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Grid Resilience Reports

Washington

Energy & Resources | Networks
12/10/2024

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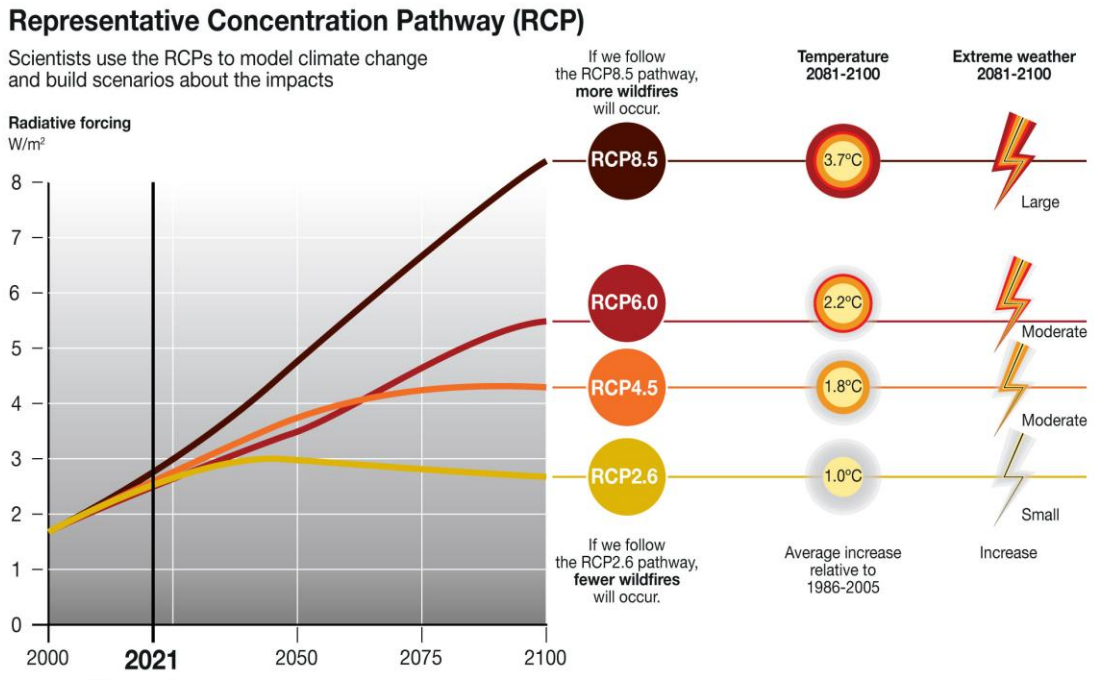
Grid Resilience Reports

Climate Science Background, Data Sources, and Analysis Approach

RCPs and SSPs provide viable climate pathways for an uncertain future

Generating Emission Scenarios

- **Representative concentration pathways (RCPs) project GHG concentrations:** Defined by the IPCC in 2014 as scenarios of future emission concentrations and other radiative forcing that align to climate projections.[1] RCPs use assumptions relating to policy decisions and individual behavior that may change future GHG emissions concentrations.[1] SSPs have largely replaced RCPs.
- **Shared socioeconomic pathways (SSPs) provide 5 'storylines' to contextualize RCPs** and to provide the various future pathways possible.[2] They consider how the world could evolve socioeconomically and politically, including how various levels of climate change mitigation and adaptation could be achieved and will influence future climate scenarios.[3]
- RCPs included in the CLIMRR dataset include RCP 4.5 and RCP 8.5.
- SSPs included in the Hydrosource dataset include SSP585, SSP370, SSP245, and SSP126.



GRID-Arendal/Studio Atlantis, 2021

Modeling Scenario: RCP 4.5

- **"Moderate" scenario**: Emissions peak around 2040 and then slowly begin to decline.[4] Temperatures warm about 3.2 °F from a 2000 baseline.[5]
- CO2 emissions plateau before falling mid-century, as energy use sharply declines and there is large scale reforestation.[6]

Modeling Scenario: RCP 8.5

- **"Rapid growth" scenario:** Emissions continue to rise throughout the twenty-first century.[4] Temperatures warm about 6.6 °F from a 2000 baseline.[5]
- CO2 emissions are three times higher than the present by end-century, with a large increase in methane emissions and continued fossil fuel use.[6]

[1] Source: ComEd Vulnerability Study 2023
[2] Source: Jupiter
[3] Source: Carbon Brief
[4] Source: Help (cal-adapt.org)
[5] CoastAdapt
[6] Climate Copernicus

Baringa leverages national downscaled climate datasets with high granularity to assign county-level climate exposure

	CLIMRR by Argonne National Lab (ANL)	HydroSource by Oak Ridge National Lab (ORNL)	RAWS by Western Regional Climate Center (WRCC)
Dataset Description	The Climate Risk and Resilience Portal (CLIMRR) provides highly localized climate projections from mid- to end-century using a supercomputer to model 60 climate variables.	HydroSource is a comprehensive national water energy digital platform consisting of hydropower-related data set, models, visualizations, and analytics tools.	The Wildland Fire Remote Automated Weather Stations (RAWS) data set provided by WRCC is a quality-controlled repository of hourly data for 17 select weather metrics from a network of weather stations across western states.
Data Provider Description	Argonne National Lab is a federally-funded science and engineering research center sponsored by the Department of Energy.	Oak Ridge National Lab is a federally funded research and development center sponsored by the Department of Energy.	The Western Regional Climate Center is one of 6 Regional Climate Centers in the United States. WRCC works jointly with NOAA to coordinate climate activities and conduct applied research on climate issues in the West.
Years Covered	Historical, Mid-Century, End-Century	1980-2099	2000-2022
Spatial Resolution	12 km (aggregated to county)	County	Weather station (aggregated to county)
Hazards	RAIN, FIRE, HEAT, COLD, DROUGHT	FLOOD	WIND

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Baringa leverages national downscaled climate datasets with high granularity to assign county-level climate exposure (cont.)

