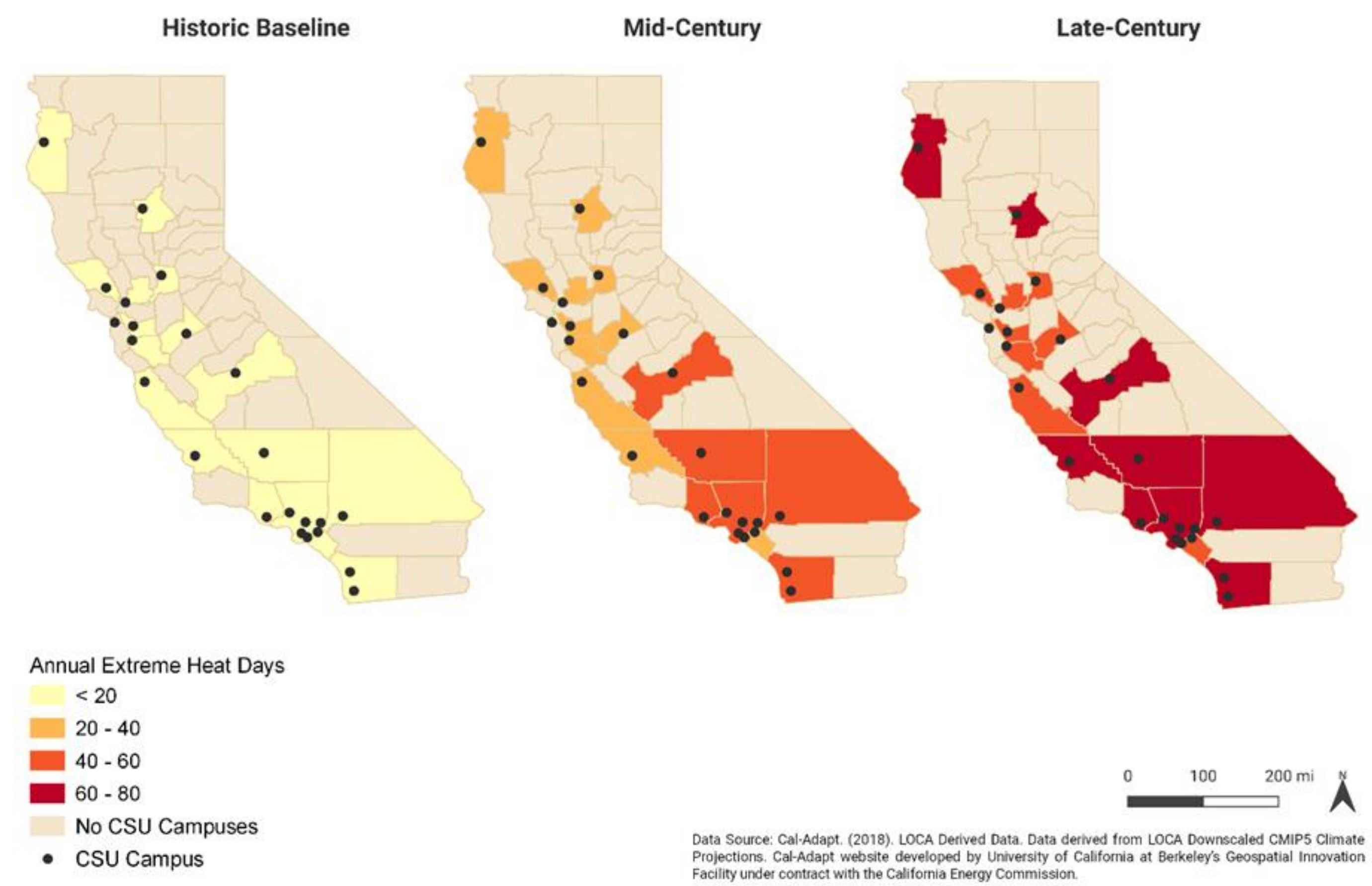

Figure 2: Trend in Annual Extreme Heat Days Across California Counties[2]

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[1] Map | National Risk Index (fema.gov)

[2] 2021 Hazard Vulnerability Risk Assessment. The California State University System

Flooding

The CSU system is at risk from flooding, which poses significant challenges to its campuses and nearby communities. Factors such as human behavior, social vulnerability, and changes in hydrology and land use contribute to the system's vulnerability to floods. Health impacts from flooding include waterborne illnesses, respiratory problems, and mental health issues, affecting vulnerable populations. Poor housing quality and limited finances increase vulnerability to flood risks.

Risk: The CSU system faces interconnected hazards, with floods, storms, and water quality issues being related. Major infrastructure damage can persist long after a flood event. These challenges affect the diverse CSU populations and their well-being, both on and off campuses. With annual rainfall and flooding expected to increase, the risk of flooding to the CSU campuses is ranked as **Likely**. A case study example of the flooding impacts to a CSU campus is summarized in **Figure 4**, **Figure 5**, and **Figure 6**.

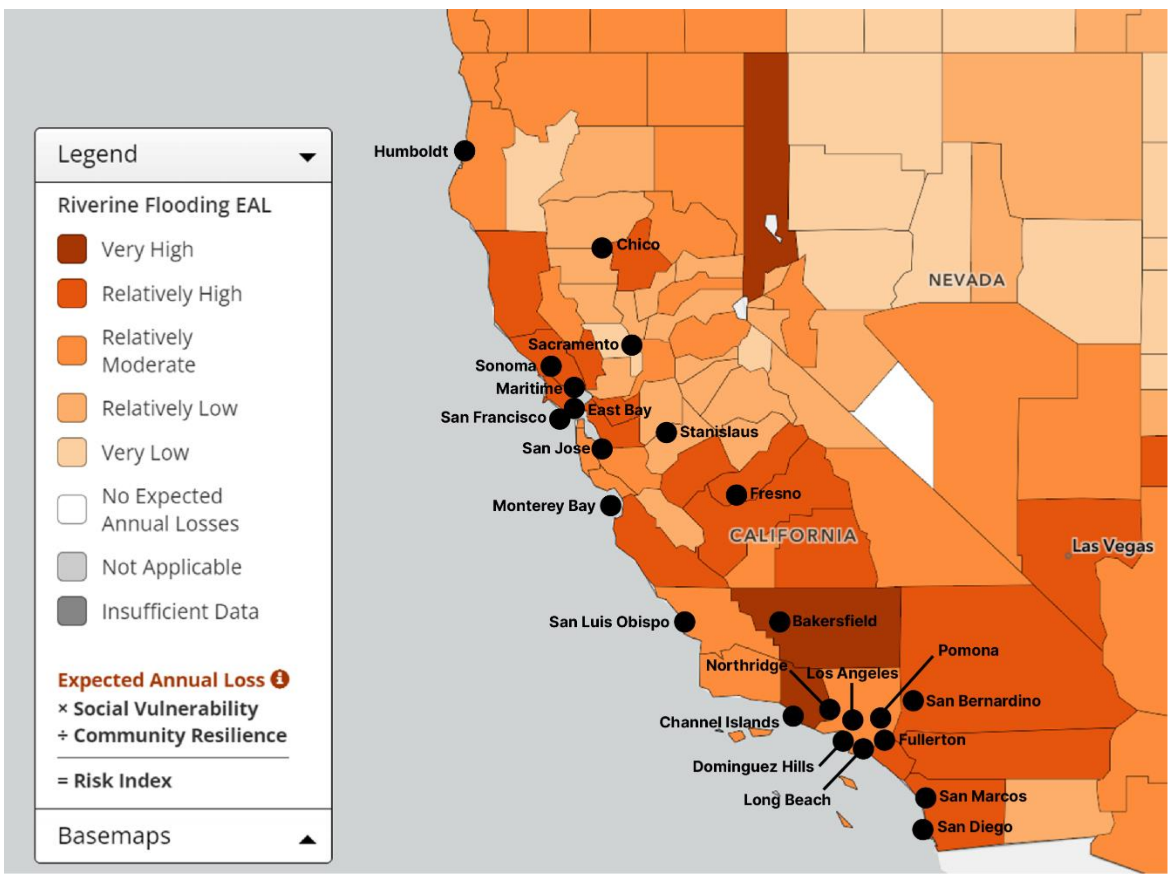

Figure 3: *FEMA Flooding Risk Map*[3]

CSU Impacts: In September 2022, Tropical Storm Kay caused flash flooding at CSU San Bernardino. Heavy rains produced flood waters that entered doorways of buildings located at or below ground level and caused the impacts in the following graphic. Additionally, photos of the damage are included below.

Figure 5: *Flooded Hallway at CSU San Bernardino*[4]

Figure 6: *Flooded Gym at CSU San Bernardino*

CSUSB 2022 Flooding Impacts

$20,200,000
in Total Damages

18
Flooded Buildings

225
Remediation Workers Working 24/7 Shifts

2
Days of Fully Halted Campus Operations
Departments Impacted for Multiple Weeks

Figure 4: *Summary of CSUSB 2023 Flooding Impacts*

[3] Map | National Risk Index (fema.gov)

[4] "CSUSB Flood Lessons Learned" Presentation

Wildfires

Wildfires in California are becoming more frequent and damaging due to severe weather, including high temperatures, low humidity, and strong winds. The State's development pressure on wildland areas has increased its risk of property loss and human health and safety from wildfires. Several CSU campuses are located in high to very high fire hazard zones, while others are susceptible to the effects of wildfire smoke.

Particulate matter in wildfire smoke is of significant concern for human health. These particles can be inhaled deep into the lungs, posing a risk to cardiovascular health. Wildfires also produce carbon monoxide, which can cause serious health effects and, at high concentrations in confined areas, death. Weather conditions, terrain, and other factors can alter concentrations of these pollutants throughout wildfire events.

Risk: Some of the largest wildfires in California's history have impacted CSU campuses in recent years. The Hill Fire in 2018 caused an evacuation of the Channel Islands campus. The Camp Fire, near Chico, affected Chico State students and employees and inundated the campus with harmful smoke. During the fall 2020 wildfire events, seven CSU campuses closed or curtailed activities due to smoke impacts and the fires damaged property at Swanton Pacific Ranch and the SSU preserve. Given the consistent distribution of high and very high severity zones from the north to the south of the State, it is reasonable to rank the annual probability of a wildfire occurrence within a CSU-based community as **Highly Likely**. A case study example of wildfire impacts to a CSU campus is summarized in **Figure 9**.

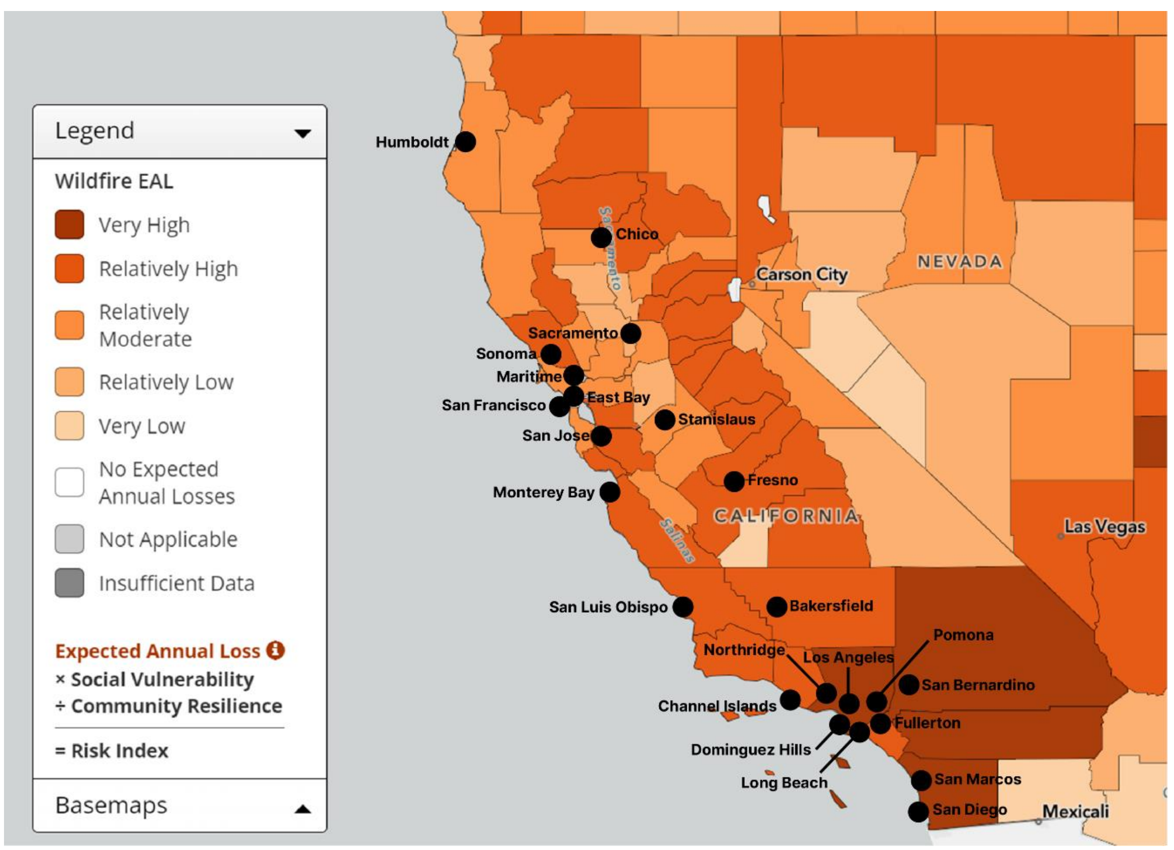

Figure 7: *FEMA Wildfire Risk Map*[5]

CSU Impacts: In November 2018, the deadliest and most destructive wildfire in California history, the Camp Fire, severely damaged CSU Chico, and Sacramento State University and closed nearly a dozen surrounding campuses due to poor air quality. By the time the fire was fully contained, after 17 days of active firefighting, the fire had destroyed more structures than California's next seven worst fires combined and caused 86 human fatalities.

Figure 8: *Camp fire smoke at CSU Chico*[6]

Figure 10: *Camp fire smoke at CSU Chico*

Camp Fire 2018 CSU Chico Impacts

300+
Faculty and Student Homes Destroyed

16
Days of Fully Halted Campus Operations

37
CSU Employees from Other Campuses Deployed to Assist

7
Other CSU Campuses Shut Down Due to Poor Air Quality

Figure 9: *Summary of Camp Fire 2018 CSU Impacts*

[5] [Map | National Risk Index (fema.gov)]

[6] [The Fires of 2018: What Happens Now? | CSU (calstate.edu), ,] (Jason Halley/University Photographer/CSU Chico)

Poor Air Quality

Poor air quality poses significant health risks to individuals. Exposure to pollutants in the air, such as particulate matter and toxic gases, can lead to respiratory problems, cardiovascular issues, and increased risk of lung cancer. It can also aggravate existing conditions like asthma and allergies. Prolonged exposure to polluted air can have long-term health effects, including reduced lung function, chronic respiratory diseases, and even premature death. Children, the elderly, and individuals with pre-existing health conditions are particularly vulnerable to the adverse effects of poor air quality.

Risk: The likelihood that a CSU campus will experience poor air quality depends on the specific campus location and surrounding environmental conditions. For campuses located near industrial activity or in wildfire hazard zones, the probability of experiencing poor air quality is **Likely**.

Figure 11: *Smog hotspots in California*[7]

Power Quality and Capacity, Energy Demands

Any disruption to power on campus can have severe consequences. Both increased energy demand as well as a lack of power quality can disrupt critical services, affect public safety, and hinder economic activities. Increased energy demand can lead to power outages when the existing infrastructure is unable to handle the higher loads, resulting in system failures. This is especially of concern in areas experiencing extreme temperatures. The combination of excessive demand due to cooling loads, as well as the increased probability of Public Safety Power Shutoffs due to wildfire prevention, put those areas at a higher risk of power outages at critical times. Additionally, severe weather conditions can cause poor power quality. When the power supplied is not within the required frequency and voltage limits, vital equipment systems can be impacted or shutdown.

Risk: The primary concern for CSU System leadership is the potential hazards to students, faculty, and staff caused by power outages and poor power quality, particularly affecting infrastructure such as HVAC and air filtration systems, medical devices, communication and security systems, and elevators. Community members with physical disabilities are especially vulnerable to disruptions in these systems. Electricity outages also hamper billing systems and records, necessitating manual procedures and paper copies. Classroom teaching and learning is hindered without functioning lighting and computer equipment. Overall, the power outage hazard is ranked as **Likely.**

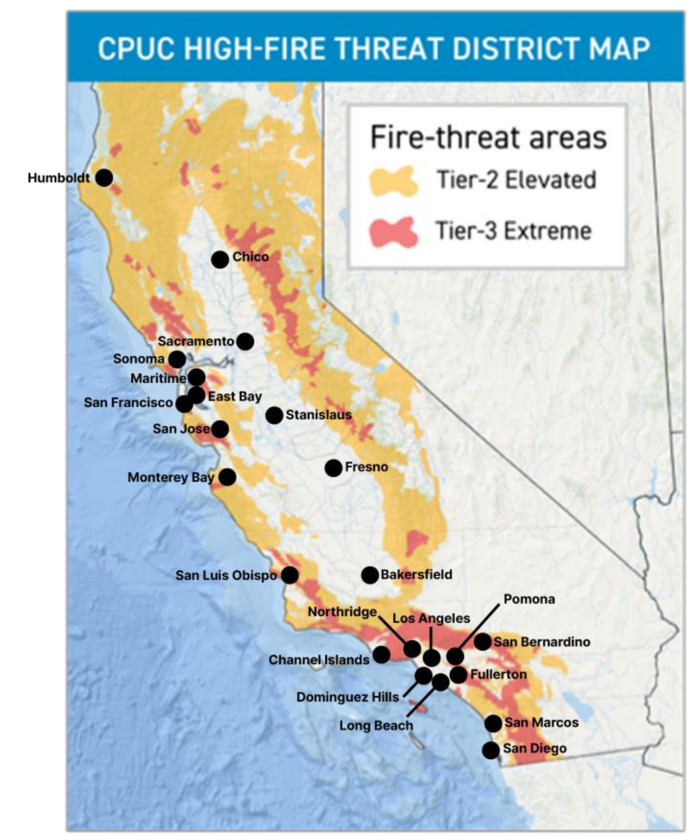

Figure 12: *California Public Utilities Commission Map of Fire-Threats Associated with Public Safety Power Shutoffs*[8]

[7] California Air Quality: Mapping The Progress | California Healthline

[8] How weather factors into a PG&E Public Safety Power Shutoff (pge.com)

Water Supply

Water scarcity and drought conditions can directly affect operation and maintenance of CSU campuses. Limited water availability can result in restrictions on water usage, minimizing irrigation use and negatively impacting landscaping and overall campus aesthetics. It can also impact the availability of water for sanitation, drinking, and other essential campus functions. Water shortages also affect the broader community surrounding CSU campuses. In times of drought, water conservation measures and restrictions may be implemented, impacting the local communities' access to water resources.

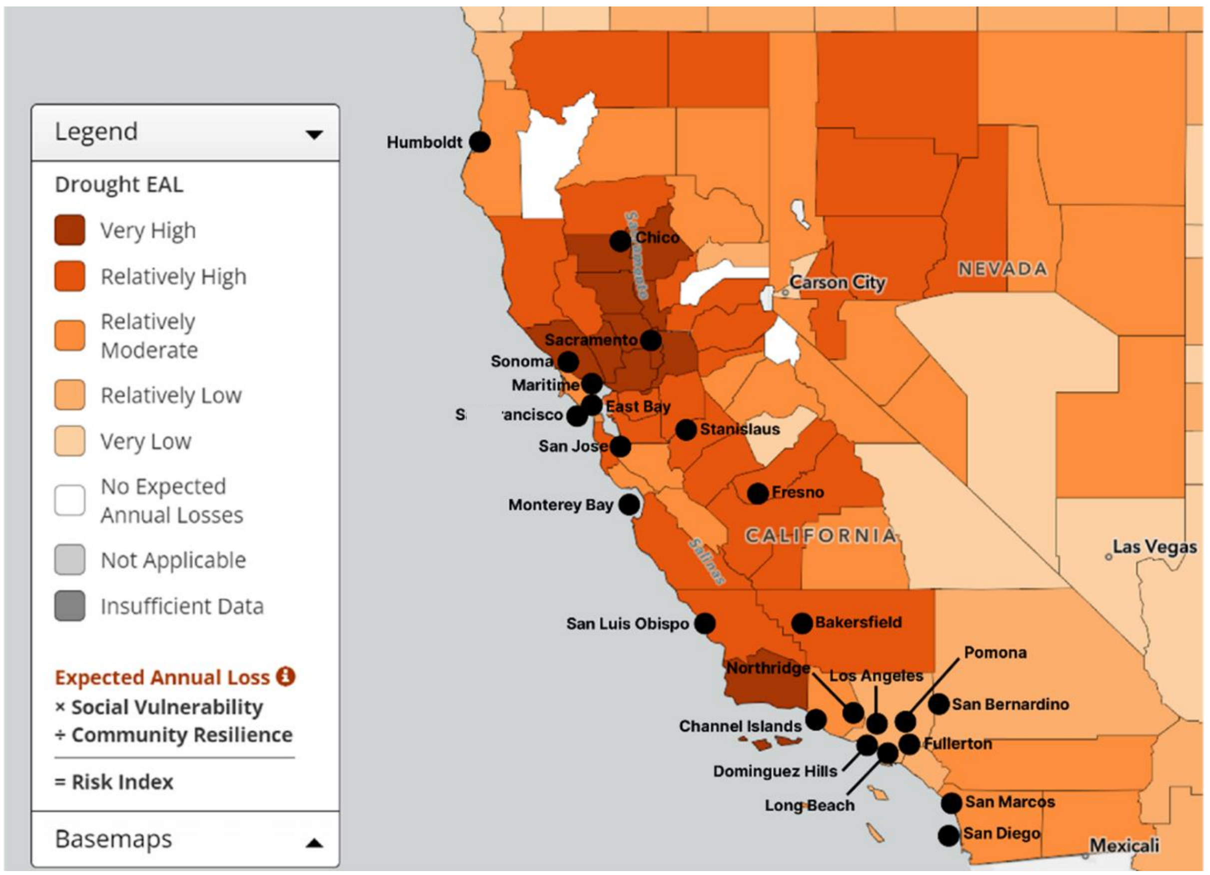

Figure 13: FEMA Water Supply Risk Map[9]

Risk: The CSU system includes campuses located in regions that are particularly vulnerable to water scarcity, such as areas heavily reliant on local water sources or areas with limited access to alternative water supplies. These campuses may face more significant challenges in managing their water resources and ensuring a sustainable supply for campus operations. Overall, the probability that campuses will face issues with limited water supply is **Likely**.

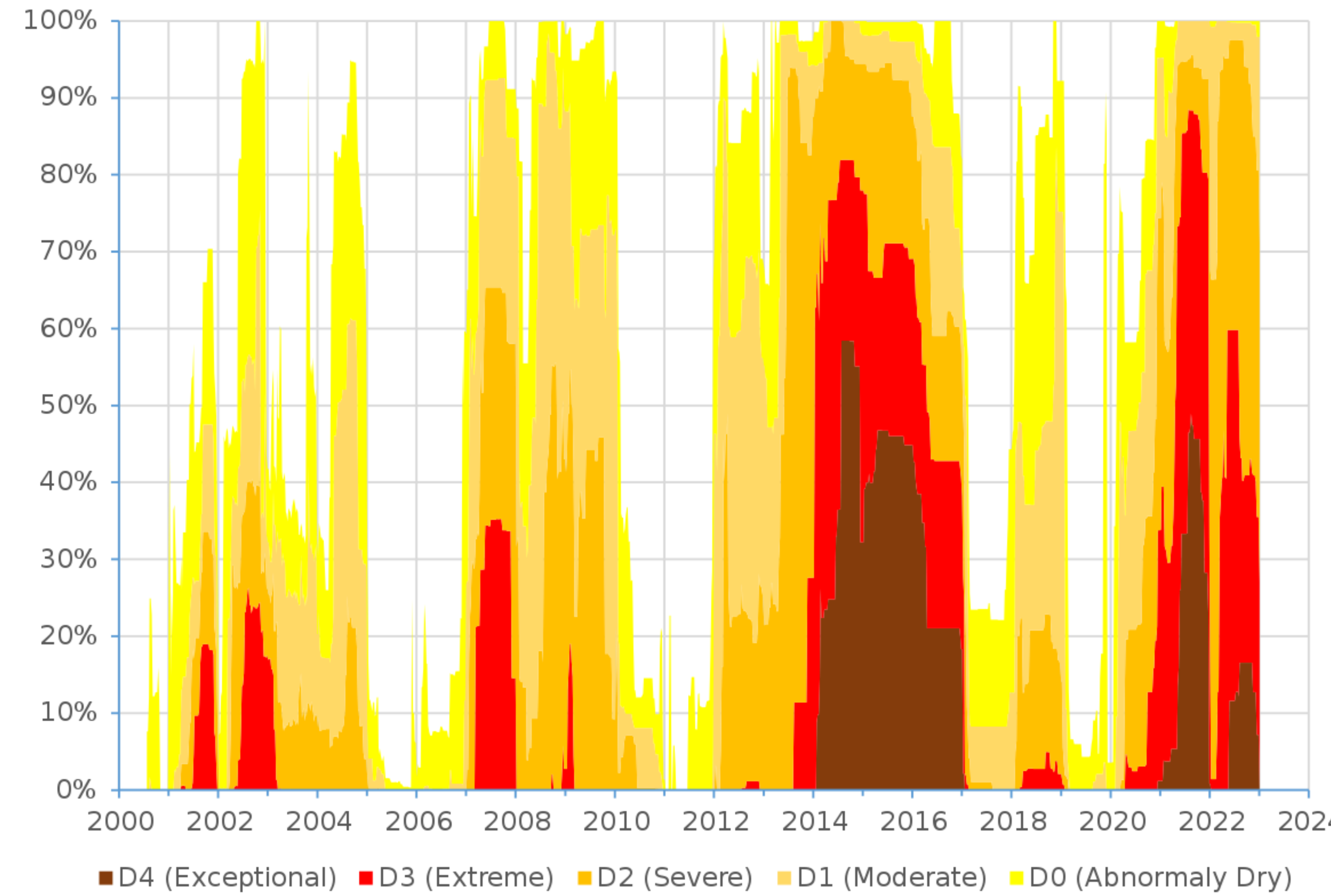

Figure 14: Timeline of California by Severity of Drought Conditions[10]

[9] [Map | National Risk Index (fema.gov)]

[10] [California | Drought.gov]

Climate Change

Table 2 is a Climate Hazard Identification Matrix that demonstrates the direct and indirect (cascading) hazards that result from the effects of climate change. For example, wildfires directly lead to the hazard of worsened air quality due to smoke; they also indirectly lead to increased risk of flooding, as wildfires burn vegetation and soil, which in a natural state, absorb and retain water.

It is crucial to identify not just immediate impacts from the effects of climate change, but also the cascading downstream risks that may arise. **Table 2** identifies how these six specific climate change effects contribute to increased climate change hazards.

Table 2: *Climate Change Effects as an Impact on Increasing Climate Hazards*

Effects of Climate Change	Flooding	Extreme Heat	Wildfires (Direct)	Air Quality	Power Quality	Energy Demands	Water Supply
Temperature Change		Direct	Indirect		Indirect	Indirect	Indirect
Sea Level Rise	Direct						
Wildfire	Indirect		Direct	Direct	Direct		
Precipitation	Direct						
Extreme Weather Events	Direct	Direct	Direct	Direct	Direct	Direct	
Drought			Indirect	Indirect	Indirect		Direct

Direct | Indirect

Cascading Climate Hazards

Climate hazards that happen together or within the same window can cause cascading effects. **Figure 15** and **Figure 16** are two examples describing these compounding hazards. The first shows how high winds paired with severe drought conditions can cause extreme spreading of wildfires, affecting utility infrastructure or triggering Public Safety Power Shutoffs (PSPS). The second shows how prolonged drought followed by flooding can cause downed trees, ultimately leading to safety concerns and infrastructure or property damage. These interconnected events can put campus populations in danger; cause disruptions in academic research and activities; and negatively affect public perception and enrollment.

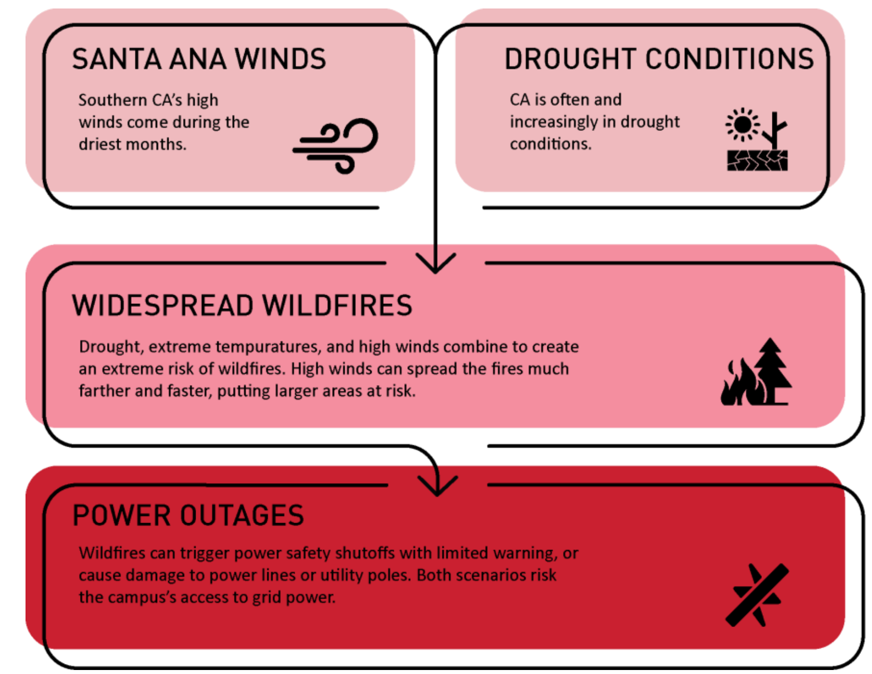

Figure 15*: Cascading Impacts Example 1*

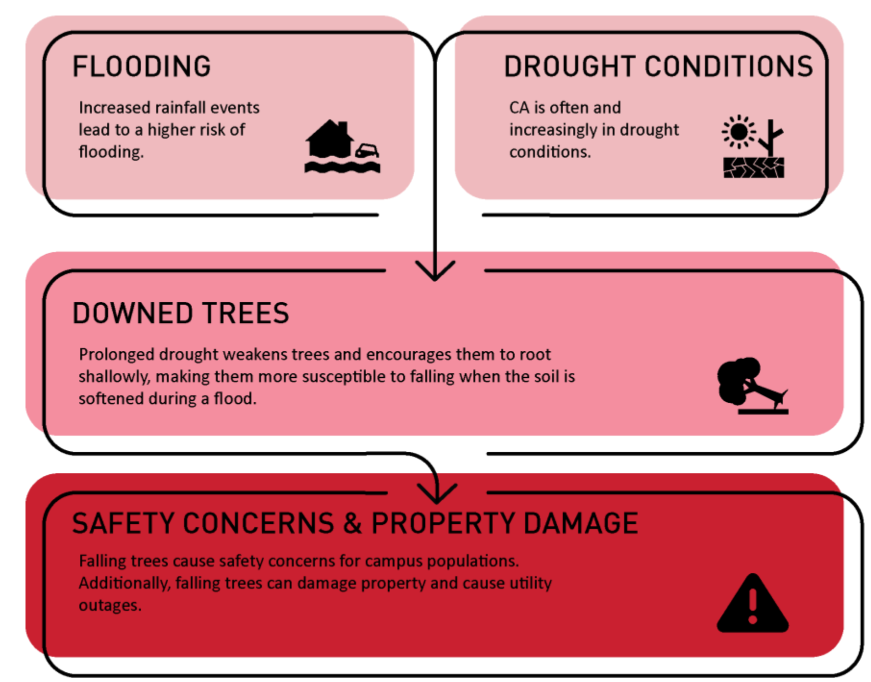

Figure 16: *Cascading Impacts Example 2*

1.3 Climate Adaptation

Emissions Scenarios

Climate adaptation models are used to understand the climate change impacts that we need to adapt to, allowing us to plan, so that communities can be less vulnerable. These models, called Representative Concentration Pathways (RCP), lay out different outcomes, based on possible emissions scenarios. The RCPs are defined by the total solar radiative forcing, or the difference between how much energy enters and leaves Earth's atmosphere, through the year 2100. Lower pathways, such as RCP-2.6 and RCP-4.5, represent more moderate climate effects, while higher RCPs such as RCP-8.5 represent extreme climate change scenarios. **Figure 17** shows the projected temperature increases for various RCP scenarios.

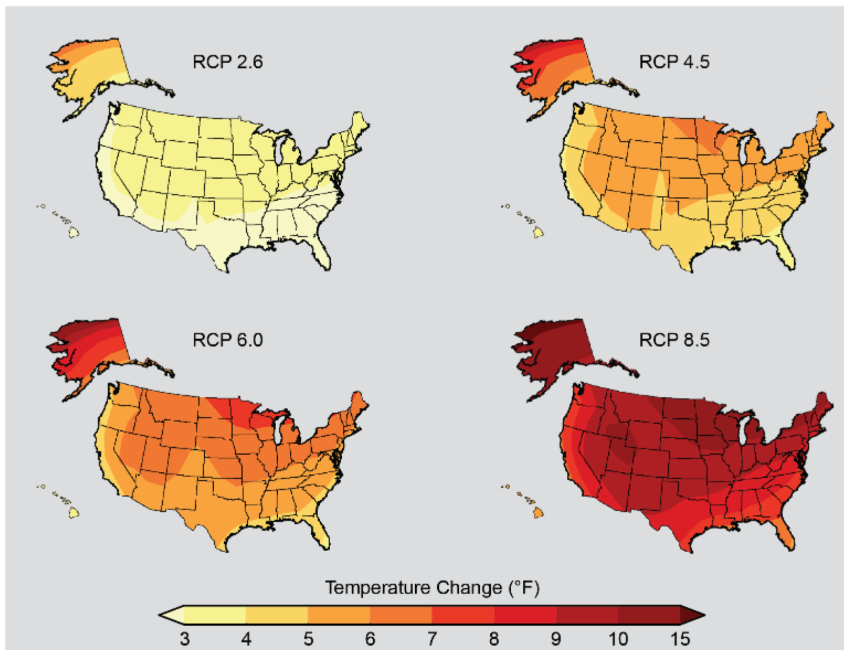

Figure 17: *Projected Temperature Change by 2071-2099*[11]

The online resource Cal-Adapt is an example of a tool that can be used to generate future weather predictions for specific locations. It provides detailed future weather prediction data based on selected RCP scenarios, either RCP-4.5 (moderate) or RCP-8.5 (extreme). Data is available for metropolitan areas worldwide, and an EPW weather file can be uploaded to generate results specific to any region. Cal-Adapt or other similar tools can be used by individual campuses to aid in planning for future climate impacts.

[11] Projected Temperature Change by 2071-2099 (CMIP5 models) :: North Carolina Institute for Climate Studies (ncics.org)

Climate Adaptive Design Conditions and Resources

To keep up with the changing climate and increasing temperatures, design standards such as mechanical equipment sizing will need to be updated to meet future demands. It is recommended that all campuses utilize an RCP climate scenario planning tool, as described in **Table 3**. It will inform projected temperatures and update campus design standards, including oversizing equipment for increased demand. The tools and databases below also address other risks, such as future drought, flooding, air quality, storm, and wildfire conditions. A campus can utilize the resources below to define the risks affecting their campus more accurately on a highly granular scale and see how the risks are projected to change over time. It is highly recommended that a campus reviews these tools and databases when evaluating possible infrastructure projects.

Table 3: *Climate Adaptive Design Conditions and Resources*

Database Name	Description
Cal-Adapt Tools Database, Located at: https://cal-adapt.org/tools/	Users can investigate how effects such as temperature, precipitation, snowpack, sea level rise, and wildfires are forecasted to increase in the future under either high, medium, or low emissions scenarios. These tools can be helpful reference points when updating design standards or evaluating if existing infrastructure and equipment can handle future climatic conditions.
Weathershift Database, Located at: https://weathershift.com/	The WeatherShift tool uses data from global climate change modeling to produce weather files "morphed" for changing climate conditions. These files contain hourly values of key weather variables for a typical year and are intended to be used for simulating building energy requirements for future years.
Climate Mapping for Resilience and Adaptation (CMRA) Tool, Located at: https://resilience.climate.gov/#assessment-tool	This is a federally funded website that tracks live climate hazards, such as wildfire events, drought, extreme heat, and inland and coastal flooding. Users can aim at their specific region and see current hazards, as well as projected future changes under lower and higher emissions scenarios. The tool is less granular than the EJScreen tool but has robust forecasting capabilities.
Environmental Justice Screening and Mapping (EJScreen) Tool, Located at: https://ejscreen.epa.gov/mapper/	This is a website created by the Environmental Protection Agency that shows granular threats to human health, with a specific focus on air quality concerns. Additional layers can be used to place land areas into percentile risk categories for flooding, wildfires, sea level rise, and historical floodplain proximity. This tool's granular data is valuable for evaluating a specific college campus location.

CHAPTER 2: Planning Process Framework

2.1 CSU Framework

This CSU Resiliency Framework report is intended to be used by individual campuses to identify courses of action that can increase resilience in response to the campuses' specific climate hazards and operational requirements. This chapter dives into the planning process in depth, beginning with an overview of the steps and then highlighting the detail of each step more fully. The planning process shown below in **Figure 18** follows the general sequence of steps. **Figure 19** shows an example of a campus going through the entire process. Each step is explained in detail in the next five subsections. A campus should follow this process for each risk, critical operation, and supporting infrastructure type until enough strategies have been identified to satisfy campus resilience planning efforts.

IDENTIFY RISKS — 1

Identify regional climate risks to human health and infrastructure specific to the individual campus

1. Determine which external risks are relevant to the campus.
2. Quantify the cost impacts of being affected by each climate hazard. Potential financial ramifications are identified within Chapter 1.
3. Identify infrastructure systems that are most at risk due to their region's extreme climate events.

DEFINE NEEDS — 2

Use business continuity plans to identify critical operations and infrastructure required to maintain functionality

1. Identify the critical operations. A list of possible critical operations for a typical campus is given in this step's subsection.
2. Identify the facilities that support those operations.
3. Identify the infrastructure systems that sustain those facilities. This breakdown is described in the following section.

ASSESS EXISTING CONDITIONS — 3

Identify any gaps in current infrastructure conditions that could prevent the campus from meeting internal needs

1. Are internal needs met when confronted by external risks? Chapter 3 lists possible points of concern for each component within the infrastructure system.
2. Utilize utility master plans and studies to evaluate existing conditions.
3. Quantify the gap between needs and current status.

EVALUATE STRATEGIES — 4

Evaluate strategies to address gaps in campus resilience to top climate risks

1. Campus should now have a relatively well defined "gap" between their resilience requirements and existing conditions.
2. The campus can now begin evaluating specific strategies to close this gap. Specific mitigation strategies are provided in detail in Chapter 3 and are categorized by the infrastructure type they support.

IMPLEMENT PLAN — 5

Secure funding and create a phased implementation timeline considering importance and cost of each project

1. Prioritize projects based on criticality, cost, availability of funding, and any other real world implementation concerns.
2. With potential strategies identified and prioritized, a campus can now work on securing funding for their projects.
3. Assemble a phased implementation timeline.

Figure 18: *Flowchart of Campus Resilience Planning Steps*

CSU Example:

1 IDENTIFY RISKS

Identify regional climate risks to human health and infrastructure specific to the individual campus

2 DEFINE NEEDS

Use business continuity plans to identify critical operations and infrastructure required to maintain functionality

3 ASSESS EXISTING CONDITIONS

Identify any gaps in current infrastructure conditions that could prevent the campus from meeting internal needs

4 EVALUATE STRATEGIES

Evaluate strategies to address gaps in campus resilience to top climate risks

5 IMPLEMENT PLAN

Secure funding and create a phased implementation timeline considering importance and cost of each project

example

1. The campus is in an area prone to both wildfires and inland flooding. After a wildfire burns vegetation and reduces the soil's ability to retain water, the area will be extremely susceptible to flooding during the next storm surge. Flooding can inundate infrastructure, knock down utility poles, and cover access roads to campus, delaying repairs and deliveries of crucial supplies.

2. One of the campus's critical operations is to function as an Emergency Operations Center for the community and must have an uninterruptable power supply to the on campus EOC. This means the electrical infrastructure system needs to be suitably robust and redundant to handle any climate hazard.

3. The campus is currently served by one electrical feeder from the utility on aged, overhead power lines that enter to a single substation. The EOC has a backup power generator with limited fuel. A flood could down utility poles and close roadways, interrupting the delivery of more fuel. The electrical distribution or backup power systems should be upgraded.