	CLIMRR by Argonne National Lab (ANL)	HydroSource by Oak Ridge National Lab (ORNL)	RAWS by Western Regional Climate Center (WRCC)
Key Metrics	Seasonal Fire Weather Index; Annual Precipitation; Cons. Days w/o Precipitation; Days Above X°F Heat Index; Annual Cooling Degree Days; Seasonal Max Temperature; Annual Min Temperature; Annual Heating Degree Days; Seasonal Min Temperature	Annual VIC Runoff (SSP585)	Hourly Max Wind Gust
Mapping/Analysis	Used a Python script that returned the most extreme value (high or low depending on hazard) from grid cells intersecting a particular county.	Averaged across the 7 different climate model values provided for the SSP585 warming scenario to return a single, composite runoff level for each county in each year. 2000 was used for historical, 2050 for mid-century, and 2090 for end-century.	Mapped weather stations to their respective counties. If a county had multiple weather stations, the station with the highest average hourly value was selected to represent the county. Counties with no stations were mapped to the closest station in a neighboring county. GEV analysis was conducted using the pyextremes EVA function to derive return periods.
Rationale	• Reputable data provider • Accessible, open-source data allows for our methodology to be reproduced/quality checked • Provides climate projections for hazards with a significant climate signal • More than sufficient spatial resolution to gauge climate exposure at a county level	• Reputable data provider • Climate projections forecast change in exposure over time • Same spatial resolution as outage data (county level) • Data set includes pluvial flooding (from flash floods and surface runoff) which is more likely to contribute to outages because it is faster-acting and can hit urban centers	• Reputable data provider • Wind does not have a strong climate signal, so projections were not required • Sufficient density of stations per state to assign to counties • Quality checked • Hourly resolution was sufficient for deriving return periods

Baringa is leveraging forward-looking climate projections to inform its technical assistance work for states in WECC

Wind

Source: **Western Regional Climate Center (WRCC)**
Input metric: Hourly max wind speed (mph)
Output: Wind speed at key return periods via GEV distribution

Wildfire

- Source: **CLIMRR (ANL)**

Input metric: Fire weather index (FWI) by grid cell
Output: Maximum fire weather index by county

Precipitation

Source: **CLIMRR (ANL)**
Input metric: Annual total precipitation (in/year) by grid cell
Output: Max annual total precipitation (in/year) by county

Drought

Source: **CLIMRR (ANL)**
Input metric: Consecutive days with no precipitation by grid cell
Output: Max consecutive days with no precipitation by county

Heat

Source: **CLIMRR (ANL)**
Input metrics:

- Days above 95, 105, 115, 125 °F
- Annual cooling degree days
- Seasonal maximum temperatures

Output: Input metrics applied from a grid cell level to a county level

Cold

Source: **CLIMRR (ANL)**
Input metrics:

- Annual minimum temperature
- Annual heating degree days
- Seasonal minimum temperatures

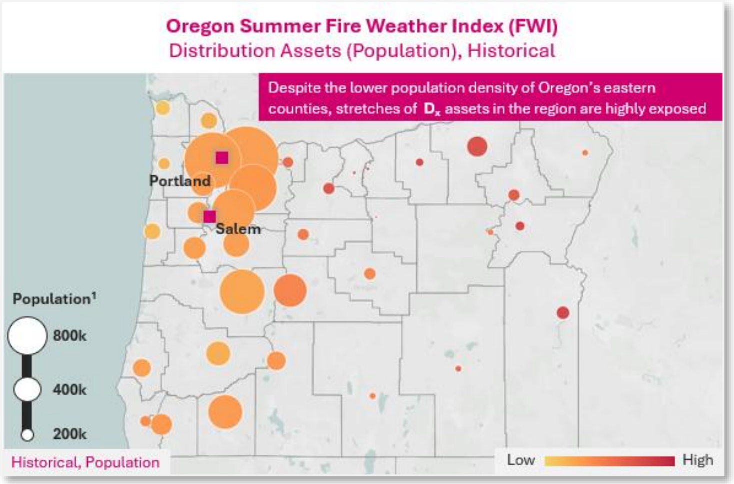
Output: Input metrics applied from a grid cell level to a county level

Flood

Source: **Hydrosource (ORNL)**
Input metric: Annual Variable Infiltration Capacity (VIC) model runoff (mm/year)
Output: Average annual VIC runoff (pluvial flooding) for 4 warming scenarios and 3 time periods (historical, mid-century, end-century)

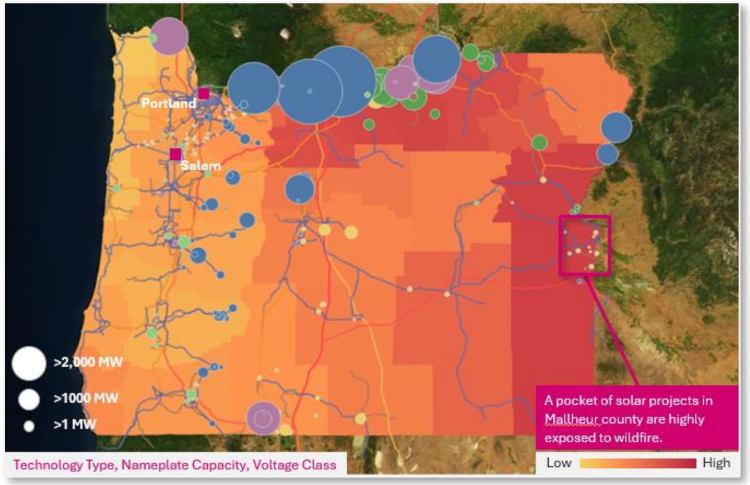
This report is standardized to include 3 different data visualizations that provide insights for Distribution, Transmission, and Generation across 7 extreme weather hazards