4. The campus evaluates specific strategies such as upgrading the electrical infrastructure by adding a redundant feeder on the opposite side of campus, upgrading the existing feeder by burying it in a concrete conduit, or focusing on backup power generation. These strategies would sustain critical operations in direct response to the campus's relevant risks.

5. The campus can now begin the implementation plan. In this case, the campus may start by increasing onsite fuel storage. Projects should be prioritized based on importance and availability of funding. Then, the campus can secure funding and search for resilience grant programs to create an actionable timeline for implementing additional projects.

Figure 19: *Example of a Campus Proceeding Through Framework*

Identify External Risks

When utilizing this framework, the campus should first determine which external risks are relevant. External climate change-related risks will vary geographically, and a campus's location may make it more vulnerable to certain types of threats than others. Chapter 1 and its table of climate adaptation resources and databases can be used when evaluating the risks affecting specific geographic areas.

The impacts of each of these external risks are more fully defined in Chapter 1, with case studies showing the effects of real-world flooding and wildfire events as examples. It will be up to the individual campus to identify which risk is relevant to its geographical location and prioritize accordingly. Additionally, Chapter 3 provides details about how each infrastructure type is affected by each specific risk. A campus can then determine which of the infrastructure systems are most at risk due to their region's extreme climate events. They can then prioritize these infrastructure systems higher when they reach the fourth step, "Evaluate Strategies." Examples of how certain external risks may affect different infrastructure types are shown in **Table 4**. It is important to note that a direct risk means that an infrastructure type is more likely to be affected by a specific hazard than by a hazard that causes an indirect risk. Therefore, if a critical infrastructure type is affected directly by one hazard and indirectly by another, the campus should likely prioritize the direct risk as the one to mitigate first. An example is shown in **Figure 20**.

Table 4: *External Climate Hazard by Effect on Infrastructure Type*

	Campus Infrastructure								
Possible External Hazard	**Electrical**	**Natural Gas**	**Potable Water**	**Central Heating and Cooling**	**Storm Drain and Stormwater**	**Sanitary Sewer**	**Critical Data and Comms**	**Fire Alarm and Fire Water**	**Roadway Utility**
Extreme-Heat Events	Direct Risk		Indirect Risk	Direct Risk			Direct Risk	Indirect Risk	Direct Risk
Flooding	Direct Risk	Indirect Risk	Direct Risk	Indirect Risk	Direct Risk	Direct Risk	Direct Risk	Indirect Risk	Direct Risk
Wildfires	Direct Risk	Indirect Risk	Indirect Risk	Indirect Risk			Direct Risk	Direct Risk	Indirect Risk
Poor Air Quality									
Power Quality and Capacity	Direct Risk			Indirect Risk			Indirect Risk		
Energy Demands	Direct Risk		Indirect Risk	Indirect Risk			Indirect Risk		
Water Supply			Direct Risk	Indirect Risk			Indirect Risk	Direct Risk	

Direct Risk **Indirect Risk**

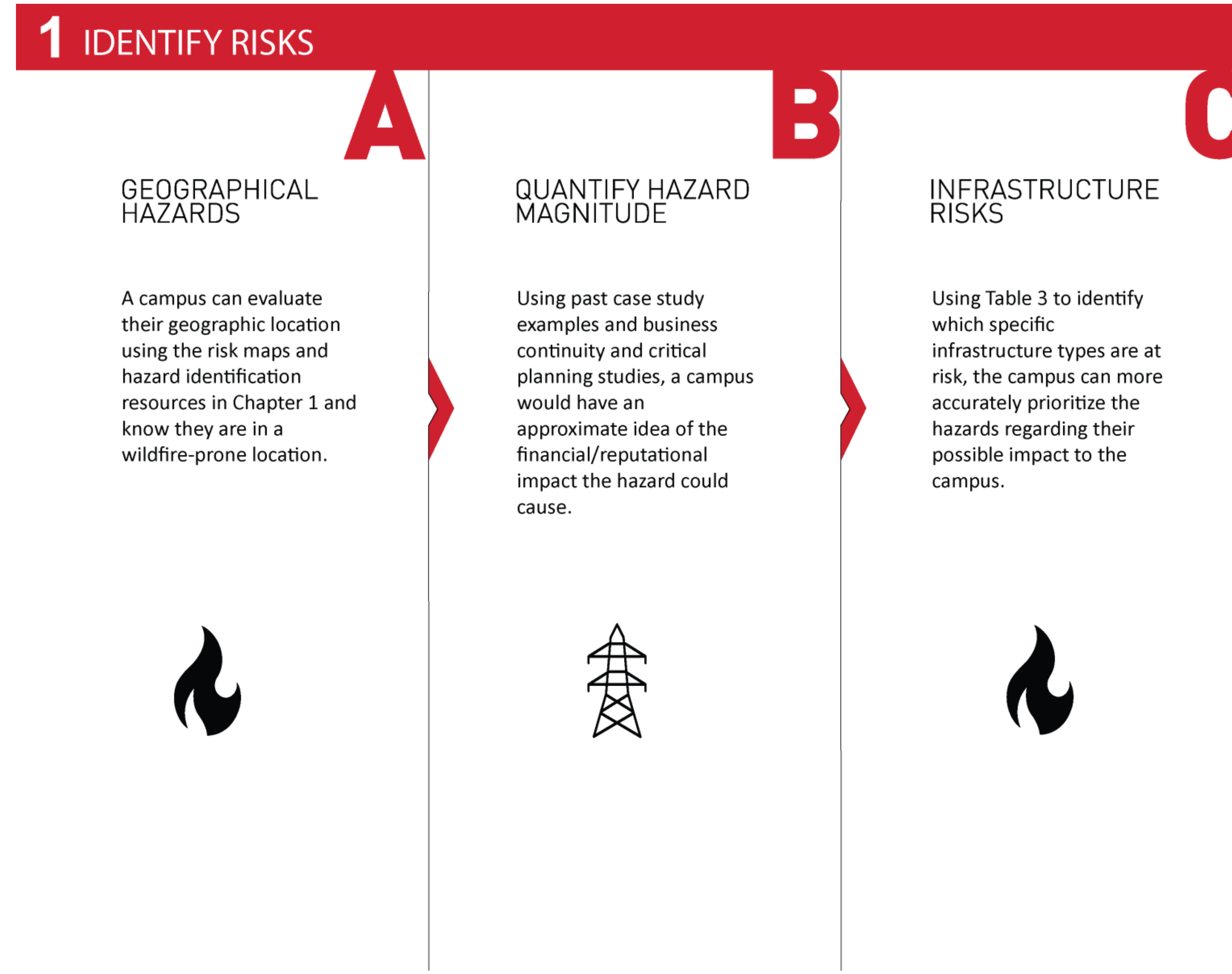

Figure 20: *Sub Steps of "Identify Risks"*

Define Internal Needs

The next step of the resiliency planning process is to define what the campus needs to operate. Specifically, a campus should identify its critical operations, what facilities support those operations, and what infrastructure systems sustain them. It is likely the existing business continuity plans will already address most or all of these critical needs, and the plans should be consulted by a campus during this step.

A campus can use this filtering process to identify which infrastructure systems are the most critical to the campus and then prioritize the resilience strategies associated with that infrastructure type. The table below provides a non-exhaustive list of what critical operations may look like at a typical CSU campus. An example is provided in **Figure 21**.

Table 5: *Example Critical Operations, Facilities, and Infrastructure Systems*

Critical Operations	Facilities Needed to Support the Critical Operations	Infrastructure Systems Serving the Critical Facilities
Student Health and Safety	Dormitory Buildings	• Electricity • Data and Communications • Central Heating and Cooling • Potable Water • Sanitary Sewer • Fire Alarm and Fire Water
	Cafeteria and Dining Halls	• Electricity • Natural Gas • Potable Water
Emergency Response	Police Station	• Electricity • Data and Communications • Roadway Utility
	Onsite Hospital or Health Clinic	• Electricity • Data and Communications • Roadway Utility • Potable Water • Central Heating and Cooling • Sanitary Sewer
Payroll Processing	Admin Offices, Data Center	• Electricity • Data and Communications
Educational Continuity	Classrooms, Data Center	• Electricity • Data and Communications
Medical and Scientific Research	Laboratory Buildings, Climate Controlled Areas	• Electricity • Data and Communications • Central Heating and Cooling • Potable Water

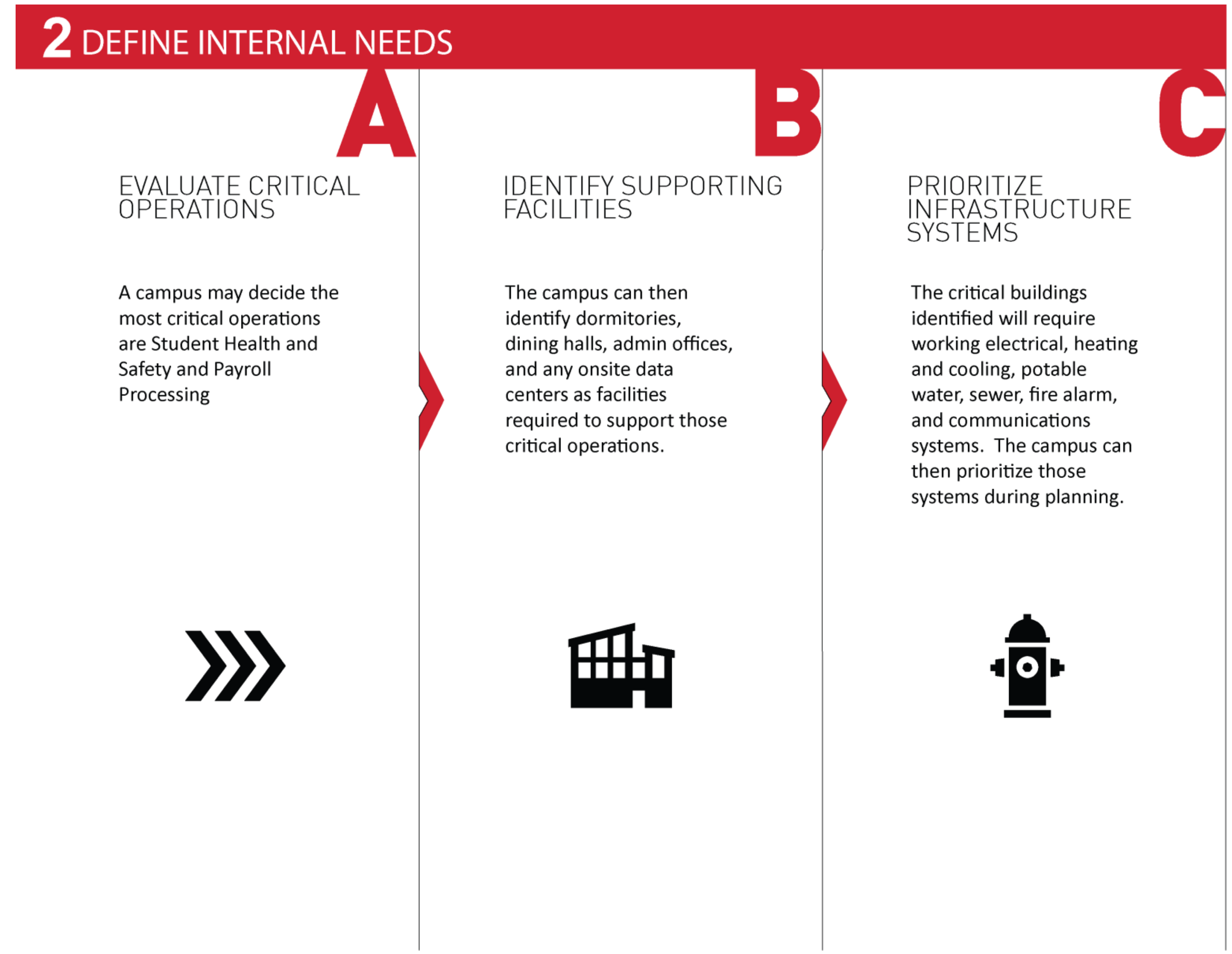

Figure 21: *Sub Steps of "Define Internal Needs"*

Assess Existing Conditions

Once an individual campus's external risks and internal needs are identified and well-defined, the campus can begin to assess its existing conditions. This is defined as how well a campus can meet its internal needs when confronted with external risks. This step can serve as a gap analysis between where the campus needs to be in terms of resilience versus where it currently is.

The existing conditions considerations are listed in detail for each infrastructure type, listing possible points of concern for each component within the infrastructure system. Additionally, a campus should look at existing plans and studies of the campus's infrastructure systems to investigate if any problem areas have already been identified in past exercises. This will provide additional value to assessing the status of campus systems.

Facility managers, capital planners, and designers can assess their campus's utility systems to help evaluate where future resiliency efforts should be focused. This focusing effort will help with evaluating possible mitigation strategies as discussed in the next section and will inform the eventual implementation plan. An example of this step of the process is shown in **Figure 22**.

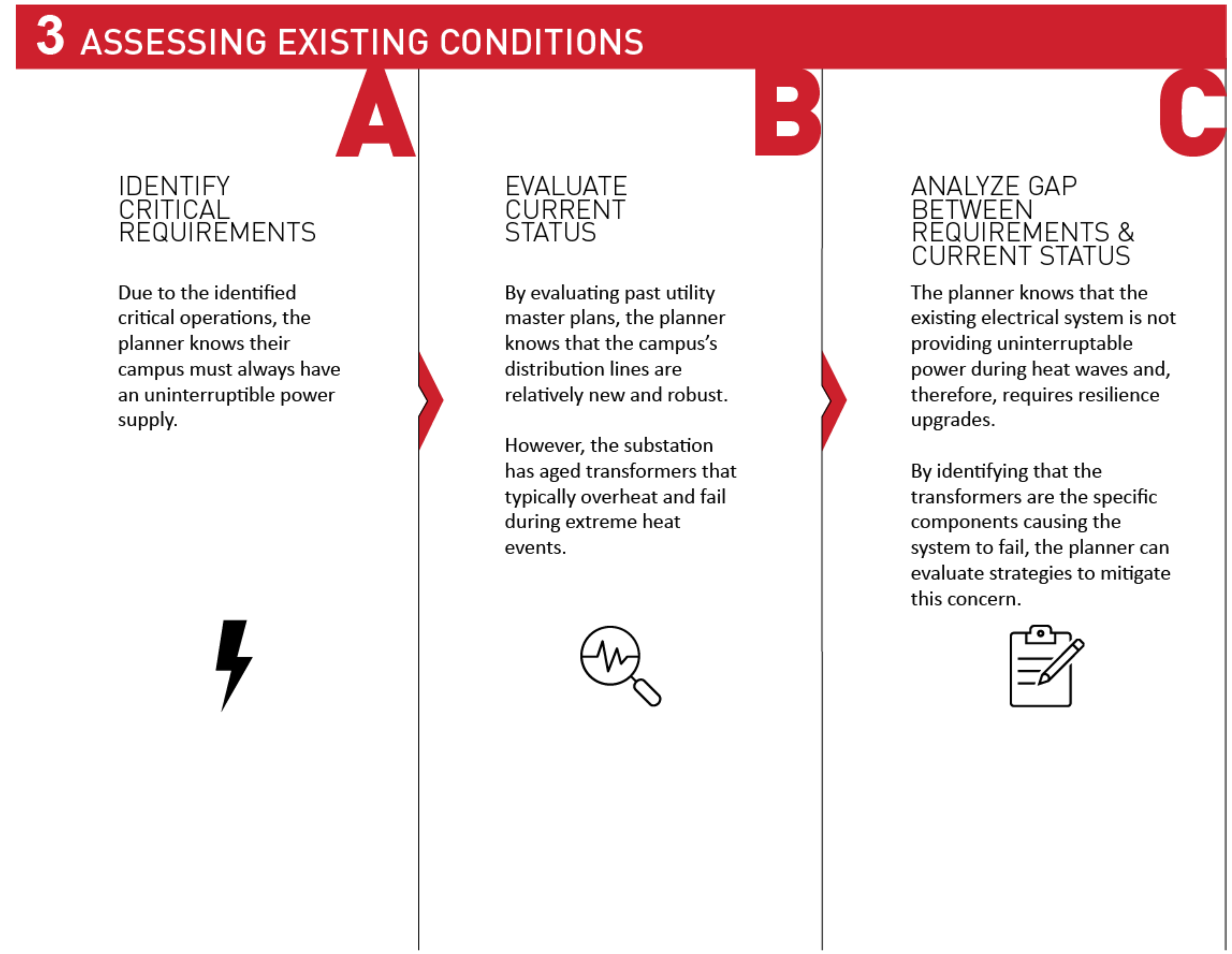

Figure 22: *Sub Steps of "Assessing Existing Conditions"*

Evaluate Strategies

After completing the three previous steps of the resilience planning process, the campus should have a relatively well-defined "gap" between where it currently is and where it needs to be regarding resilient operations. At this point, the campus can begin evaluating strategies to help close this gap, focusing on particularly vulnerable infrastructure systems, mitigating especially hazardous threats relevant to their geographical region, or reinforcing the capabilities of critically important operational functions.

Specific mitigation strategies are detailed in Chapter 3 and categorized by the infrastructure type they support. Additional considerations for implementation and cost are provided for each mitigation strategy. To continue the same example from the previous section, **Figure 23** shows the possible mitigation strategies that the campus may have identified, following the gap analysis between the infrastructure's requirements and current state.

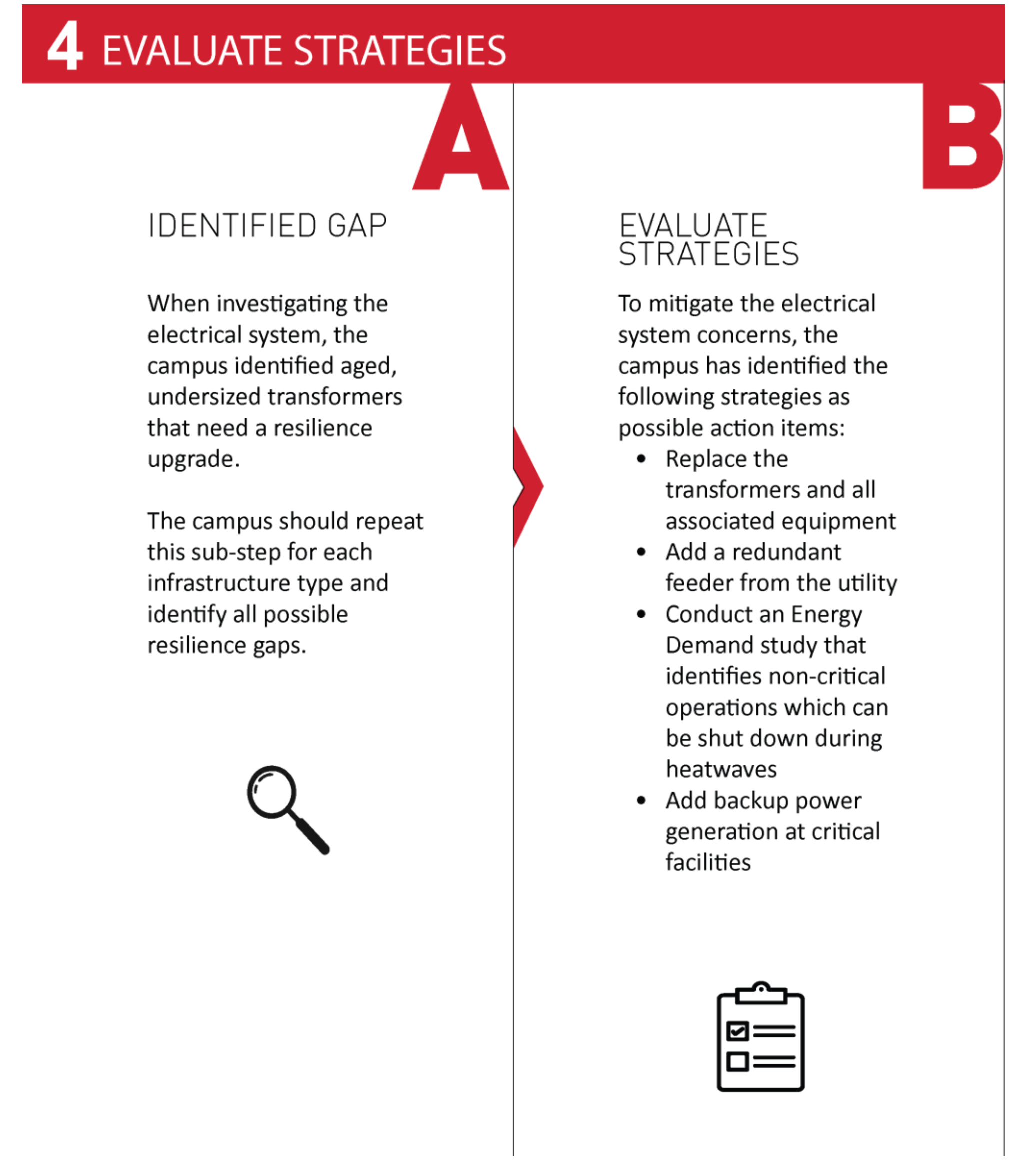

Figure 23: *Sub Steps of "Evaluate Strategies"*

Implement Plan

With potential strategies identified and prioritized, a campus can now work on securing funding for its projects and assembling a phased implementation timeline. The campus should begin by prioritizing projects based on criticality, cost, availability of funding, and any other real-world implementation concerns, such as construction difficulties or long lead times for ordering parts.