1 Distribution Maps



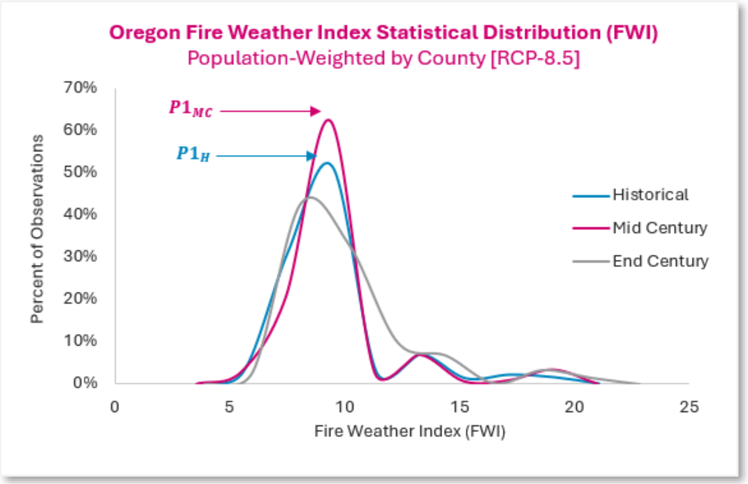
- **Purpose:** Uses population as proxy for volume of distribution assets given that the location of distribution assets is restricted.
- **Interpretation*:** Locate areas of high exposure by identifying counties with coincident large bubbles and dark colors. This indicates a combination of high volume of distribution (Dx) assets and significantly high extreme weather projections.

2 Transmission & Generation Maps



- **Purpose:** Overlays transmission and generation assets on climate projections by county.
- **Interpretation:** Locate areas of high exposure by identifying assets in counties of high risk. Exposure differs by asset class and will be highlighted in Key Insights tables throughout.

3 Statistical Distribution Graphs



- **Purpose:** Contains statistical insights related to each metric. Indicates change in dispersion and severity of risk over time on average
- **Interpretation:** An increase in the width of the peak indicates a decrease in concentration of exposure, meaning more counties are exposed to more severe weather. A shift right in the curve indicates that on average, counties are experiencing more severe weather.

***Note:** Analysis addresses risk given volume of assets and does not account for risk to remote customers at end of radial distribution grids.

Asset Class Overviews

Summary

L Low M Moderate H High

Increased extreme heat exposure will have significant impacts on Generation, and T&D assets, while fire exposure generally poses a larger threat to just T&D

Key Takeaways

- Fire poses a threat of failure to Dx and Tx assets in central counties with high exposure that border densely populated western metro areas.
- Extreme heat exposure is concentrated in SE and south-central counties, causing derating of electricity supply and T&D infrastructure.
- Despite warming over time, average minimums stay close to 32°F in northern counties, maintaining potential icing exposure across all asset classes.

Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution (Tx & Dx)	AWPI*	Projects to Address Exposure
FIRE	H	↑	**Wind and solar assets are not insulated from fire exposure** • Soot from fires could hurt turbine capacity factors for wind farms in Klickitat and Columbia counties that are heavily exposed to wildfire • Ash from wildfires accumulates on solar panels, reducing plant output during wildfire season.	**Centrally located counties face high exposure, posing risk to western adjacent population centers** • Major population centers border high-exposure counties, posing a threat to Dx and Tx assets in the case of wildfire spread and growing by 30% to 2100 [RCP-8.5]. • Tx lines in east and north that will become critical as WA transitions to a net importer, have significant wildfire exposure.		**Gen:** Enclosures, emergency response planning, panel cleaning, equipment elevation. **T&D:** Undergrounding, veg management, pole wrapping/upgrades, reconductoring.
HEAT	M	↑	**Extreme heat exposure contributes to plant derating** • Thermoelectric generators that rely on water-based cooling methods will experience derating. • Extreme heat causes derating for solar PV, decreasing energy output when demand is highest.	**Extreme heat can cause asset failure and demand spikes** • Extreme heat contributes to demand spikes, capacity derating, and failure for Dx and Tx assets. • Tx lines in east and north that will become critical as WA transitions to a net importer, have significant heat wildfire exposure, yielding capacity constraints and derating in times of need.		**Gen:** Climate-adjusted production modeling, DERs, enclosures. **T&D:** Undergrounding, reconductoring, DLR, line/cable upgrades, cooling systems.
COLD	M	↓	**Temperatures warm, but icing exposure persists** • Many generators face continued exposure to icing and other cold-related failures through mid-century.	**Cold exposure coincides with population centers** • Peak cold exposure coincides with population centers in the northwestern counties of the state, posing a threat of Dx and Tx icing and asset failure.		**Gen:** Enclosures, heating systems, equipment upgrades, insulation. **T&D:** Undergrounding, covered conductors, pole upgrades, enclosures.

*** AWPI = Alignment with proposed investment (40101(d) Round 1 project proposals)**

Will complete upon receipt of projects

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Baringa

L Low M Moderate H High

Increased drought exposure coupled with increased precipitation indicates that extreme precipitation is more likely, causing flooding and posing a threat to hydro output

Key Takeaways

- Flood exposure will increase in western counties, posing a threat to low-lying distribution assets in the region.
- WSDOC could consider working with utilities to update Dx design standards throughout the state and funding T&D hardening projects in western counties.
- Increased drought exposure and changing precipitation patterns could warrant projecting hydro generation output with climate-adjusted forecasts.

Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution (Tx & Dx)	AWPI*	Description
FLOOD	H	↑	**Natural gas and hydro assets are heavily exposed to flooding** • Grays Harbor Energy Center is highly exposed to flood, jeopardizing control houses and buildings. • Hydro plants in the western counties are at risk of dam overtopping.	**Peak flood exposure coincides with T&D asset density** • Flood exposure is projected to increase in populated western counties by mid-century. • Flooding poses a threat to a high density of Dx assets, particularly low-lying substations.		**Gen:** Reinforce dams, fortify control houses, elevate equipment. **T&D:** Enclose/elevate substations, build flood walls, upgrade Dx poles.
WIND	M	→	**Consider hardening for renewable generators in highly exposed regions** • Wind and hydro assets are exposed to high wind speeds in SE counties, which can decrease electricity output and cause failure.	**WSDOC could consider Tx structure and Dx pole upgrades in western counties** • WSDOC could prioritize Dx hardening in NW counties and Tx structure reinforcement in SW counties with crucial export lines to OR and CA.		**Gen:** Upgraded design standards, debris filtering. **T&D:** Pole upgrades, decreased spans, undergrounding.
DROUGHT	M	↑	**Decreased output for hydro and thermoelectric generators** • Hydroelectric assets along the Columbia River are exposed to peak drought levels at 75 days per year by 2050, contributing to decreased output.	**Drought exposure does not have a material impact on transmission and distribution assets**		**Gen:** Forecast hydro production with climate-adjusted inputs, upgrade air intakes.
RAIN	M	→	**Potential negative impacts on hydro generation** • Extreme precipitation events may become more likely over time, putting pressure on dams and increasing risk of failure.	**Precipitation exposure does not have a material impact on transmission and distribution assets**		**Gen:** Reinforce dams, monitor precipitation levels, request hydro data from neighboring SEOs.

*** AWPI = Alignment with proposed investment (40101(d) Round 1 project proposals)**

Will complete upon receipt of projects

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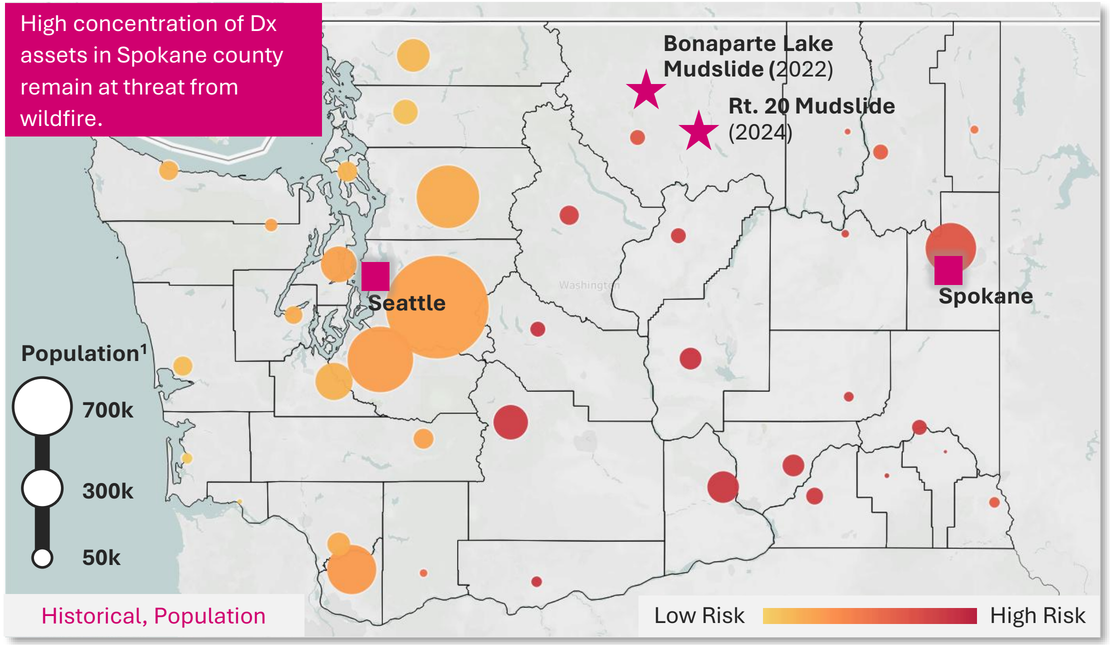
Wildfire

Asset Analysis

Major population centers border high-exposure counties, posing a threat to distribution assets in the case of wildfire spread

Washington Summer Fire Weather Index (FWI)

Distribution Assets (Population), Historical [RCP-8.5]