Once the relevant strategies have been assessed for priority, the campus can begin securing funding. The campus should look to typical university funding sources, federal grants and incentives for resilience planning, and FEMA programs that proactively provide funding to avoid future emergencies resulting from climate disasters. This exercise will help inform what the available budget will be.

The total amount of secured funding can then be used to create the phased implementation timeline, which will allocate the available resources to specific projects. The phased timeline will allow a maximum number of projects to be identified and implemented. This process is illustrated in **Figure 24**.

It is the expectation that the identified projects can be implemented as part of CSU's existing, ongoing efforts. For example, if a campus has progressed through the resilience framework and identified mitigation strategies using steps 1-4, the campus can implement the projects as part of any of the typical planning processes shown below:

- Campus Master Plan
- Climate Hazard Mitigation and Resilience Plan
- Utility Master Plan or Critical Infrastructure Plan
- Climate Adaptation Design Standards Update
- General Asset Management or Capital Outlay Plan

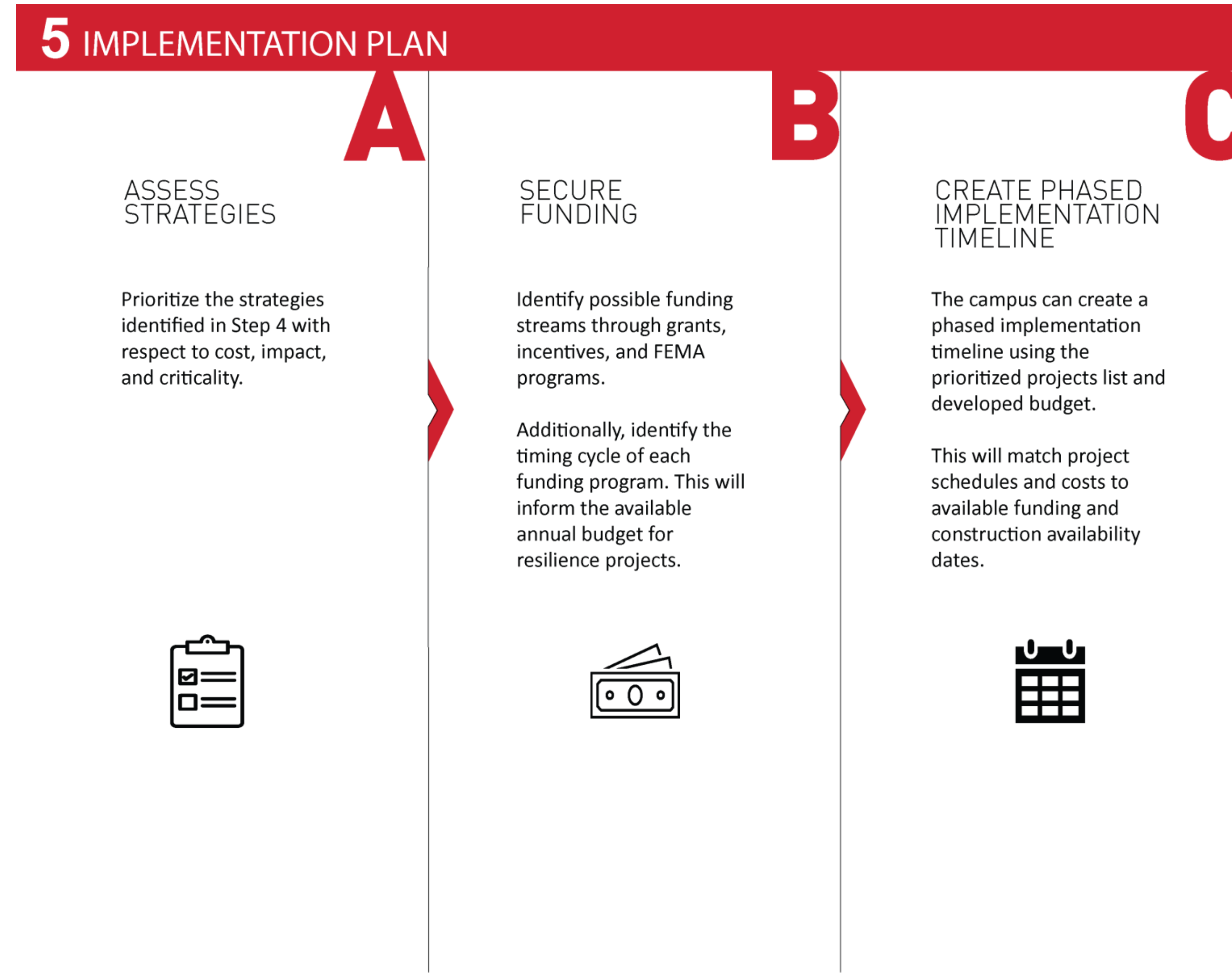

Figure 24: *Sub Steps of "Implementation Plan"*

CHAPTER 3: Climate Adaptive Strategies for Infrastructure Systems

3.1 Campus Infrastructure

This chapter explores individual infrastructure systems and provides detailed resilience information on each technology type. For each infrastructure type's subsection, the report provides a summary of the technology type, key design considerations for each major system component, a table of implementable resilience strategies, and a breakdown of how each strategy mitigates the risk per climate hazard. In order, the scope of the infrastructure types within the report is shown to the right.

While this chapter dives specifically into how individual infrastructure systems are affected by climate hazards with some detail on cascading impacts, it is important to remember that infrastructure types depend on one another for normal operations. The below graphic shows an example of these interdependencies, illustrating how hypothetical infrastructure types might operate in conjunction with one another.

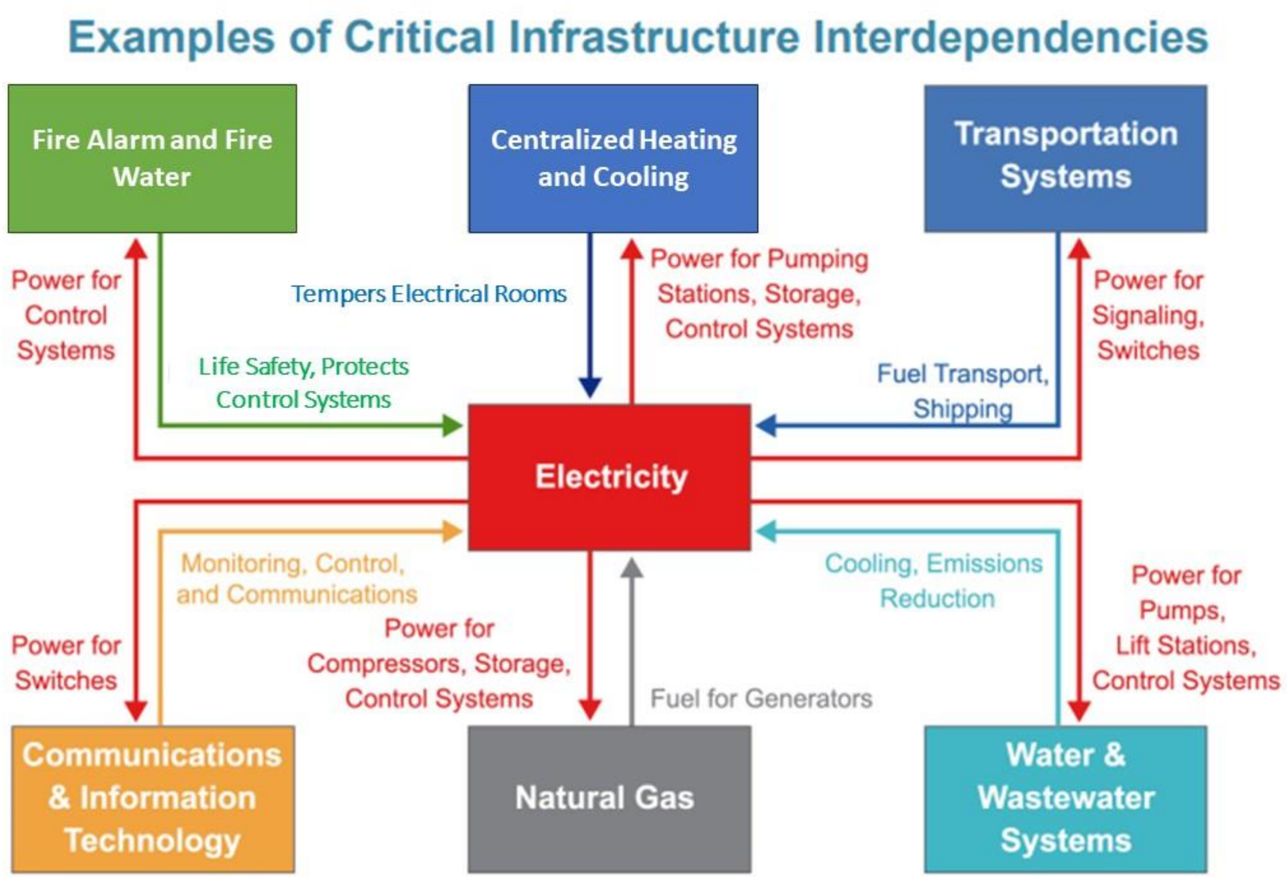

Figure 25: Example chart showing the interdependencies of utility types. This graphic is purely representative, is not necessarily accurate to CSU campuses, and is intended for illustrative purposes only.[12]

Electrical
The infrastructure supplying power from the utility and distributing electricity within the campus, up to the individual building point of entry.

Natural Gas
The infrastructure supplying natural gas from the utility and distributing and storing gas within the campus, up to the individual building point of entry.

Critical Data and Communications
Systems that allow connectivity to the internet and data saved on servers. Focuses on campus distribution networks and communications hubs within buildings.

Central Heating and Cooling
Central Utility Plants (CUP) and the hot water, steam, and chilled water distribution systems up to the individual building point of entry.

Potable Water
The distribution piping, pumping, storage, and other equipment up to the individual building point of entry.

Storm Drain and Stormwater
The drainage system and any treatment plants or pump houses up to the point of exiting campus.

Sanitary Sewer
The drainage system and any treatment plants or pump houses up to the point of exiting campus.

Fire Alarm and Fire Water
The distribution piping, pumping, storage, and other equipment up to the individual building point of entry plus the pressurized water lines and alarm systems within the building.

Roadway and Utility Infrastructure
The roadway and transportation systems entering, exiting, and within campus. Includes the associated traffic controls, lighting, and other auxiliary technology support systems.

[12] Adapted from Full Report | Fourth National Climate Assessment (globalchange.gov)

3.2 Electrical Infrastructure

Summary

Climate change can pose significant hazards to electrical infrastructure, including power plants, transmission lines, and distribution networks. Extreme weather events, such as heatwaves, droughts, hurricanes, and wildfires, can damage or disrupt power infrastructure. Additionally, rising sea levels and increased storm severity can cause flooding and water intrusion, potentially damaging electrical equipment. Climate change can also lead to changes in energy demand, as hotter temperatures can increase the need for cooling. Also, climate change can lead to changes in renewable energy potential, as weather patterns and seasonal variability can impact the availability of wind and solar resources. Electrical infrastructure should be designed and built to mitigate these hazards to withstand more extreme weather conditions. Transitioning to a more robust, decentralized, and renewable energy system can increase resilience and reduce vulnerability to climate change.

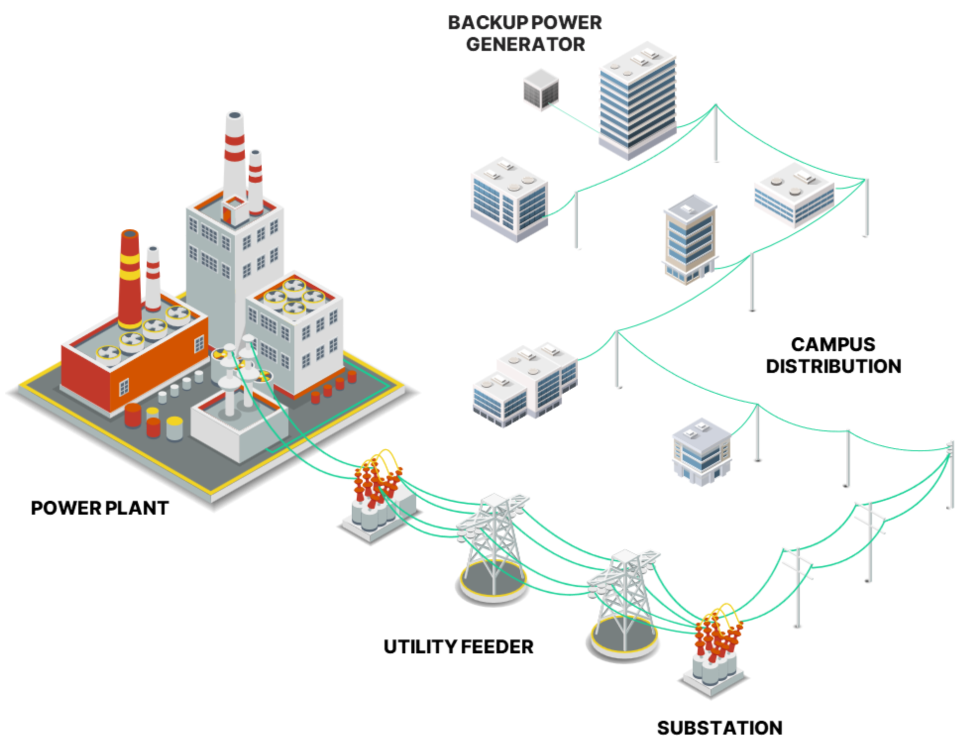

Figure 26: *Example Electrical Infrastructure*

Critical Infrastructure and Key Considerations

The electrical infrastructure system has multiple vulnerabilities that should be considered when evaluating a campus's overall resilience. First and foremost, a campus should focus on any single point of power supply. A failure in non-redundant components, such as a utility feeder, substation, or distribution line, would cause all downstream electrical systems to lose power. Additionally, undersized or outdated backup power systems could exacerbate critical operations sustainment issues during an outage.

For an electrical transmission and distribution system with no additional resilience features, these focus areas are summarized in **Table 6**, with key considerations per component. To accommodate the 23 different campuses that will use this report, a campus ought to evaluate the specific design options per infrastructure component to help identify where their respective resilience gaps are. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 8**.

Table 6: *Critical Components of an Electrical Infrastructure System*

Infrastructure Component	Climate Resilience Considerations
Utility Feeder	• Redundant power supply lines with adequate capacity • Geographical separation between entering utility feeders • Physically hardened lines rated to withstand extreme heat, wildfires, and high winds • Age and general condition • Located away from potential hazards such as trees
Substation	• Adequate capacity to meet electrical load • Redundant substations • Redundant equipment within substation • Located out of floodplain • Age and general condition
Distribution System	• Looped vs radial distribution layout • Automatic sectionalizer capabilities • Physically hardened lines rated to withstand extreme heat, wildfires, and high winds • Age and general condition
Backup Power/Generation Systems	• Backup power for all critical operations and facilities • Adequate fuel reserves for fossil fuel powered generators • Capacity of backup systems • Electrified backup battery systems where mandated • Automatic transfer switch capabilities • Regular maintenance and testing • Located out of floodplain • Age and general condition

Climate Impacts

Extreme heat: Extreme heat events typically lead to an increased cooling load and, therefore, higher electrical demand. If demand is higher than the current electrical distribution system can handle, sections of the system may short circuit, causing downstream power outages. Furthermore, extreme heat will reduce the efficiency of the transmission grid. Additionally, extreme temperatures can cause specific pieces of electrical equipment, such as transformers and switchgear at substations, to lose capacity or overheat and fail. Having redundancy in both power supply and distribution system chokepoints (such as substations) can improve the resiliency of the electrical infrastructure as it relates to extreme heat.

Wildfires: Wildfires can cause forced shutdowns of electrical infrastructure to avoid further ignition events. Additionally, the increased heat from wildfires in proximity to campuses can cause individual pieces of electrical equipment to fail or may damage overhead utility poles. Having additional feeders supplying the campus from different directions may allow the campus to operate using one power feeder while shutting the other down for safety. Additionally, hardening the distribution system through practices such as burying power lines in concrete conduits may provide adequate protection from the extreme heat of wildfires.

Flooding: Flooding can negatively affect the electrical infrastructure system by causing direct water damage to switchgear and transformers at substations, infiltrating loosely buried electrical distribution lines, or, in severe cases, knocking down overhead utility poles. Loss of electrical power to the campus could cause a cascading series of effects, such as losing pumping capabilities for stormwater, sewer, and potable water systems or communication system failures. Hardening the electrical distribution system and ensuring all individual components are sufficiently weatherized will increase the infrastructure's resiliency against future floods.

Power Quality and Capacity: Power quality and capacity may be a future issue as campuses and surrounding communities grow and demand further power from the existing transmission system. Irregular or extreme power demands may lead to the electric utility voluntarily causing rolling brownouts or unintentional power surges in the delivered electricity. These power surges may cause short circuits in the campus distribution system. Additionally, as extreme heat events lower the efficiency of distribution systems, it is possible that heat waves will reduce the total capacity of power delivered. Upgrading the electrical power supply with adequate power conditioning systems will provide an increased level of resilience to safeguard against rolling blackouts or overloaded circuits.

Energy Demands: Energy demands may be a future issue as campuses and surrounding communities grow and demand further power from the existing transmission system. If demand is higher than the current electrical distribution system can handle, sections of the system may short circuit, causing downstream power outages. Upgrading the electrical power supply to be fully redundant or oversized to allow for a margin of safety will provide an increased level of resilience to safeguard against rolling blackouts or overloaded circuits.

Water Supply: Water supply may be critical to the electrical infrastructure system, as it relates to water-cooled HVAC systems. While electrical transmission and distribution infrastructure typically do not need external sources of cooling, individual building level electrical and server rooms may house sensitive equipment that need constant cooling to avoid damage. A consistent water supply is important for water-cooled HVAC systems to remain functional and provide constant tempering to these sensitive spaces. More information on this topic is given in the section on Water Infrastructure.

Resilience Strategies

Table 7 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, a redundant electrical feeder will cause the risk of energy demands to reduce greatly but will only somewhat mitigate the risks presented by extreme heat.