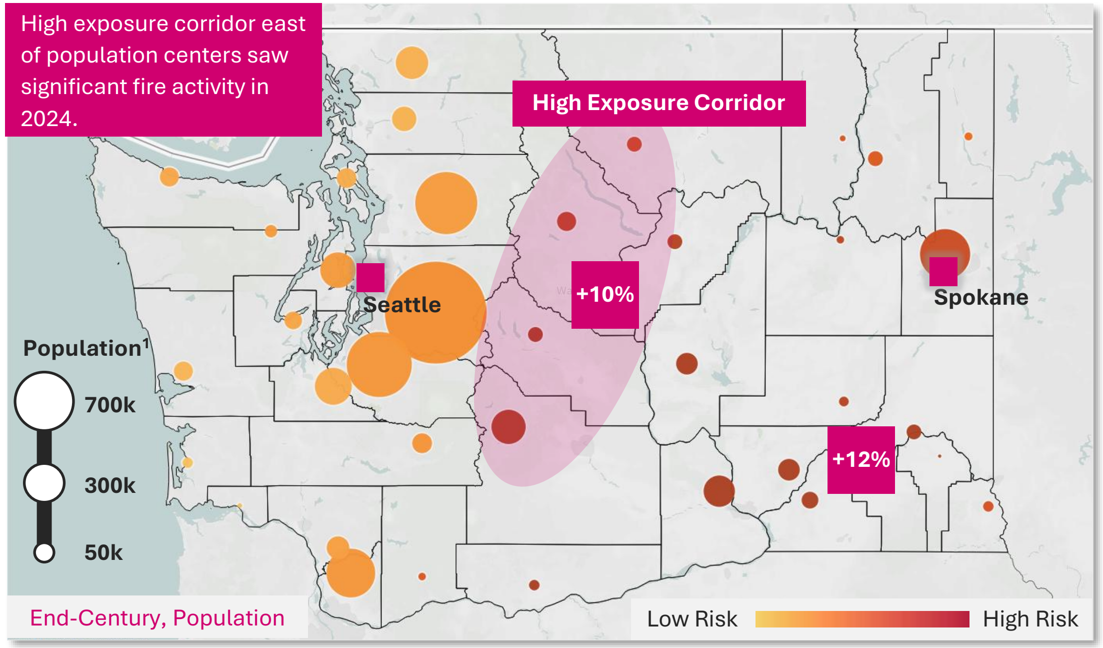


KEY OBSERVATIONS

- Historical wildfire exposure is concentrated in the Washington's **eastern counties** due to the region's drier climate and hotter temperatures.
- **Dx and Tx assets in Spokane County exhibit high exposure**, though highest exposure remains in sparsely-populated counties in the east.
- Assets in border counties remain at risk given fire's propensity to spread.

Washington Summer Fire Weather Index (FWI)

Distribution Assets (Population), End-Century [RCP 8.5]



KEY OBSERVATIONS

- Wildfire exposure generally increases by end-century, particularly becoming **more severe for eastern portions of the state.**

●	**Kittitas County**	Rural county significantly exposed to wildfire, posing a threat of prolonged outages for radial customers and fire spread to western population centers.

[1]Population bubbles are continuous and therefore labels are approximate

Source: ClimRR, US Census Bureau, City and Town Population Totals

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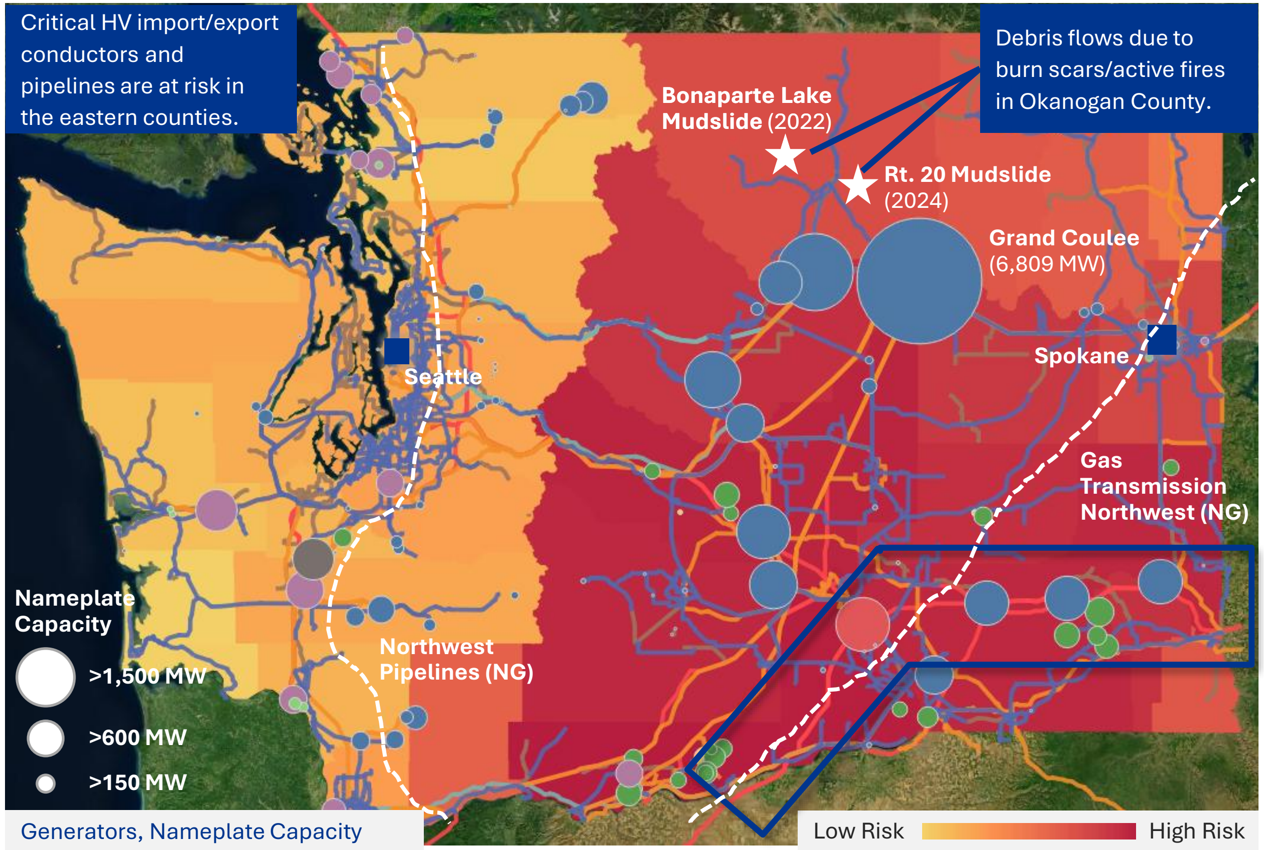
While most generators are insulated from wildfire risk, critical tie lines that support import and export capabilities are vulnerable to wildfires in the eastern region of the state.