Table 7: *Electrical Resilience Strategies by Effect on Climate Hazard*

Mitigation Strategies	Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Redundant and/or Upgraded Feeder		Low Impact	Low Impact	High Impact	High Impact	
Energy Demand Study				High Impact	High Impact	
Hardened Electrical Distribution System	High Impact	Low Impact	High Impact			
Automatic Sectionalizers	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	
Centralized Microgrid + Backup Power Generation Capabilities	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
Decentralized Microgrids + Backup Power Generation Capabilities	Low Impact			High Impact		
Deferred Maintenance						

Table 8: Electrical Infrastructure Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Capital Cost
Energy Demand Study	Planning	Conduct a study to evaluate future growth at the campus based on historical trends. Verify the study considers higher demand for electrical cooling during summer months in future years. Use the study results to determine if the electrical feeders from the utility are adequately sized.	Use results from the study to determine if the campus must request an upgraded or additional utility feeder or invest in microgrid and backup power systems.	Identifies potential future hazards.	$
Hardened electrical distribution system	Infrastructure	Increase the resiliency of the electrical distribution system by one or more of the following actions: -Bury the power lines (either directly or in a concrete conduit) -Conduct a vulnerability assessment of poles for overhead powerlines and institute the results of the study (potentially replacing poles)	Evaluate the Hazards section to determine which are relevant to the individual campus, then harden the electrical distribution system accordingly.	Increases existing infrastructure reliability.	$$$
Automatic Sectionalizers	Infrastructure	Install automatic sectionalizers on the electrical distribution system to provide the capability to shut down problematic circuit lengths. This will allow larger portions of the campus to stay operational if a small segment of the distribution circuit fails.	The automatic sectionalizers are only effective on a looped circuit or distribution system with significantly overlapping circuits that allow for alternate pathways of power supply.	Increases existing infrastructure robustness with additional capabilities.	$$$
Centralized Microgrid + Backup Power Generation Capabilities	Infrastructure	Evaluate the feasibility and requirement for a centralized backup power system that could power a circuit of critical buildings or the entire campus. Size appropriately based off the critical buildings/total circuit loads and ensure there is sufficient onsite storage for diesel/supply lines for natural gas for adequate sustainment duration	Only one of these backup power strategies should be implemented at any campus at once. Additionally, the generators can be rented as a cheaper alternative.	Increases existing infrastructure robustness with additional capabilities.	$$$
Decentralized Microgrids + Backup Power Generation Capabilities	Infrastructure	Evaluate the efficacy of installing building level backup power generators at each critical building on the campus. Ensure the generators are sized appropriately based off the electrical demand of the critical building.	Only one of these backup power strategies should be implemented at any campus at once. Additionally, the generators can be rented as a cheaper alternative.	Increases existing infrastructure robustness with additional capabilities.	$$$
Deferred Maintenance	Planning	Defer maintenance on electrical systems unless identified as a need due to a vulnerability study. Will increase the availability of support staff for quicker repairs as needed.		Expands capacity for emergency system repair.	$
Cross-Training/Redundancy in Maintenance Expertise	Staffing	Provide additional training between maintenance staff personnel to ensure there is redundancy in expertise when evaluating difficult repairs.	This could be "medium-voltage" maintenance staff cross-training with "low-voltage" maintenance staff or more cross-disciplinary, such as data and electrical maintenance cross-training.	Expands capacity for emergency system repair.	$
Emergency Repair Prioritization (Contracted Maintenance)	Planning	Coordinate an emergency supply contract with the utility provider to identify the campus as a high priority customer during times of outage. This could possibly be an agreement that the campus' feeders are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair.	$

3.3 Natural Gas

Summary

Climate change can pose significant hazards to natural gas infrastructure and distribution systems. Extreme weather and natural events, such as earthquakes, winter storms, hurricanes, and wildfires, can damage or disrupt natural gas infrastructure. Depending on if the natural gas is being used for heating, power generation, or both, these outages can have severe economic and social impacts. Additionally, colder winter temperatures may potentially lead to lines freezing or bursting, while wildfires can cause public safety shutoffs or failures of the distribution system itself.

Climate change can also lead to changes in energy demand, as hotter temperatures can increase the need for cooling (if the natural gas is used to power generators) and colder temperatures can increase the need for heating. Additionally, changes in renewable energy potential due to weather patterns and seasonal variability can impact the availability of wind and solar resources. To mitigate these hazards, natural gas infrastructure should be designed and built to withstand more extreme weather conditions. Transitioning to a more robust, decentralized, and renewable energy system can increase resilience and reduce vulnerability to climate change.

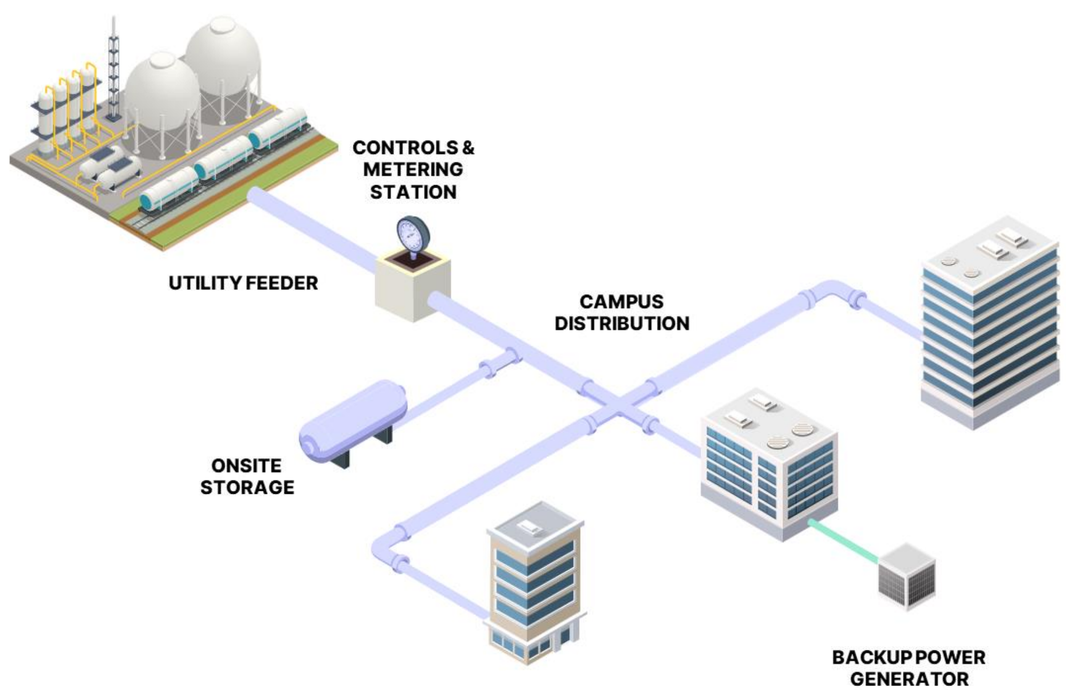

Figure 27: Example Natural Gas Infrastructure

Critical Infrastructure and Key Considerations

A natural gas infrastructure system has multiple vulnerabilities that can be focused on to increase the overall resilience of the campus. First and foremost, a campus should focus on any single point of supply, as a failure in those components would likely cause downstream components to lose pressure and thus the ability to transport gas.

For a natural gas distribution system, these specific vulnerabilities would be the feeders from the utility, any pumping stations that pressurize the distribution network, any centralized onsite storage areas that account for a campus's power generation fuel during an outage, and any singular pipelines along the distribution network itself. Additionally, any areas that could affect the external generation and delivery of natural gas should be accounted for when determining a system's resiliency. For example, a campus must consider any roads that are used by trucks delivering natural gas or regional natural gas power plants that have historically struggled with outages when evaluating their natural gas distribution system. While these factors are largely outside the campus's control, they should be considered for a holistic resilience evaluation.

For a natural gas system with no additional resilience features, these focus areas are summarized below in **Table 9**, with key considerations per component. To accommodate the 23 different campuses using this report, a campus should evaluate the specific design options per infrastructure component to identify its respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 11**.

Table 9: Critical Components of a Natural Gas Infrastructure System

Infrastructure Component	Climate Resilience Considerations
Utility Feeder	• Redundant natural gas supply lines with adequate capacity • Geographical separation between entering utility feeders • Physically hardened pipes rated to withstand flooding, wildfires, and extreme heat • Age and general condition • Redundant road supply routes if fuel is brought in via truck
Pumping Station	• Backup power for all critical pumps and pump houses • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition
Distribution System	• Looped vs radial distribution layout • Sectionalizer capabilities • Physically hardened lines rated to withstand extreme heat, wildfires, and high winds • Age and general condition
Onsite Storage	• Adequate capacity to sustain critical operations • Located out of floodplain • Age and general condition • Emergency backup power

Climate Impacts

Extreme heat: Extreme heat events typically lead to an increased cooling load and, therefore, higher electrical demand. If power is generated at a campus (whether as a backup power source or at a cogeneration plant), it is possible that this higher demand may cause strain on the generation source, potentially depleting the fuel source quicker or causing the generation equipment to fail. Additionally, extreme temperatures can cause specific pieces of natural gas distribution equipment, such as exposed pieces of piping, to over-pressurize and possibly rupture and fail. A hardened and protected distribution system can improve the resiliency of the natural gas infrastructure related to extreme heat.

Wildfires: Wildfires can cause forced shutdowns of natural gas infrastructure to avoid further ignition events. Additionally, the increased heat from proximity during extreme events can cause individual pieces of distribution equipment to fail. Having additional feeders supplying the campus from different directions may allow the campus to operate using one gas feeder while shutting the other down for safety. Additionally, hardening the distribution system through practices such as vulnerability assessments and upgraded piping can increase the system's resilience.

Flooding: Flooding can severely damage pumping stations and affect river crossings that gas pipelines cross through. Additionally, if the local power grid fails due to flooding, it is likely that pumping operations will be negatively affected as well. If the natural gas is brought in by truck or rail, inland and coastal flooding can damage bridges, storage facilities, and roads, therefore disrupting the supply line. Hardening the natural gas distribution system and putting in place redundant supply routes and methods, as well as adequate onsite storage, will increase the overall resilience of the natural gas infrastructure.

Power Quality and Capacity: Natural gas generates a significant portion of most utilities' electricity. Higher demands on electricity, potentially caused by heat waves and subsequent calls for increased cooling, may cause a strain on natural gas supplies. Additionally, if natural gas is used at a campus for cogeneration or as a backup power generator, fuel supply lines or onsite storage capacities may be challenged during times of high electrical demand. Consider oversizing onsite storage capacities and putting in place redundant, alternate supply methods to increase the resilience of the natural gas infrastructure.

Energy Demands: If energy is not delivered to natural gas facilities, such as refineries or pump stations, it is highly likely that the natural gas supply network will be disrupted. Pumps, control valves, and refining operations are all reliant upon electricity and can be negatively affected during power outages or times of otherwise high energy demand.

Water Supply: A reduced water supply can impact drilling and fracking operations, potentially causing regional shortages in natural gas. Water is also typically used for fuel refining and processing and could cause further shortages at refineries as well.

Resilience Strategies

Table 10 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, centralized onsite storage will reduce the risk of energy demands greatly, but it will only slightly mitigate the risks of wildfires.

Table 10: *Natural Gas Resilience Strategies by Effect on Climate Hazard*

Mitigation Strategies	Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Redundant and/or Upgraded Feeder	Low Impact		Low Impact			
Centralized Onsite storage	High Impact		Low Impact		High Impact	High Impact
Hardened Natural Gas Distribution System	High Impact		High Impact			
Distribution Vulnerability Assessment	High Impact		High Impact			
Looped/Overlapping Distribution Piping	High Impact		Low Impact			
Emergency Supply Prioritization (Contracted Truck Delivery)			Low Impact		High Impact	Low Impact
Deferred Maintenance						

Table 11: Natural Gas Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Redundant and/or Upgraded Feeder	Infrastructure	**Request/Install/Upgrade** a redundant natural gas feeder from the utility. Verify both feeders are **adequately sized** so that either one could independently handle the load of the entire campus if the other feeder fails.	Implement in tandem with "Energy Demand Study" and use the results of the study to inform the necessity of a redundant feeder and, if needed, the capacity.	Increases existing infrastructure reliability.	$$$
Centralized Onsite Storage	Infrastructure	Install centralized onsite storage tanks to provide a buffer for sustainment outage duration in the case of the utility feeders failing. Verify the storage tanks are adequately sized to power generators or heating systems to meet minimum sustainment duration requirements as outlined in emergency procedure.	This strategy works best in tandem with dual fuel or natural gas-powered generators, in order to provide backup power generation capabilities. Otherwise, the natural gas can be used for heating.	Increases existing infrastructure robustness with additional capabilities.	$$
Hardened Natural Gas Distribution System	Infrastructure	Increase the resilience of the natural gas distribution system by one or more of the following actions: -Fix any possible leaks or areas of overly high/low pressurization -Verify the distribution lines are adequately robust to endure floods, high heat, wildfires, and other relevant hazards	Evaluate the Hazards section to determine which are relevant to the individual campus, then harden the natural gas distribution system accordingly.	Increases existing infrastructure reliability and performance.	$$$
Distribution Vulnerability Assessment	Planning	Conduct a vulnerability assessment of the distribution lines, points of entry to facilities, and pumping/step up/step down stations and verify they are in adequate condition	The results of this assessment can be used to identify areas of the distribution system that need hardening and prioritize the order of repairs.	Identifies potential future hazards.	$
Looped/Overlapping Distribution Piping	Infrastructure	Verify the distribution piping within the campus is either looped or overlapping to provide alternate routes of natural gas supply to facilities in case of a segment failing. Identify valving strategies that will allow isolation of faulty segments as needed, to allow for gas to utilize an alternative pathway.	This can be implemented when adding an additional segment of piping or bringing service to a new facility. Any redundant interconnections will increase resilience.	Increases existing infrastructure reliability and provides alternate supply routes.	$$
Emergency Supply Prioritization (Contracted Truck Delivery)	Planning	Coordinate an emergency supply contract with the natural gas provider to identify the campus to receive natural gas as a high priority customer during times of outage. This could possibly be contracted delivery via fuel truck or an agreement that the campus's feeders are prioritized when evaluating repair logistics.	This could be pitched as a life-safety concern for on-campus students and allow campuses to be on a higher priority list for restoring service behind hospitals and other critical areas.	Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Deferred Maintenance	Planning	Defer maintenance on natural gas systems unless identified as a need due to a vulnerability study. Will increase availability of support staff for quicker repairs as needed.		Expands capacity for emergency system repair.	$

3.4 Critical Data and Communication

Summary

Critical Data and Communications systems are vital to campus operations, especially for the business continuity of operations. Payroll, classes, and general operations all rely on a robust network served by incoming utility fibers that can be physically affected by natural climate events. Additionally, many campuses have satellites and antennae that operate as components of emergency response systems and are critical to maintaining the safety and security of those on campus. Climate hazards such as flooding, wildfires, extreme heat, and power outages can all directly affect the infrastructure and negatively impact data and communications capabilities. Mitigation strategies to secure backup power to communications systems and physically harden data fibers will increase the resilience of this infrastructure type.

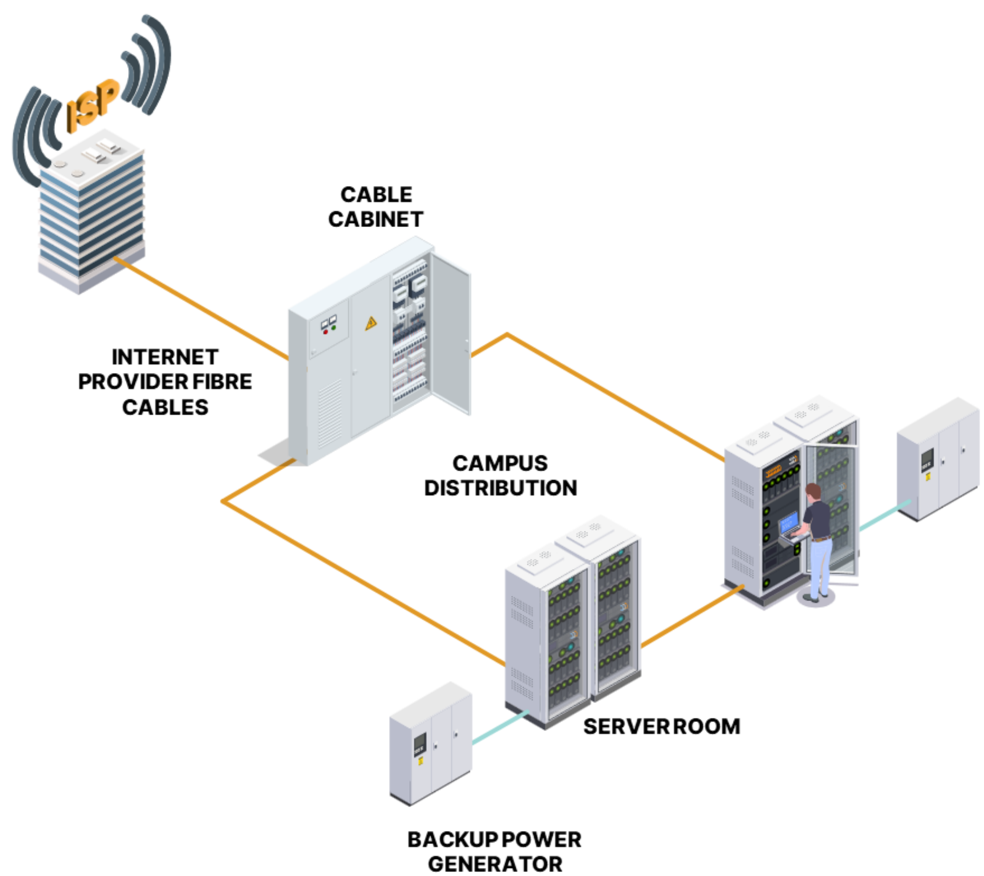

Figure 28: Example Critical Data and Communication System

Critical Infrastructure and Key Considerations

The critical data and communications infrastructure has multiple vulnerabilities that ought to be considered when evaluating a campus's overall resilience. Specifically, utility fibers, antennae, satellites, distribution networks, and electrical power supply are all crucial components for sustaining the operation of the data and communication system. Server rooms are also an integral part of the system. While the rooms themselves are typically within buildings and outside this report's scope, the infrastructure serving the rooms, such as data fiber cables and electrical supply, are addressed.

For a critical data and communications system with no additional resilience features, these focus areas are summarized in **Table 12**, with key considerations per component. To accommodate the 23 different campuses using this report, a campus ought to evaluate its specific design options per infrastructure component to help identify where the respective resilience gaps are. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 14**.

Table 12: Critical Components of a Data and Communication System

Infrastructure Component	Climate Resilience Considerations
Distribution Lines	• Radial vs looped distribution • Meshed/Interconnected layout • Adequate capacity • Hardened against extreme heat, wildfires, and flooding • Age and general condition
Server Rooms	• Located out of floodplains • Backup power supply • Adequate cooling capacity • Redundant cooling systems
Internet Fiber Cables	• Multiple cables from the internet provider • Service from multiple internet providers • Geographic separation between internet provider cablings • Preferred vendor contracted for repairs • Adequate capacity • Hardened against extreme heat, wildfires, and flooding • Age and general condition
Antennae/Satellites	• Location/Line of sight • Backup power supply/Battery systems • Sufficiently hardened against extreme heat, high wind events, and storms • Age and general condition

Climate Impacts

Extreme heat: During extreme heat events that frequently trigger power outages, overheating of IT equipment, such as server rooms, becomes a concern. If a server room overheats, the campus risks valuable equipment, and operations shut down, and the loss of important data. Data transmission lines might also lose capacity as the temperature increases, reducing or interrupting campus communications.

Wildfires: Wildfires can cause forced shutdowns of electrical infrastructure to avoid further ignition events. If the regional electrical infrastructure fails, the disruption in power supply may impact data operations reliant upon electricity.

Flooding: Flooding is a major concern for any communications infrastructure or IT equipment located below or at grade. Water could infiltrate underground conduit housings, damaging communications wiring within. Any equipment on or below the first floor would be at risk as the water level rises. Additionally, wet ground could cause utility poles to fall, interrupting the campus's power and internet service.

Power Quality and Capacity: Large spikes in power quality and capacity can potentially disrupt critical communications infrastructure that is not protected by power conditioning equipment, such as UPS systems. A power outage caused by a breaker trip will similarly cause server rooms without backup power systems to reset, potentially causing large losses of data and communications capabilities.

Energy Demands: Increasing energy demands can cause potential disruptions to IT equipment, as demands that are higher than the electrical infrastructure's supply capacity can cause temporary outages. While most IT equipment will likely be considered critical and thus prioritized if a campus must shut off non-essential electrical demands, any data or communication systems without backup power capabilities will still be at risk of losing power.

Water Supply: Changes in regional water supply are not anticipated to have a significant effect on critical data and communications systems.

Resilience Strategies

Table 13 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, backup power systems at critical network hubs will greatly reduce the risk of energy demands, but it will only somewhat mitigate the risks presented by extreme heat.

Table 13: *Data and Communications Resilience Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Diversified and Redundant Fiber Distribution Network**	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	
	Hardened Data Distribution System	Low Impact	Low Impact	Low Impact			
	Backup Power Systems at Critical Network Hubs/Server Rooms	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
	Flood Protection	High Impact	Low Impact	Low Impact			
	Preferred Vendor Priority Repairs Contract	High Impact	High Impact	High Impact			
	Multiple Internet Service Providers	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	
	Co-locate Servers	High Impact	High Impact	High Impact	High Impact	High Impact	
	Redundant and Adequately Sized HVAC Systems for Server Rooms		High Impact	Low Impact			

Table 14: Critical Data and Communications Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Diversified and Redundant Fiber Distribution Network	Infrastructure	Install a diverse and redundant set of fiber optic cables throughout the campus. This strategy has two parts: verifying the incoming internet service provider cabling has redundant entrances to campus that are ideally geographically separated and designing the distribution system to be looped and overlapping. This will increase the likelihood that there is an intact fiber pathway for data to travel along if any segment of the distribution system fails.	This can be implemented incrementally and should be evaluated for feasibility whenever data service is brought to a new building or any significant infrastructure renovation projects are considered.	Increases existing infrastructure reliability and provides alternate routes for data pathways.	$$$
Hardened Data Distribution System	Infrastructure	Evaluate and confirm that the data distribution cables are adequately hardened to withstand physical hazards such as flooding, extreme heat, and wildfires. This could take the form of a vulnerability assessment, identifying aged or weakened components and taking action to fix them.	Evaluate the Hazards section to determine which are relevant to the individual campus, then harden the data distribution system accordingly.	Increases existing infrastructure reliability.	$$$
Backup Power Systems at Critical Network Hubs/Server Rooms	Infrastructure	Provide backup power generation at all critical facilities that act as communications hubs for the campus. If any server rooms are critical to operations, verify the rooms have redundant power supplies with adequate energy storage and UPS systems, to avoid fluctuations in power quality or supply.	This could be battery back-up systems or fossil fuel-based generators. Evaluate which is a better fit regarding costing, footprint, and potential mandates around fossil fuel combustion.	Increases existing infrastructure robustness with additional capabilities.	$$
Flood Protection	Planning	Verify critical data equipment is located out of known floodplains, to reduce the possibility of water intrusion. For facilities and equipment that are in areas known to flood, relocate the equipment to second story server rooms or verify the servers and building envelope are adequately waterproofed to withstand flooding events.	Evaluate maps for historical flood plains and utilize past campus flooding case studies to highlight priority areas.	Identifies potential future hazards and increases existing infrastructure reliability.	$
Preferred Vendor Priority Repairs Contract	Planning	Coordinate an emergency supply contract with the utility provider to identify the campus as a high priority customer during times of outage. This could possibly be an agreement that the campus's data systems are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Multiple Internet Service Providers	Planning	Procure internet service from at least two different providers to have an alternate source of network connectivity, in case a provider briefly experiences an outage in operations.	If possible, plan to have the two internet service provider cables enter the campus from two different geographic directions, to diversify network supply routes.	Increases existing infrastructure reliability and provides alternate routes for data pathways.	$
Co-locate Servers	Planning	Consider a backup, alternate location for an additional set of critical servers. While other strategies increase instantaneous network connectivity capabilities, having an additional set of servers will support the campus retaining its saved data in the case that one server room experiences damage or failure.	The alternate location could be another physical server room elsewhere on campus, an additional location off campus, or the campus can rent server space in a co-located, corporate data center and back up its data via the cloud.	Increases reliability by providing a backup source of saved data and reduces the likelihood of lost information.	$$
Redundant and Adequately Sized HVAC Systems Treating Server Rooms	Infrastructure	Verify that server rooms have redundant cooling systems to act as a backup in case an HVAC system fails. Additionally, verify that the HVAC systems are adequately sized for current cooling loads and future design conditions, which may mandate upsizing the cooling system.		Increases existing infrastructure reliability and performance.	$$

3.5 Central Heating and Cooling

Summary

Many college campuses utilize large, centralized heating and cooling plants (also called central utility plants) to provide hot and chilled water used for temperature control within buildings. These centralized designs reduce maintenance needs but create a resilience vulnerability; if a central utility plant fails, the campus will be without heating and cooling capabilities. The central utility plants can be affected by multiple external hazards, but the primary concern is loss of power to the plant or physical damage to the equipment from flooding or wildfires.

Climate change can also lead to changes in energy demand, as hotter temperatures can increase the need for cooling, and colder temperatures can increase the need for heating. If either of these temperature changes put excessive strain on the power grid and cause rolling brownouts, it will impact the operations of the central heating and cooling plant. To mitigate these hazards, central utility plants should have backup power sources (either fuel or electrical, depending on the equipment) and redundant equipment to support continuous operation.

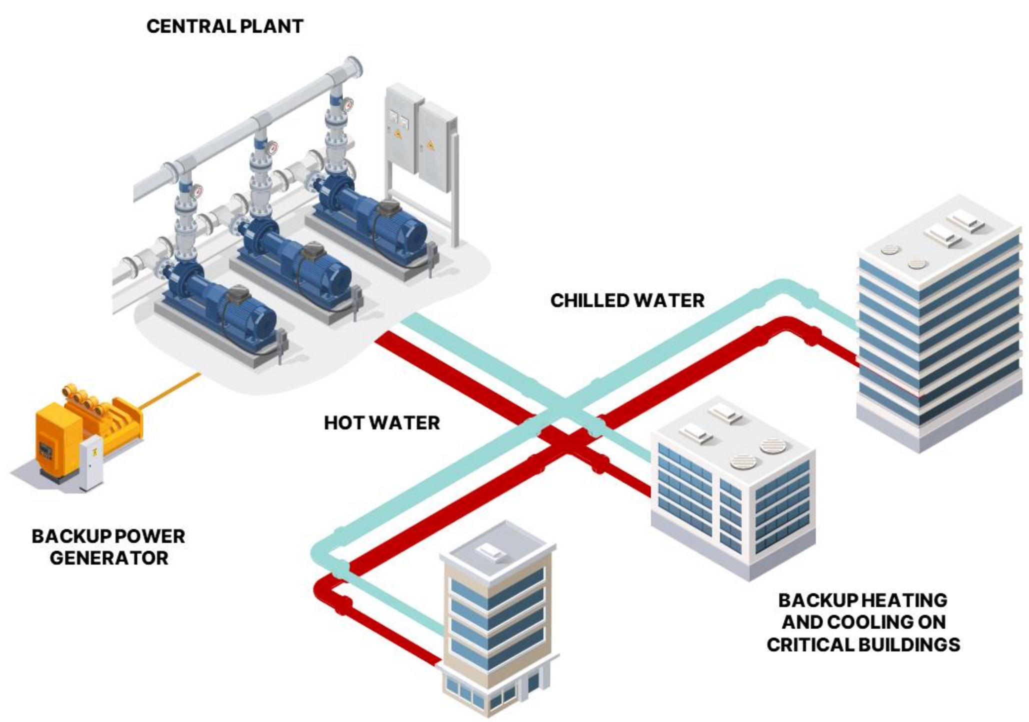

Figure 29: *Example Central Heating and Cooling System*

Critical Infrastructure and Key Considerations

A centralized heating and cooling system has multiple vulnerabilities to increase the overall resilience of the campus. Specifically, the vulnerabilities would be any thermal equipment at the central plant such as boilers, chillers, heat pumps, and distribution pumps. If these pieces of equipment fail, and there are no redundancies, it will impact the thermal continuity of the campus. Additionally, the power supply infrastructure is critical to supporting operations at the thermal plant.

Any singular point of supply for distributing hot or chilled water to facilities could also be a vulnerability, as any failure would cause all downstream facilities without backup mechanical equipment to lose heating and cooling capabilities. Finally, while not technically an infrastructure system, having an adequately trained and staffed crew of maintenance personnel is crucial in the complicated equipment operating correctly.

For a centralized heating and cooling system with no additional resilience features, these focus areas are summarized in **Table 15**, with key considerations per component. To accommodate the 23 different campuses that will use this report, a campus ought to evaluate its specific design options per infrastructure component, to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 17**.

Table 15: *Critical Components of a Central Heating and Cooling Infrastructure System*

Infrastructure Component	Climate Resilience Considerations
Maintenance Personnel	• Adequate capacity to maintain systems and conduct repairs • Expertise in equipment
Central Plant (Heating and Cooling Equipment)	• Adequate capacity to meet heating and cooling demand • Redundant equipment • Back-up power for all heating and cooling equipment • Spare parts on hand for replacement • Age and general condition • Trained maintenance staff
Central Plant (Pumps)	• Back-up power for all critical pumps and pump houses • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition
Distribution System	• Looped vs radial distribution layout • Adequately insulated to avoid transmission losses • Physically hardened lines rated to withstand extreme heat, wildfires, and high winds • Age and general condition

Climate Impacts

Extreme heat: Extreme heat events typically lead to an increased cooling load and, therefore, higher electrical demand. The primary risk from extreme heat events is the increased electrical demand causing brownouts and the central utility plant equipment losing power. Additionally, extreme cooling demands may cause the cooling equipment to operate at its maximum capacity, putting strain on the equipment and potentially shortening its useful life. While heatwaves may exceed the existing equipment's cooling capacity, that would likely cause buildings to be warmer than desired, rather than damaging the equipment at the plant.

Wildfires: Wildfires can cause forced shutdowns of electrical infrastructure, in order to avoid further ignition events. If a central plant does not have its own backup power source, this will interrupt the operations of the heating and cooling systems. Additionally, the increased heat from proximity during wildfires can cause exposed, individual pieces of distribution equipment to fail, or overly heat chilled water distribution lines, reducing their efficiency. Hardening the distribution system through practices such as vulnerability assessments and upgraded piping can increase the system's resilience. Additionally, backup power systems support power continuity at the central plant during public safety power shutoffs.

Flooding: Flooding can severely damage central plant equipment that is in flood plains and on ground level. Additionally, floods can affect chilled and hot water distribution lines, potentially causing them to rupture in extreme cases. If the local power grid fails due to flooding, it is likely that heating, cooling, and pumping operations will also be negatively affected. Hardening the chilled and hot water distribution system so the heating and cooling equipment is properly elevated and securing back-up power generation for the central plant will increase the system's overall resilience.

Power Quality and Capacity: Higher electricity demands, potentially caused by extreme temperatures and increased demands for cooling or heating, may cause a strain on electrical capacity. Consider onsite back-up power capabilities, such as microgrids and generators, to increase the resilience of central heating and cooling plants.

Energy Demands: If energy is not being delivered to the central utility plants, they cannot provide heating and cooling capabilities. Additionally, if the campus buildings are demanding heating and cooling that is more than what the central utility plant can provide, it will put a strain on the central mechanical equipment. This will likely reduce the useful life of the equipment.

Water Supply: A reduced water supply can impact heating and cooling operations that distribute thermally treated water. Most central plant systems are closed-loop and thus should only lose negligible amounts of water. However, any central plants using open-air cooling towers will require significant amounts of make-up water to maintain adequate volumetric flow in the chilled water distribution system. Not being able to supply this make-up water would severely impact cooling operations.

Resilience Strategies

Table 16 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, the central plant on back-up power will cause the risk of energy demands to reduce greatly, but it will only slightly mitigate the risks of wildfires.

Table 16: *Central Heating and Cooling Resilience Strategies by Effect on Climate Hazard*

Mitigation Strategies	Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Future Thermal Demand Study and Equipment Upgrades		Low Impact	Low Impact	High Impact	High Impact	
Central Plant on Back-up Power	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
Hardened Chilled Water, Hot Water, and Steam Distribution Lines	High Impact	High Impact	High Impact			Low Impact
Redundant Distribution Booster Pumps	Low Impact					
Higher Cycles of Concentration at Cooling Towers		Low Impact	Low Impact			High Impact
Valve Controls/Optimization at the Building Level		Low Impact	Low Impact	Low Impact	Low Impact	
Emergency Repair Prioritization (Contracted Maintenance)	Low Impact	Low Impact	Low Impact			
Deferred Maintenance						

***Table 17:** Central Heating and Cooling Resilience Strategies*

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	CapEx Considerations
Future Thermal Demand Study and Equipment Upgrades	Planning	Conduct a study to evaluate future growth at the campus based on historical trends. Verify the study considers higher demand for cooling during summer months and heating during winter months in future years. Use the results of the study to determine if the thermal equipment at the central plant is adequately sized, and upgrade the equipment as needed.	If equipment upgrades or capacity increases are needed, consider a modular setup that simplifies incorporating additional heating or cooling modules, or evaluate upsizing the existing equipment when it reaches the end of its useful life.	Identifies potential future hazards and increases existing infrastructure reliability and performance during emergencies.	$
Central Plant on Back-up Power	Infrastructure	Verify the distribution booster pumps, heating, cooling, and controls equipment at the central plant are all on back-up power and can operate independently from grid power in the case of an outage. Verify the back-up power is sized to allow for adequate runtime.	This could be battery back-up systems or fossil fuel-based generators. Evaluate which is a better fit regarding costing, footprint, and potential mandates around fossil fuel combustion.	Increases existing infrastructure reliability with back-up power during emergencies.	$$
Hardened Chilled Water, Hot Water, and Steam Distribution Lines	Infrastructure	Verify the hot water, steam and chilled water distribution systems are adequately hardened and insulated. This could take the form of a vulnerability assessment, identifying existing leaks or aged components in disrepair and taking action to fix them. This can be used to passively improve normal operations or increase the system's durability against climate events.	Evaluate the Hazards section to determine which are relevant to the individual campus, then harden the distribution system accordingly.	Increases existing infrastructure reliability and performance.	$$$
Redundant Distribution Booster Pumps	Infrastructure	Verify there are redundant booster pumps at the central plant to allow for continued operations in case of failure. Additionally, verify there are onsite spare parts to expedite repairs as needed.		Increases existing infrastructure reliability and expands capacity for emergency system repair.	$$
Higher Cycles of Concentration at Cooling Towers	Planning	Update design and operations standards to allow for higher cycles of concentration at central plant cooling towers. This reduces the need for make-up water and allows operations to continue for longer when the water supply is disrupted.	This strategy can be supplemented with straining or water-softening techniques at the cooling tower.	Increases existing infrastructure robustness with additional capabilities.	$
Valve Controls/Optimization at the Building Level	Infrastructure	Retro-commission the valve controls at buildings connected to the central chilled water loop to optimize operations. This will help manage the cooling capacity at the central plant and reduce the likelihood of exceeding the plant's maximum cooling capacity during heat waves. Additionally, increased energy efficiency lowers the strain placed on the plant during times of high demand and increases sustainment duration during a power outage.		Increases existing infrastructure reliability during emergencies and general performance during normal operations.	$
Emergency Repair Prioritization (Contracted Maintenance)	Planning	Coordinate an emergency supply contract with the preferred mechanical vendor to identify the campus as a high-priority customer during outages or times when equipment fails. This could possibly be an agreement that the campus is prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Deferred Maintenance	Planning	Defer maintenance on mechanical systems unless identified as a need due to a vulnerability study. Will increase availability of support staff for quicker repairs as needed.		Expands capacity for emergency system repair. Saves money on repairs until they are needed.	$

3.6 Potable Water

Summary

Potable water systems are vital to the operations of a campus, especially for life safety and sustaining residence hall operations. The distribution systems themselves are typically one of the more robust infrastructure types, as the pipelines are usually underground, hardened, and transporting a non-volatile substance. However, the source of potable water, especially in California, is highly variable. Climate risks, such as drought, flooding events, and wildfires can affect the utility transmission network for potable water. Mitigation strategies to conserve water and mitigate the effects of drought can be highly effective in verifying the resilience of this infrastructure type.

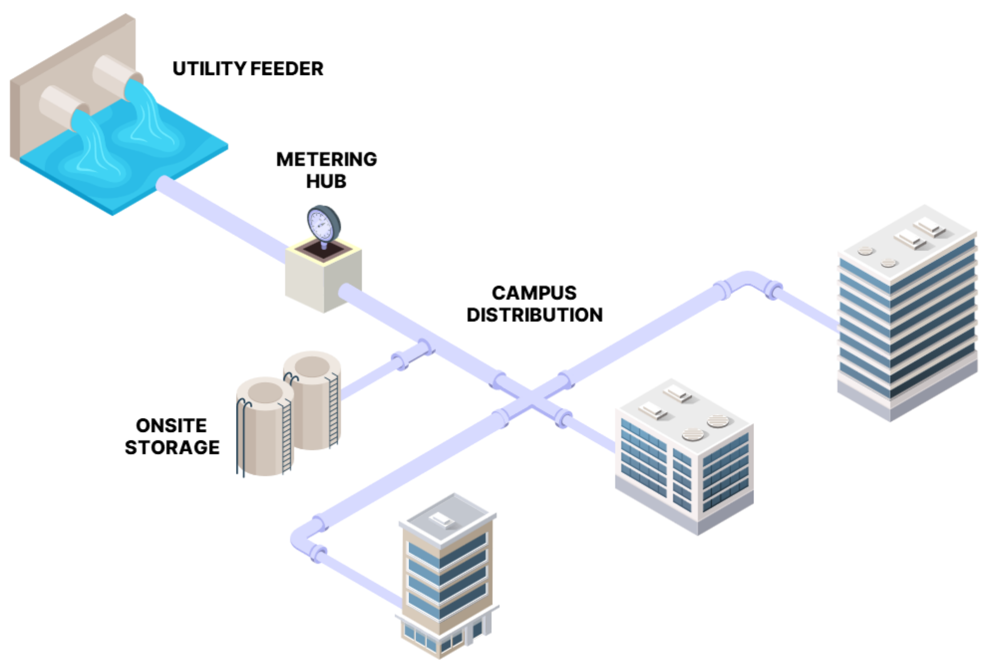

Figure 30: *Example Potable Water System*

Critical Infrastructure and Key Considerations

The potable water system has multiple vulnerabilities that ought to be considered when evaluating a campus's overall resilience. Specifically, an effective potable water system depends on the supply line fed from the utility, the onsite distribution system, and the pumping network. Additionally, upstream issues, such as water scarcity in the area that the utility is sourcing its water from, can affect supply to the campus and other customers of the utility. This issue of water scarcity can be mitigated by onsite storage systems.

For a potable water system with no additional resilience features, these focus areas are summarized in **Table 18** with key considerations per component. To accommodate the 23 different campuses that will use this report, a campus ought to evaluate its specific design options per infrastructure component to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 20**.

Table 18: *Critical Components of a Potable Water System*

Infrastructure Component	Climate Resilience Considerations
Utility Feeder	• Redundant water supply lines with adequate capacity • Geographical separation between entering utility feeders • Physically hardened pipes rated to withstand external hazards • Age and general condition
Distribution System	• Looped vs radial vs linear distribution layout • Sectionalizing capabilities • Physically hardened pipes rated to withstand external hazards • Age and general condition
Pumps	• Back-up power for all critical pumps and pump houses • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition
Onsite Storage	• Adequate capacity • Located out of floodplain • Age and general condition • Emergency back-up power for pumping systems • Redundant pumps at centralized storage location

Climate Impacts

Extreme heat: Extreme heat, especially when causing drought conditions, can negatively impact a region's water supply. Additionally, heightened temperatures may cause issues in power supply and electrical demand. If power sources to pumping stations and water treatment plants fail, the potable water supply to campuses will be negatively affected. Finally, the increased demand for potable water during extreme heat may strain an already limited water supply.

Wildfires: Wildfires can negatively impact the power infrastructure in a region. If the power to local pumping stations and water treatment plants is shut down, a campus may experience loss of potable water supply. Additionally, wildfires cause significant smoke and ash pollution in the air, which may contaminate local potable water reservoirs.

Flooding: Flooding can have adverse effects on potable water supplies. A flood can cause non-potable water to infiltrate reservoirs of potable water supplies and contaminate the supply or reroute existing water sources, causing potable water shortages. Additionally, potable water pipelines that cross over creeks and rivers may be negatively impacted by increased water levels and cause damage to the infrastructure. Furthermore, pumping stations that become fully submerged by floods may cease operations and reduce the water supplied to campuses.

Power Quality and Capacity: Power quality and capacity issues could potentially disrupt pumping operations that do not have battery back-up systems. However, most alarm systems are considered critical to life safety and are mandated by code so they have power back-up systems. Verifying these back-up power capabilities will guarantee the resilience of these systems.

Energy Demands: Power quality and capacity issues could potentially impact fire alarm systems that do not have battery back-up systems. However, most alarm systems are considered critical to life safety and are mandated by code so they have power back-up systems. Verifying these back-up power capabilities will guarantee the resilience of these systems.

Water Supply: Potable water is extremely impacted by regional shortages in water supply. Water conservation strategies and onsite storage are the best options for increasing the infrastructure's resilience in response to this hazard.

Resilience Strategies

Table 19 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. A campus that knows specifically which risks it faces can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, onsite storage will greatly reduce the risk of low water supply, but it will only somewhat mitigate the risks presented by flooding.