Washington Summer Fire Weather Index (FWI)
Generators, Mid-Century [RCP-8.5]



Onshore Wind	Coal Plant	Hydroelectric	Nuclear	Solar Photovoltaic
Biomass	Natural Gas Plant	Pumped Storage	Batteries	Other
500kV	345kV	220-287kV	100-161kV	DC

Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Transmission	• Import/export 500+ kV lines connecting WA to OR are highly exposed in SE counties • WSDOC could **consider hardening these highly exposed lines given their crucial role during extreme weather events.**
Restoration	• Wildfire causes **ingress/egress issues** through destruction of roads and transportation, slowing restoration times and reopening.
Natural Gas	• **Gas Transmission Northwest**, a major NG pipeline, is exposed to elevated levels of wildfire exposure in east WA. Even in undergrounded sections, measurement and control assets are highly vulnerable.
Solar	• During wildfire season, **ash from nearby burns accumulates on solar arrays**, inhibiting irradiation exposure and decreasing plant output.

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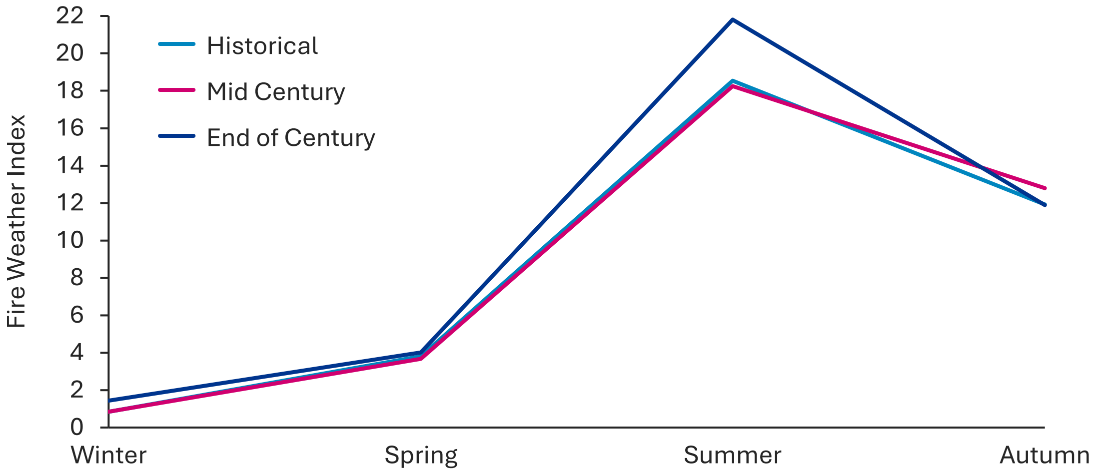
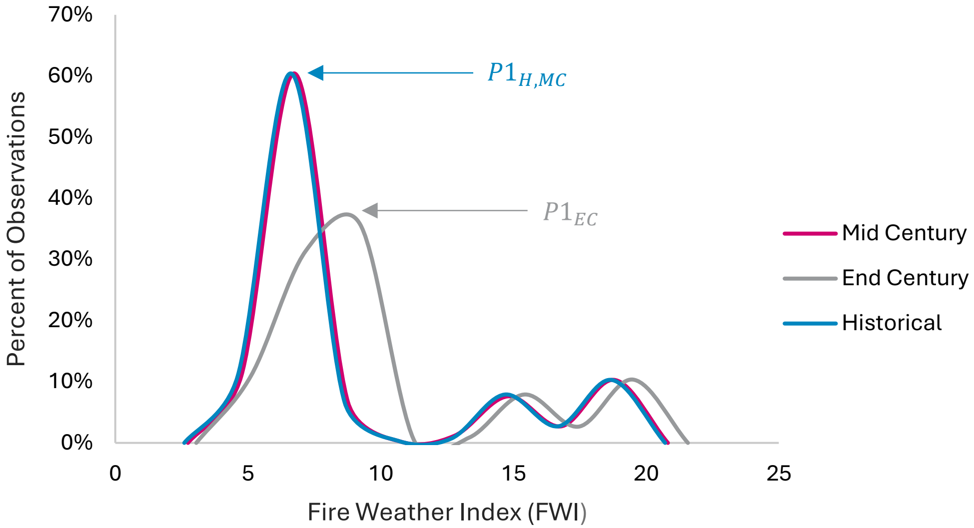
By end-century, Summer wildfire season is expected to both increase in severity and duration, increasing exposure for distribution assets and decreasing window for planned maintenance

Washington Average Seasonal Fire Weather Index (FWI)
Population-Weighted by County [RCP-8.5]



Washington Fire Weather Index Statistical Distribution (FWI)
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- **End-century wildfire exposure is elevated**, with the sharpest increase occurring between Spring and Autumn by about 18% from historical FWI.
- Elevated wildfire exposure around the summer suggests a **lengthening of the wildfire season** combined with an **increase in severity.**
- The change in length of wildfire season suggests that the window to for scheduled maintenance during the shoulder seasons is diminishing.