Table 19: *Potable Water Resilience Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Redundant and/or Upgraded Feeder**	Low Impact					Low Impact
	Water Demand Study		Low Impact				Low Impact
	Hardened Water Distribution System	Low Impact					Low Impact
	Prioritization Plan of Water Usage/Critical Buildings	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	High Impact
	Onsite Storage	Low Impact	Low Impact	Low Impact	High Impact	High Impact	High Impact
	Deferring Non-Critical Uses to Non-Potable Water Sources	Low Impact	Low Impact	Low Impact	High Impact	High Impact	High Impact
	Deferred Maintenance						

Table 20: Potable Water Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Redundant, Upgraded, or Feeders	Infrastructure	Request/Install/Upgrade a redundant potable water supply feeder from the utility. Verify both feeders are adequately sized so that either one could independently handle the demand of the campus's critical loads if the other feeder fails. If available, verify the feeds enter campus from separate geographic directions.	Implement in tandem with "Water Demand Study" and use the results of the study to inform the necessity of a redundant feeder and, if needed, the capacity.	Increases existing infrastructure reliability by providing alternate supply methods.	$$$
Water Demand Study	Planning	Conduct a study to evaluate future growth at the campus based on historical trends. Verify the study considers higher demand for water and reduced supply during summer months in future years. Use the results of the study to determine if the potable water feeders from the utility are adequately sized.	Use results from study to inform "Redundant and/or Upgraded Feeder"	Identifies potential future hazards.	$
Hardened Water Distribution System	Infrastructure	Verify the potable water distribution system is adequately hardened. This could take the form of a vulnerability assessment, identifying existing leaks or aged components in disrepair and taking action to fix them.	Evaluate the Hazards section to determine which are relevant to the individual campus, then harden the water distribution system accordingly.	Increases existing infrastructure reliability and performance.	$$$
Prioritization Plan of Water Usage/Critical Buildings	Planning	Create a prioritized list of critical facilities and/or services that require water for operations. Consider a tiered list denoting a need for "uninterruptable water supply," "critical but can handle short outages," and "non-critical/doesn't use water."	Can utilize results from the “Water Demand Study” to evaluate where there is a need for water.	Highlights priority actions to take during an outage/emergency and increases sustainment duration of critical operations.	$
Deferring Non-Critical Uses to Non-Potable Water Sources	Planning	Use the prioritized list of critical facilities and/or operations that require an uninterruptable water supply. Establish a plan to switch any lower priority operations to using non-potable water as the water source or shutting off its water supply completely.	Implement in tandem with "Prioritization Plan of Water Usage/Critical Buildings" and use the study results to inform which uses are not critical. Can also be implemented with greywater harvesting as the non-potable water source.	Increases sustainment duration of critical operations during an outage.	$
Onsite Storage	Infrastructure	Install onsite storage tanks to provide a buffer for sustainment outage duration in the case of the utility feeders failing. Verify the storage tanks are adequately sized to continue operations and meet minimum sustainment duration requirements as outlined in emergency procedure outlines.	If feasible (depending on location and proximity of critical operations requiring potable water), prioritize a single centralized location over multiple building level storage tanks.	Increases sustainment duration of critical operations during an outage.	$$
Emergency Repair Prioritization (Contracted Maintenance)	Planning	Coordinate an emergency supply contract with the utility provider to identify the campus as a high priority customer during times of outage. This could possibly be an agreement that the campus’s feeders are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Deferred Maintenance	Planning	Defer maintenance on potable water systems unless identified as a need due to a vulnerability study or other concern.		Expands capacity for emergency system repair. Saves money on repairs until they are needed.	$

3.7 Storm Drain and Stormwater

Summary

Storm drain and stormwater infrastructure are crucial systems for sustaining operations during times of flooding, high precipitation, and other inundation events. Storm drains, when operating correctly, effectively divert high water levels away from campus and avoid further damage to buildings and infrastructure systems. As climate change causes extreme weather events with increasing severity and regularity, storm and stormwater drainage systems will become even more important aspects of a resilient campus's infrastructure. To increase the resilience of these systems, a campus should consider upsizing the capacity of the relevant infrastructure and verify there is redundancy in the pumping system components and power supplies.

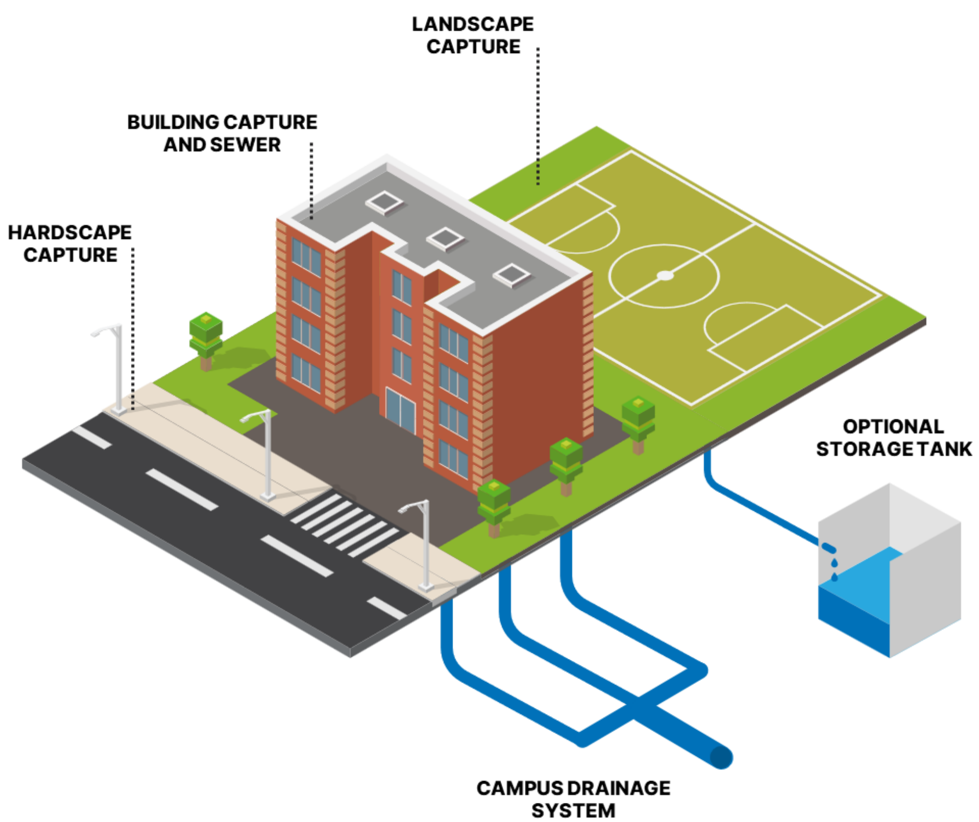

Figure 31: *Example Storm Drain, Stormwater, and Sanitary Sewer Infrastructure*

Critical Infrastructure and Key Considerations

The storm drain and stormwater infrastructure system has multiple vulnerabilities that ought to be considered when evaluating a campus's overall resilience. Specifically, the vulnerable components are the pipes, drain entrances, retention ponds, and pumping systems. If these components do not have the capacity to drain excess water during a storm surge, it will cause a build-up of standing water. While a typical stormwater drainage system will have been adequately sized for the climate conditions existing during its design, future storms capable of more severe downpour and flooding can cause the influx of water to a campus to be higher than the total drainage flow rate.

Additionally, significant water buildup on a campus can impact pumping infrastructure, either through physical damage to the pumps themselves or by damaging upstream electrical infrastructure and impacting the pumps' power supply. Either occurrence would affect the stormwater drainage system's total discharge capacity.

For a storm drain and stormwater system with no additional resilience features, these focus areas are summarized in **Table 21**, with key considerations per component. To accommodate the 23 different campuses using this report, a campus ought to evaluate the specific design options per infrastructure component to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 23**.

Table 21*: Critical Components of a Storm Drain and Stormwater System*

Infrastructure Component	Climate Resilience Considerations
Building/(Discharge) Pipes	• Capacity of ingress to discharge system (size of storm drain entrance) • Age and general condition • Backflow flooding during high-capacity events
Drainage System	• Instantaneous capacity of drainage infrastructure • Diameter of pipes • Storage capacity • Harvesting capabilities • Age and general condition
Bioswales/Retention Ponds	• Capacity of retention pond • Located in floodplain
Pumps	• Back-up power for all critical pumps and pump houses • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition

Climate Impacts

Extreme heat: Extreme heat, if it is sustained and leads to drought, can affect the volatility of regional water cycles. While drought would not immediately cause increased flooding or affect drainage systems, higher temperatures can cause increased humidity and allow more water to be absorbed into the atmosphere. This causes higher precipitation levels during storm events, potentially leading to water levels that are beyond the capacity of the existing drainage systems.

Wildfires: Wildfires, depending on their severity, will negatively impact a region's surrounding vegetation and plant life. Plants and specifically, forests, are excellent nature-based solutions for increasing soil's capacity to absorb water and mitigate volatile flooding events. When wildfires destroy the local flora, this mitigation disappears, and local campuses are much more vulnerable to flooding during the next high precipitation event.

Flooding: Flooding is the greatest risk to storm drain and stormwater systems. High water levels can exceed the capacity of the drainage pipes and pumphouses. When a campus fails to evacuate standing water from storms or floods, all infrastructure types are negatively impacted. Refer to the other risks that can potentially lead to increased flooding concerns. Increasing future severity of storms can increase flooding conditions to be greater than the capacity discharge of existing infrastructure.

Power Quality and Capacity: Multiple components of a campus's storm drainage system will rely upon electricity to operate, such as pump houses and digital controls. Spikes in power supply or large variations in frequency could potentially trip breakers or reset sensitive pieces of equipment. Consider power conditioning equipment such as uninterruptible power supply systems that will support resilient pumping operations during power outages or other extreme events.

Energy Demands: Multiple components of a campus's storm drainage system will rely upon electricity to operate, such as pump houses and digital controls. Losses of power during an outage, or strained power during times of high demand, can affect the drainage system's ability to operate and reduce its overall capacity. Consider back-up power generators that will support resilient pumping operations during power outages or other extreme events.

Water Supply: A lack of water supply will likely not affect a storm drain infrastructure system.

Resilience Strategies

Table 22 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, upsizing the drainage lines will greatly reduce the risk of flooding, but it will only somewhat mitigate the risks of energy demands.

Table 22: *Storm Drain and Stormwater Resilience Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Drainage Capacity Study**		Low Impact	Low Impact	High Impact	High Impact	
	Upsize Drainage Lines	High Impact			Low Impact	Low Impact	
	Redundant Booster Pumps/Spare Parts at Lift Stations	High Impact	Low Impact	Low Impact			
	In-Line Water Tank Storage at Building Discharges	High Impact	Low Impact	Low Impact			High Impact
	Greywater Harvesting	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	High Impact
	Emergency Repair Prioritization (Contracted Maintenance)	High Impact	Low Impact	Low Impact			
	Increased Size of Retention Ponds	High Impact	Low Impact	Low Impact	Low Impact	Low Impact	
	Booster Pumps on Back-up Power	High Impact	Low Impact	Low Impact	High Impact	High Impact	

Table 23: Storm Drain and Stormwater Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Drainage Capacity Study	Planning	Conduct a study to evaluate future growth at the campus based on historical trends. Verify the study considers future storm conditions when consulting design tables. Use the study results to determine if the drainage pipes are adequately sized.	Use results from the study to inform "Upsize Drainage Lines."	Identifies potential future hazards.	$
Upsize Drainage Lines	Infrastructure	Upsize the drainage line to the nearest discharge facility. Verify the line is adequately sized to accommodate future, more severe storms and flooding conditions.	Implement in tandem with the "Drainage Capacity Study" and use the study results to inform the necessity of a redundant feeder and, if needed, the capacity.	Increases existing infrastructure reliability and performance.	$$$
Redundant Booster Pumps/Spare Parts at Lift Stations	Infrastructure	Where not already mandated by the local jurisdiction, verify there are redundant booster pumps at lift stations to allow for continued operations in case of failure. Additionally, verify there are onsite spare parts to expedite repairs as needed.	Drainage systems may be entirely gravity-based but evaluated at lift stations or areas requiring booster pumps.	Increases existing infrastructure reliability and performance.	$$
In-Line Water Tank Storage at Building Discharges	Infrastructure	Install in-line water storage tanks at individual building-level discharges before the drainage line joins the campus-level drainage system. This will provide an additional buffer capacity for stormwater storage in the event of storm surges that could temporarily exceed the capacity of the campus drainage system.	This can be done in a phased implementation program that prioritizes specific buildings. These storage tanks could also be used as water sources for the greywater harvesting strategy.	Increases existing infrastructure robustness with additional capabilities.	$$$
Greywater Harvesting	Infrastructure	Consider a greywater harvesting system that captures excess stormwater and treats it for reuse as a non-potable water source. More potable water would remain available for uses such as drinking water, showers, and food preparation.	The non-potable water could be used for non-critical operations, such as landscape irrigation, cooling tower makeup water, and flushing toilets.	Increases sustainment duration during an outage.	$$$
Emergency Repair Prioritization (Contracted Maintenance)	Planning	Coordinate an emergency supply contract with the utility provider to identify the campus as a high-priority customer during outage times. This could possibly be an agreement that the campus feeders are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Increased Size of Retention Ponds	Infrastructure	Increase the size of retention ponds to provide additional buffer capacity for stormwater storage in the event of storm surges. This will absorb significant stormwater runoff while the drainage system diverts water from the campus.	Requires existing retention ponds or could be modified to install new ones if any areas are historically flood prone.	Increases existing infrastructure reliability and avoids potential damage.	$$$
Booster Pumps on Back-up Power	Infrastructure	Where not already mandated by the local jurisdiction, verify the booster pumps at lift stations are on back-up power and can operate independently from grid power in the case of an outage. Verify the back-up power is sized to allow for adequate run time.	This could be battery back-up systems or fossil fuel-based generators. Evaluate which is a better fit regarding costing, footprint, and potential mandates around fossil fuel combustion.	Increases existing infrastructure reliability with back-up power during emergencies.	$$

3.8 Sanitary Sewer

Summary

Climate change can pose significant hazards to sanitary sewer infrastructure, including treatment plants, pumping infrastructure, and drainage networks. Extreme weather events, such as rising sea levels, floods, and power outages caused by climate hazards, can damage or disrupt sanitary sewer infrastructure. To mitigate these hazards, sanitary sewer infrastructure should be designed and built to withstand more extreme weather conditions. Transitioning to a more robust, adequately sized, and redundant system can increase resilience and reduce vulnerability to climate change.

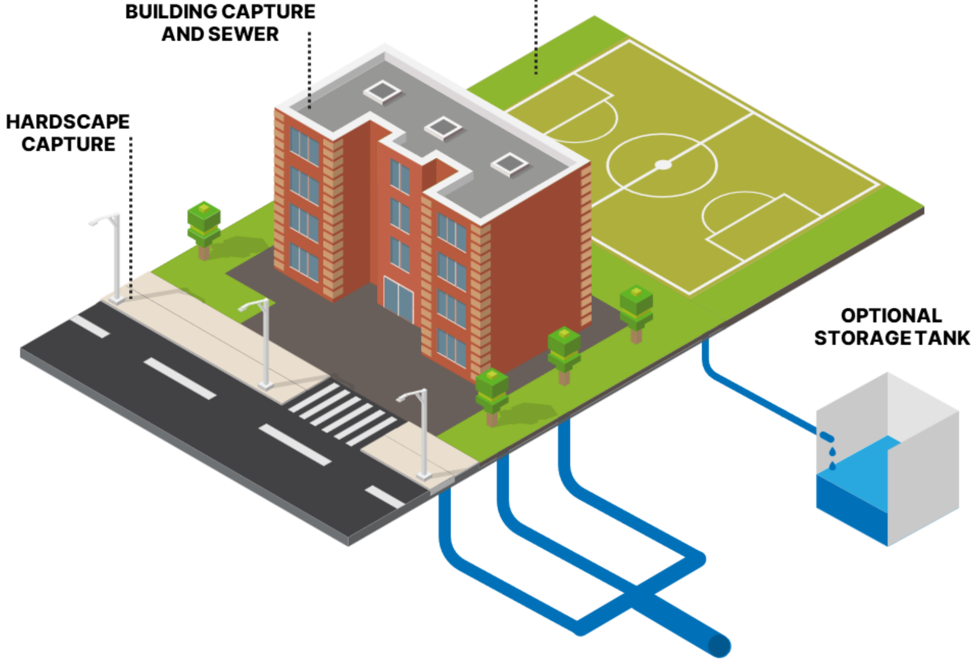

Figure 32: *Example Storm Drain, Stormwater, and Sanitary Sewer Infrastructure*

Critical Infrastructure and Key Considerations

The sanitary sewer system has multiple vulnerabilities that ought to be considered when evaluating a campus's overall resilience. In general, the most critical components are any onsite treatment plants and discharge piping infrastructure. Sanitary sewer waste must pass through a treatment plant before it can be fully disposed of. Therefore, any disruption in operations at the treatment plant can cause sewage back-ups. Additionally, if the piping system is of inadequate capacity or in poor condition and fails due to an extreme climate event, sewage can back-up or leak into the campus and surrounding areas. Finally, if the pumping systems lose power or are damaged, the operational capacity of the sanitary sewer system will also be damaged.

For a sanitary sewer system with no additional resilience features, these focus areas are summarized in **Table 24**, with key considerations per component. To accommodate the 23 different campuses using this report, a campus ought to evaluate their specific design options per infrastructure component, to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 26**.

Table 24: *Critical Components of a Sanitary Sewer System*

Infrastructure Component	Climate Resilience Considerations
Treatment Plants	• Capacity of treatment plant • Age and general condition • Back-up power supply • Spare parts on hand for replacement • Located out of floodplain
Pipes/Drainage System	• Redundant discharge routes • Age and general condition • Adequate volumetric capacity • Storage system capacity • Harvesting capabilities
Pumps	• Back-up power for all critical pumps and pump houses • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition

Climate Impacts

Extreme Heat: Extreme heat is not expected to have any significant effect on sanitary sewer systems.

Wildfires: Since wildfires increase the severity of flooding, a nearby wildfire event could indirectly contribute to both flooding and power quality concerns.

Flooding: Extreme rainfall and flooding events could cause sewer back-up in certain regions, especially areas with a combined stormwater and blackwater system such as San Francisco. This could cause sewage back-up into buildings or onto campus grounds, leading to unsanitary conditions and expensive repairs.

Power Quality and Capacity: Sanitary sewer systems rely upon treatment plants to effectively operate. If the treatment plant temporarily loses power due to an upstream electrical failure, the sewer system cannot be effectively discharged. If the treatment plant is on campus, this could cause a major back-up of sewage. Similarly, if power is lost to any booster pumps, the system's discharge capacity may be affected and could cause a sewage back-up.

Energy Demands: Sanitary sewer energy demands are not expected to significantly increase from external climate hazards to the point that it is detrimental to operations.

Water Supply: Following an extreme flooding event, there is a possibility that water sources may become contaminated by overflowing sewers, leading to a lack of potable water available to the campus.

Strategies

Table 25 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, onsite storage will greatly reduce the risk of low water supply, but it will only somewhat mitigate the risks presented by extreme heat.

Table 25: *Sanitary Sewer Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Drainage Capacity Study**		Low Impact	Low Impact	High Impact	High Impact	
	Upsize Drainage Lines	High Impact			Low Impact	Low Impact	
	Redundant Booster Pumps/Spare Parts at Lift Stations	Low Impact	Low Impact	Low Impact			
	Onsite Storage	Low Impact	Low Impact	Low Impact			High Impact
	Greywater Harvesting	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	High Impact
	Emergency Repair Prioritization (Contracted Maintenance)	Low Impact	Low Impact	Low Impact			
	Backwater Valve at Buildings	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	
	Booster Pumps on Back-up Power	Low Impact	Low Impact	Low Impact	High Impact	High Impact	

Table 26: Sanitary Sewer Resilience Strategies

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Drainage Capacity Study	Planning	Conduct a study to evaluate future growth at the campus based on historical trends. Use the results of the study to determine if the drainage pipes are adequately sized.	Use results from the study to inform "Upsize Drainage Lines."	Identifies potential future hazards.	$
Upsize Drainage Lines	Infrastructure	Upsize the existing drainage line to the nearest wastewater treatment plant facility. Verify the line is adequately sized to accommodate anticipated future growth of the campus.	Implement in tandem with "Drainage Capacity Study" and use the results of the study to inform the necessity of an additional discharge route.	Increases existing infrastructure reliability and performance.	$$$
Redundant Booster Pumps/Spare Parts at Lift Stations	Planning	Verify there are redundant booster pumps at lift stations to allow for continued operations in case any pumps fail. Additionally, verify there are onsite spare parts to expedite repairs as needed.	Drainage systems may be entirely gravity-based, but evaluate at any lift stations or areas that require booster pumps.	Increases existing infrastructure reliability and performance.	$
Onsite Storage	Infrastructure	Install onsite storage for sewage, to allow buffer periods for diversion to the nearest treatment facility if any events disrupt the typical sewage evacuation path. Verify the storage is adequately sized to handle long durations of disruption.	Can be done in a phased implementation program that prioritizes specific buildings. Additionally, these storage tanks could be used as water sources for the greywater harvesting strategy.	Increases existing infrastructure robustness with additional capabilities.	$$$
Greywater Harvesting	Infrastructure	Consider a greywater harvesting system that captures excess sanitary sewer water and treats it for reuse as a non-potable water source.	The non-potable water could be used for non-critical operations, such as landscape irrigation, cooling tower make-up water, and flushing toilets.	Increases sustainment duration of critical operations during an outage as more potable water would be available for uses such as drinking water, showers, and other domestic activities.	$$$
Emergency Repair Prioritization (Contracted Maintenance)	Infrastructure	Coordinate an emergency supply contract with the utility provider to identify the campus as a high priority customer during times of outage. This could possibly be an agreement that the campus's feeders are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	$
Backwater Valve at Buildings	Infrastructure	Install backwater valves at buildings so if there is a sewage back-up due to a downstream event, the sewage does not re-enter and flood the building.	Benefits from in-line storage tanks implemented in tandem with this strategy.	Increases existing infrastructure robustness with additional capabilities.	$$
Booster Pumps on Back-up Power	Infrastructure	Where not already required by local jurisdiction, verify the booster pumps at lift stations are on back-up power and can operate independently from grid power in the case of an outage. Verify the back-up power is sized to allow for adequate runtime.	This could be battery back-up systems or fossil fuel-based generators. Evaluate which is a better fit regarding costing, footprint, and potential mandates around fossil fuel combustion.	Increases existing infrastructure reliability with back-up power during emergencies.	$

3.9 Fire Alarm and Fire Water

Summary

Fire alarm and fire water systems are vital to the operations of a campus, especially for the life safety of students and faculty. Fire water systems depend heavily on a robust distribution and pumping network, fed by a dependent source of potable water. However, the source of potable water, especially in California, is highly variable and can be affected by many climate risks, such as drought, flooding events, and wildfires that affect the utility transmission network. Mitigation strategies to conserve water, verify redundancy in pumping equipment, and provide back-up power to the fire water pumps can be highly effective in the resilience of this infrastructure type.