KEY OBSERVATIONS

- The regions represented by P1 will experience **more severe wildfires by end-century**, as the peak shifts from about FWI 6 to about FWI 8.
- The tri-modal shape of the curve represents **three regions of the state that face distinct levels of fire risk** given differences in climate zones.
- Wildfire exposure is largely unchanged by mid-century, but by end-century, the rightward shift of the peaks indicates that the **most at-risk regions of the state will face increasingly severe fire exposure.**

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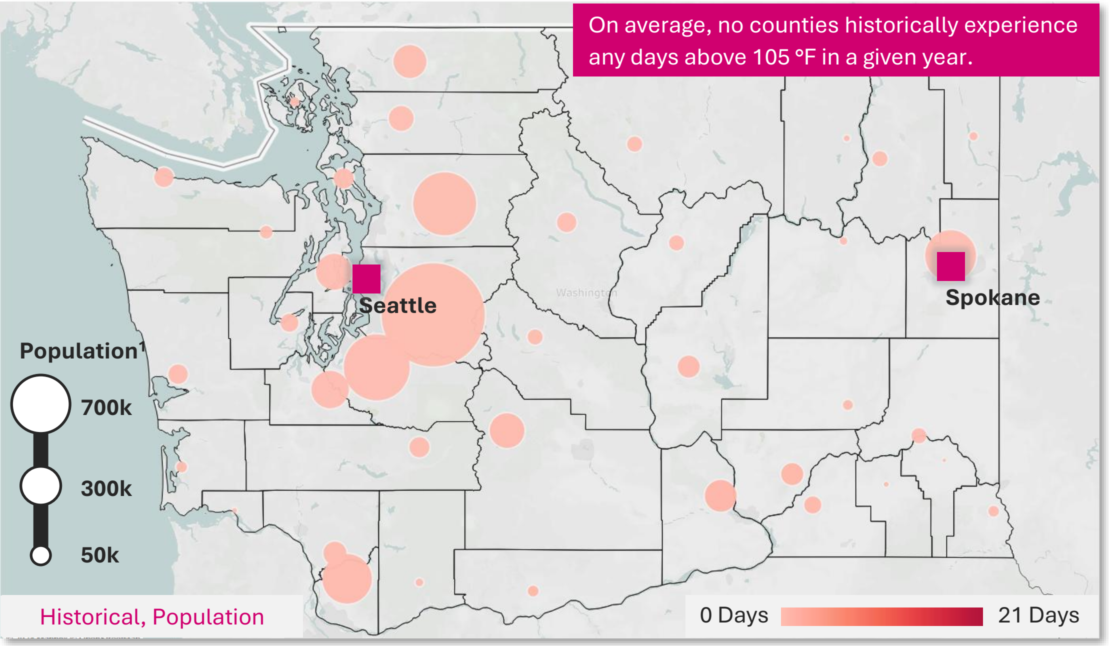
Extreme Heat

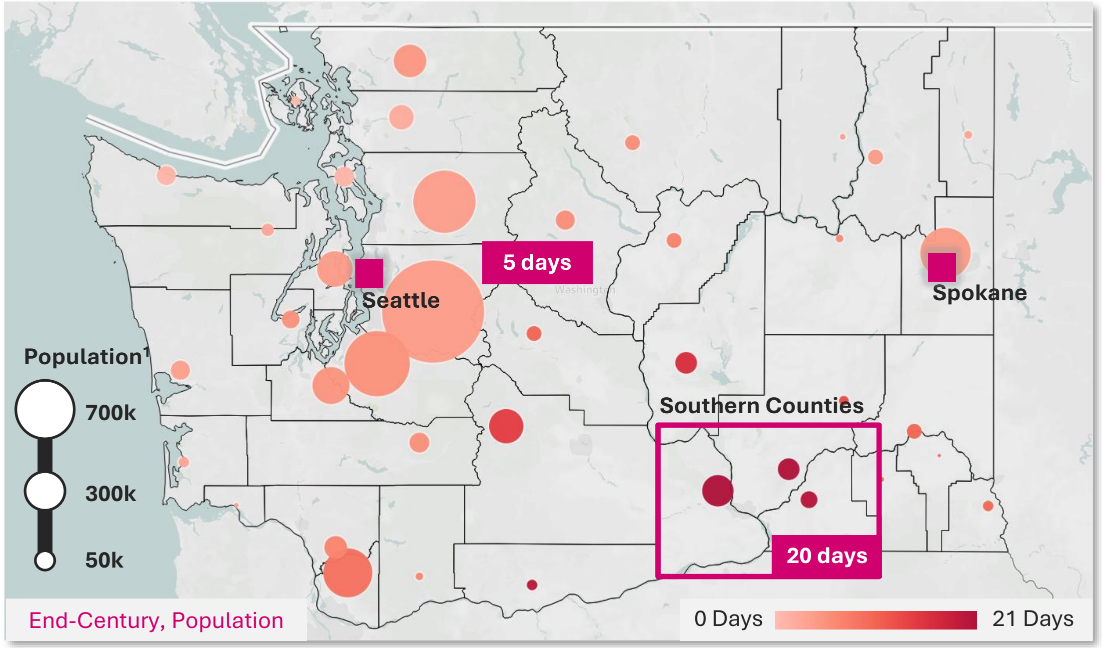
Asset Analysis

Extreme heat exposure changes drastically by end-century, inciting failure and derating of distribution assets while simultaneously increasing summer cooling load

Washington Days Above 105 °F
Distribution Assets (Population), Historical [RCP-8.5]



Washington Days Above 105 °F
Distribution Assets (Population), End-Century [RCP-8.5]



KEY OBSERVATIONS

- Currently T_x and D_x assets have **no exposure to days above 105 °F.**
- 105 °F is a particularly important threshold for distribution assets and substations, **which can fail when exposed to two consecutive days above 104 °F.**[2]

KEY OBSERVATIONS

- Highly populated counties (Pierce, King, and Snohomish) are expected to face **about 5 days >105 °F annually**.