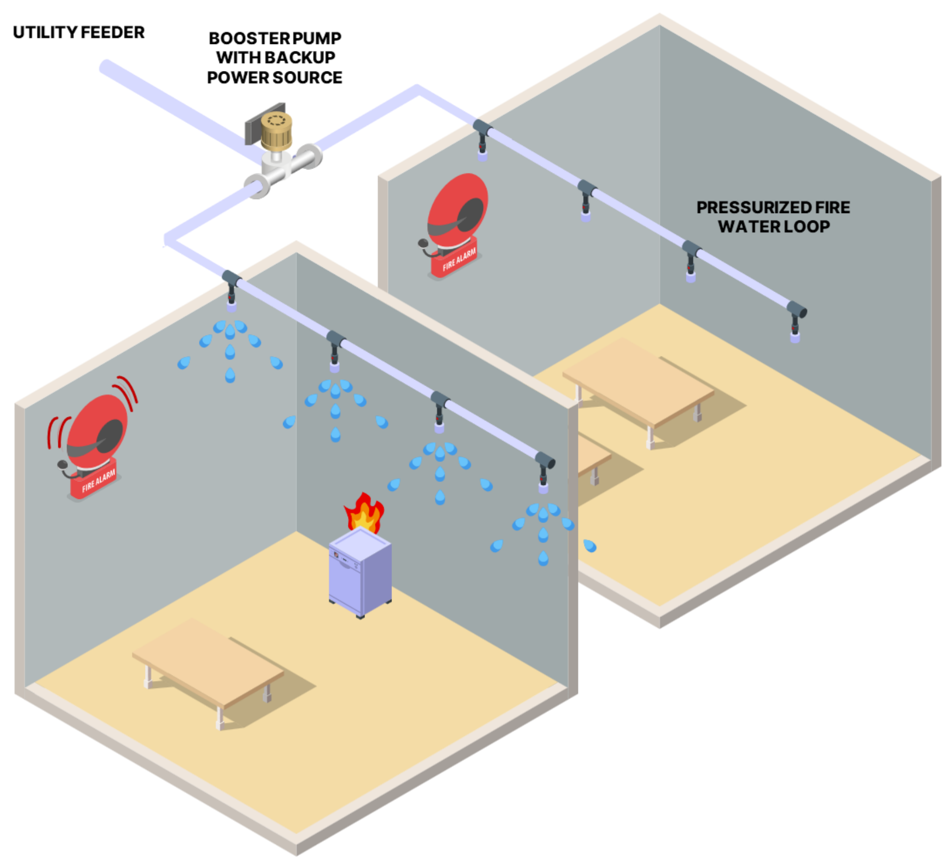

Figure 33: *Example Fire Alarm and Fire Water System*

Critical Infrastructure and Key Considerations

The fire alarm and fire water system has multiple vulnerabilities that ought to be considered when evaluating a campus's overall resilience. In general, the single most important function of the infrastructure system is to keep the building loops pressurized with enough water to adequately suppress a fire event. This function relies heavily on the water distribution system and building level booster pumps serving the fire water loops. The alarms within a facility should be evaluated as well, but they are outside the scope of this report, which focuses on the infrastructure leading up to a building.

For a fire alarm and fire water system with no additional resilience features, these focus areas are summarized in **Table 27**, with key considerations per component. To accommodate the 23 different campuses that will use this report, a campus ought to evaluate its specific design options per infrastructure component, to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 29**.

Table 27: *Critical Components of a Fire Alarm and Firewater System*

Infrastructure Component	Climate Resilience Considerations
Fire Alarms	• Age and general condition • Back-up power supply
Distribution System	• Pressurized fire water lines • Onsite water storage • Age and general condition • Alternate water supply connections (Fire Department Connection)
Pumps	• Back-up power for all critical pumps • Redundant pumps • Adequately sized pumps • Spare parts on hand for replacement • Age and general condition

Climate Impacts

Extreme heat: Extreme heat, especially when causing drought conditions, can negatively impact a region's water supply. Additionally, heightened temperatures may cause issues in power supply and electrical demand. If power sources to pumping stations and water treatment plants fail, the water supply to campuses will be negatively affected. Finally, the increased demand for potable water during extreme heat may strain an already limited water supply.

Wildfires: Wildfires can negatively impact the power infrastructure in a region. If the power to local pumping stations and water treatment plants is shut down, a campus may experience a loss of potable water supply. Additionally, wildfires cause significant air smoke and ash pollution, which may contaminate local potable water reservoirs.

Flooding: Flooding can have adverse effects on water supplies. A flood can cause non-potable water to infiltrate reservoirs of water supplies and contaminate the supply or re-route existing water sources, causing water shortages. Additionally, water pipelines that cross over creeks and rivers may be negatively impacted by increased water levels and cause damage to the infrastructure. Furthermore, pumping stations that become fully submerged by floods may cease operations and reduce the water supplied to campuses.

Power Quality and Capacity: Power quality and capacity issues could potentially disrupt pumping operations that do not have battery back-up systems. However, most alarm systems are considered critical to life safety and are mandated by code, so they have power back-up systems. Verifying these back-up power capabilities will support the resilience of these systems.

Energy Demands: Power quality and capacity issues could potentially impact fire alarm systems that do not have battery back-up systems. However, most alarm systems are considered critical to life safety and are mandated by code, so they have power back-up systems. Verifying these back-up power capabilities will guarantee the resilience of these systems.

Water Supply: Fire alarm and fire water systems are extremely impacted by regional shortages in water supply. Water conservation strategies and onsite storage are the best options for increasing the infrastructure's resilience in response to this hazard.

Resilience Strategies

Table 28 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, back-up power for booster pumps will cause the risk of energy demands to reduce greatly, but it will only mitigate the risks presented by extreme heat somewhat.

***Table 28:** Fire Alarm and Fire Water Resilience Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Back-up Power for Booster Pumps**	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
	Adequately Sized Booster Pumps		Low Impact	High Impact			
	Onsite Water Storage		High Impact	High Impact			High Impact
	Redundant Booster Pumps/Spare Parts	High Impact	Low Impact	High Impact			
	Safely Positioned Fire Department Connection (FDC)		Low Impact	High Impact			

Table 29: *Fire Alarm and Fire Water Resilience Strategies*

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Back-up Power for Booster Pumps	Infrastructure	Where not already required by the local jurisdiction, verify the fire water booster pumps are on back-up power and can operate independently from grid power in the case of an outage. Verify the back-up power is sized to allow for adequate runtime.		Increases existing infrastructure reliability with back-up power during emergencies.	$$
Adequately Sized Booster Pumps	Planning	Where not already required by the local jurisdiction, verify the booster pumps are adequately sized to keep the fire water loops pressurized.		Increases existing infrastructure reliability and performance.	$$
Onsite Water Storage	Infrastructure	Install small onsite storage tanks at each building to provide a buffer for sustainment outage duration in the case of the utility feeders failing. Verify the storage tanks are adequately sized to keep a fire water loop pressurized in the event of an emergency.		Increases sustainment duration during an outage.	$$
Redundant Booster Pumps/Spare Parts	Planning	Verify there are redundant booster pumps at buildings to allow for continued operations in case any pumps fail. Additionally, verify there are onsite spare parts to expedite repairs as needed.		Increases existing infrastructure reliability and expands capacity for emergency repairs.	$
Safely Positioned Fire Department Connection (FDC)	Infrastructure	Verify the Fire Department Connection (FDC) is positioned sufficiently far enough away from the building façade to allow for safe operation by the firefighters. It is likely these will be used specifically when the building to which it is attached is experiencing a fire event, so having the connection point adequately distanced increases life safety.		Expands capacity for emergency services and increases the safety of the emergency responders.	$

3.10 Roadway and Utility Infrastructure

Summary

Roadways are critical supply routes for transporting students and faculty to and from campus. They are also critical for supplies, such as food, water, repair parts, maintenance staff for utilities, maintenance staff for mechanical systems, and emergency response teams. Natural geographic features can reduce road systems to a singular route of entry or exit to the campus, causing a potential restriction on the delivery of crucial supplies or congestion for evacuation. Furthermore, campuses may have alternative modes of transport such as railways that students and faculty can use to enter or exit campus. The same strategies used for roadways can be applied to rails in the context of this report's scope. Finally, consideration should be given to charging stations that allow the operation of electric vehicles.

Verify that roads and bridges provide multiple, overlapping routes of entrance and exit to the campus and that all roadway infrastructure is regularly evaluated and maintained. Finally, identify any segments of road or bridge that are typically impacted during extreme climate events to highlight alternate evacuation or supply routes, in the case of flooding, wildfires, or other hazards.

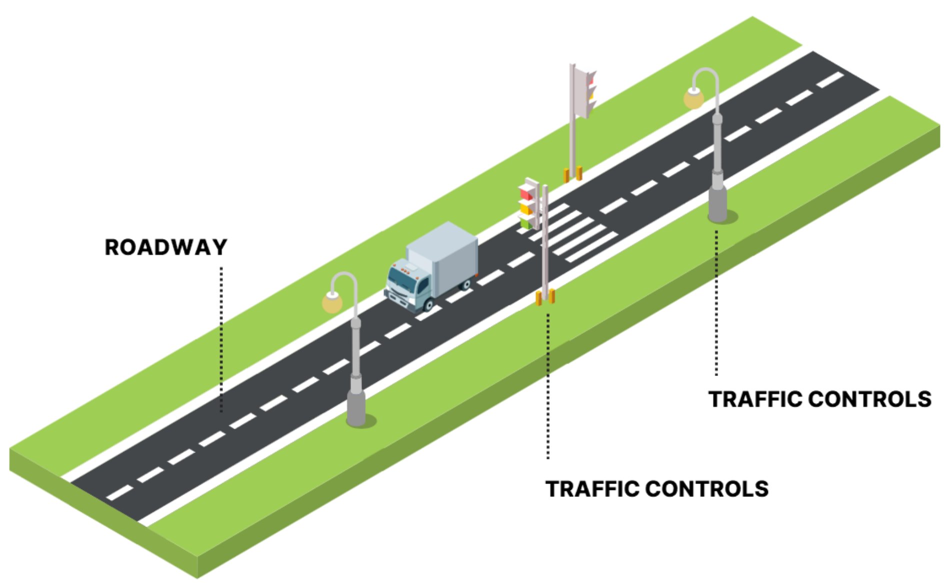

Figure 34: *Example Roadway and Utility Infrastructure*

Critical Infrastructure and Key Considerations

Roadway systems are relatively robust and resilient, as there are few operating pieces that are particularly vulnerable. When evaluating the resilience of roadway systems, focus should be given to the redundancy of routes to campus and any natural bottlenecks that reduce the roads to a single point of entry. Specifically, any bridges over rivers or gaps that are the sole entryway to the campus should be given additional focus and prioritized when evaluating repairs. Additionally, roads passing through areas that are known to be prone to flooding, erosion, or other natural hazards represent vulnerabilities in the roadway infrastructure.

For a roadway system with no additional resilience features, these focus areas are summarized in **Table 30**, with key considerations per component. To accommodate the 23 different campuses using this report, a campus ought to evaluate the specific design options per infrastructure component to help identify the respective resilience gaps. Once the gaps are identified, it will be easier to identify the relevant mitigation strategies in **Table 32**.

Table 30: *Critical Components of a Roadway and Utility System*

Infrastructure Component	Climate Resilience Considerations
Roads	• Multiple supply routes to and evacuation routes from campus • Location versus floodplains • Age and general condition
Bridges	• Multiple supply routes to and evacuation routes from campus • Adequate height • Age and general condition
Traffic Signals and Lighting	• Back-up power systems • Age and general condition • Adequate controls
Charging/Fuel Stations	• Location, redundancy, and capacity of power stations (fossil fuel or electric) • Age and general condition • Fossil fuel/electric charging stations on backup power

Climate Impacts

Extreme heat: In the most severe circumstances, extreme heat could make travel along roadways dangerous due to increased temperatures of sidewalks and asphalt. This is unlikely to have a major effect on vehicular travel but could affect foot traffic along roadways.

Wildfires: Wildfires can prompt evacuations of students and faculty from a campus. If the wildfire event is close to a road, that route may be shut down for safety. The significant outflow of vehicles, combined with potentially closed roads, can lead to problematic congestion, rendering the roadways less efficient or even unusable in the case of complete gridlock.

Flooding: Flooding may submerge roads or undersized bridges, rendering the routes unusable for travel. Additionally, if the flooding is severe, it may permanently wash away entire segments of road or bridges. This will remove that road or bridge as a usable route until it is fully repaired, reducing the efficacy of the overall roadway infrastructure system.

Power Quality and Capacity: Utility shutoffs and blackouts, regardless of cause, can impact traffic signals and roadside lighting. Either system failing could affect the safety of drivers and can cause additional congestion along roadways, increasing the time needed to deliver supplies or evacuate the local population. Additionally, any campus fleets or communities that rely upon campus-based electric vehicle chargers can be negatively impacted by power capacity concerns.

Energy Demands: Energy demands on the grid may cause rolling brownouts, which could impact traffic signals and roadside lighting. Either system failing could affect the safety of drivers and can cause additional congestion along roadways, increasing the time needed to deliver supplies or evacuate the local population. Additionally, any campus fleets or communities that rely upon campus-based electric vehicle chargers can be negatively impacted by energy demand concerns.

Water Supply: Water supply issues are unlikely to affect roadway infrastructure.

Resilience Strategies

Table 31 shows how the strategies that are outlined fully on the next page can mitigate the climate risks explained in Chapters 1 and 2. For a campus that knows specifically which risks it faces, it can use this chart to identify which strategies will have the highest mitigating impact against the relevant hazards. The "High" and "Low" in the chart mean that instituting the strategy will reduce the risk of the hazard by a "High" or "Low" amount. For example, adequate traffic systems will cause the risk of energy demands to reduce greatly, but they will only mitigate the risks presented by extreme heat somewhat.

***Table 31**: Roadway Resilience Strategies by Effect on Climate Hazard*

		Flooding	Extreme Heat	Wildfires (Direct)	Power Quality	Energy Demands	Water Supply
Mitigation Strategies	**Redundant Travel Routes**	High Impact	High Impact	High Impact			
	Alternative Modes of Travel	Low Impact	Low Impact	Low Impact			
	Adequate EV Charging Capacity/Backup Power Source	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
	Adequate Traffic Systems	Low Impact	Low Impact	Low Impact	High Impact	High Impact	
	Roadway Vulnerability Assessment	Low Impact					
	Emergency Repair Prioritization (Contracted Maintenance)	Low Impact					
	On Hand Emergency Flood Barriers	High Impact					

Table 32: Roadway and Utility Infrastructure

Strategy Name	Category	Description of Scope	Implementation Considerations	Benefits	Cost Considerations
Redundant Travel Routes	Infrastructure	Verify there are redundant travel routes and entrance/exit points throughout the entire campus. Consider expanding any single-lane bottlenecks and adding additional routes of travel for historically congested avenues.	Specific focus should be given to any roads or bridges crossing natural barriers, such as rivers, trenches, or between hills or cliffs. Verify there are alternate routes of travel through or around these obstacles.	This will improve the reliability and performance of the existing infrastructure as there will be less congestion during both normal operations and emergencies.	**$$$**
Alternative Modes of Travel	Infrastructure	Provide modes of travel that are alternate to single passenger vehicles, such as bus stops, railways that route through campus, and incentives for carpooling. This will reduce congestion during emergency evacuations and provide redundancy in delivery routes for critical supplies.	This strategy could take multiple forms depending upon local constraints. Any action that reduces reliance on exclusively roads and single vehicle travel will increase resilience.	This will improve the reliability and performance of the existing infrastructure as there will be less congestion during both normal operations and emergencies.	**$$$**
Adequate EV Charging Capacity/Backup Power Source	Infrastructure	Verify that any onsite EV chargers are of adequate capacity and, if possible, provide a source of backup power generation.	The EV chargers can serve both the campus and surrounding community. Verify the existing electrical distribution infrastructure can handle the increased demand.	This will improve the reliability and performance of the existing infrastructure and allow for extended operation during outages.	**$$**
Adequate Traffic Systems	Infrastructure	Verify the traffic control systems are regularly maintained and tested and have a back-up power source. Additionally, where it is not already mandated by the local jurisdiction, verify there is back-up power sources for any roadway lighting.		This will improve the reliability and performance of the existing infrastructure as there will be less congestion during both normal operations and emergencies.	**$$**
Roadway Vulnerability Assessment	Planning	Regularly assess the roadway infrastructure for areas in disrepair or under stress. Consider prioritizing the repair of any particularly dangerous routes or bridges.		This will improve the reliability and performance of the existing infrastructure, as there will be less congestion during both normal operations and emergencies.	**$**
Emergency Repair Prioritization (Contracted Maintenance)	Planning	Coordinate an emergency supply contract with the utility provider to identify the campus as a high priority customer during times of outage. This could possibly be an agreement that the campus's feeders are prioritized when evaluating repair logistics.		Expands capacity for emergency system repair and reduces downtime after equipment failure.	**$**
On Hand Emergency Flood Barriers	Infrastructure	Consider acquiring emergency flood barriers to keep on hand for severe storm and flooding events. Use the barriers to divert water towards existing retention ponds or drainage systems to assist with flood mitigation.		Keeps supply and evacuation routes open during flooding events, allowing for quicker repairs to critical systems and for the local community to exit the area as needed.	**$**

CHAPTER 4: Additional Resources

A non-exhaustive list of resources that the CSU system can use when evaluating design standards are given below:

Table 33: *List of Resilience Resources and Databases*

Database Name	Description
The Fifth U.S. National Climate Assessment, Located at: The Fifth National Climate Assessment | USDA	Demonstrates how climate change impacts the various landscapes and geographies of America and how communities can employ technological and nature-based solutions to lower their risk.
Navy Climate Change Adaptation Planning Handbook, Located at: wbdg.org/FFC/DOD/DODHDBK/NAVFAC_CC_Handbook_012017.pdf	Lists and categorizes the four priority climate change phenomena including: rising global temperatures, changing precipitation patterns, increasing frequency or intensity of extreme weather events, and rising sea levels and associated storm surges. The handbook lists the impacts of each of these and provides policies or directives on how the Navy is mandated to respond to them.
Resilient Defense Infrastructure and Military Installations Resiliency, Located at: 2020 Report to Congress on Resilient Defense Infrastructre and Military Installations Resiliency.pdf (osd.mil)	Provides cost effective and practical methods to verify and increase the resilience of military installations. The same methodology can be used at college campuses, although likely applied to a lesser extent.
Department of Defense Climate Adaptation Plan, Located at: Department of Defense Climate Adaptation Plan	The Plan builds upon Climate Adaptation Roadmaps and provides a framework for how any agency, department, or community can prioritize climate resilience and the associated actions needed to do so.