Benton, Franklin, and Walla Walla

Southeastern counties face extreme heat exposure of **over 20 days >105 °F, causing high asset utilization and potential failure.**

[1]Population bubbles are continuous and therefore labels are approximate. [2]EPRI Climate READi

Source: ClimRR, US Census Bureau, City and Town Population Totals

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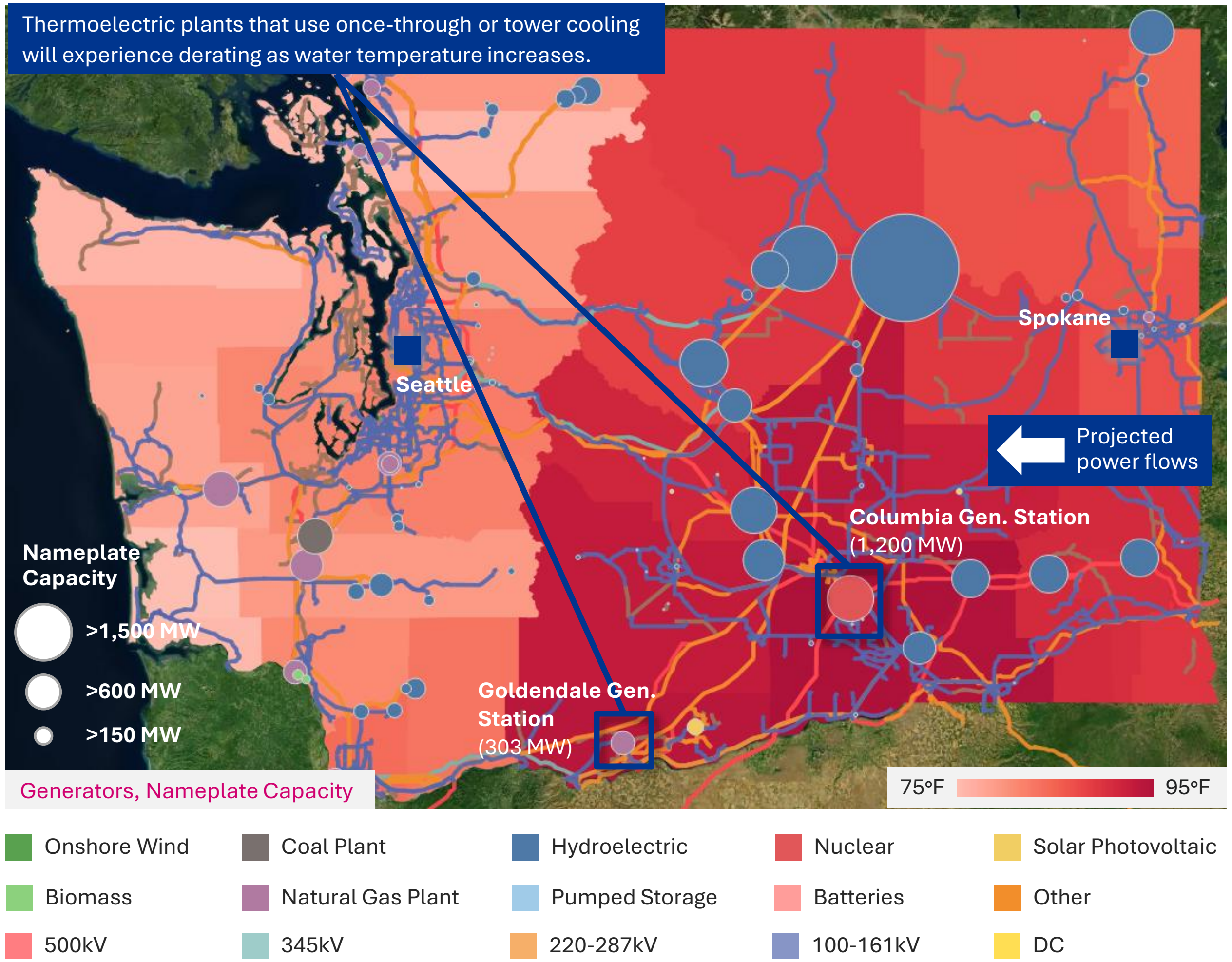
Goldendale and Columbia Generating Stations are exposed to high levels of extreme heat, which may have deleterious effects on plant cooling efficiency, reducing overall plant output

Washington Summer Average Maximum Temperature (°F)
Generators, Mid-Century [RCP-8.5]

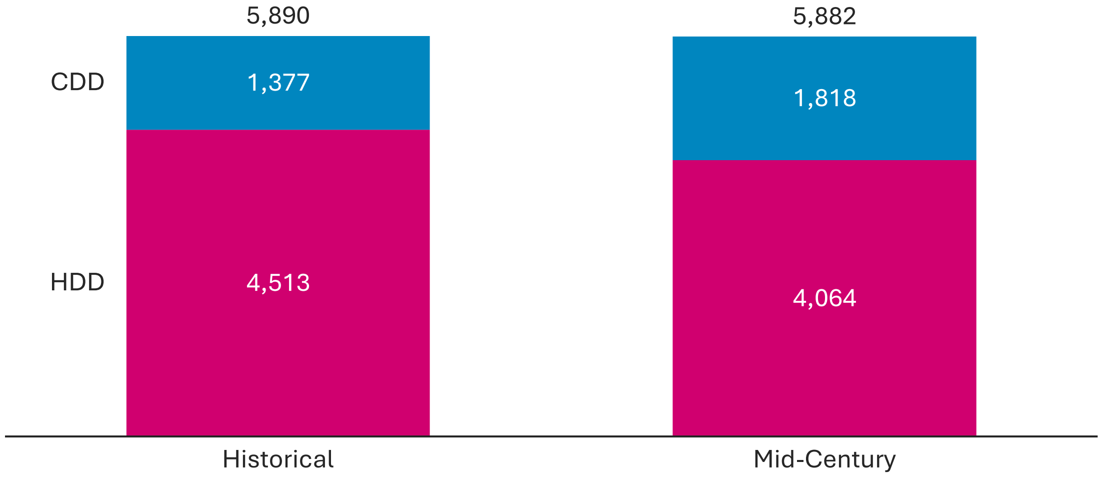


Source: ClimRR, US Census Bureau, City and Town Population Totals

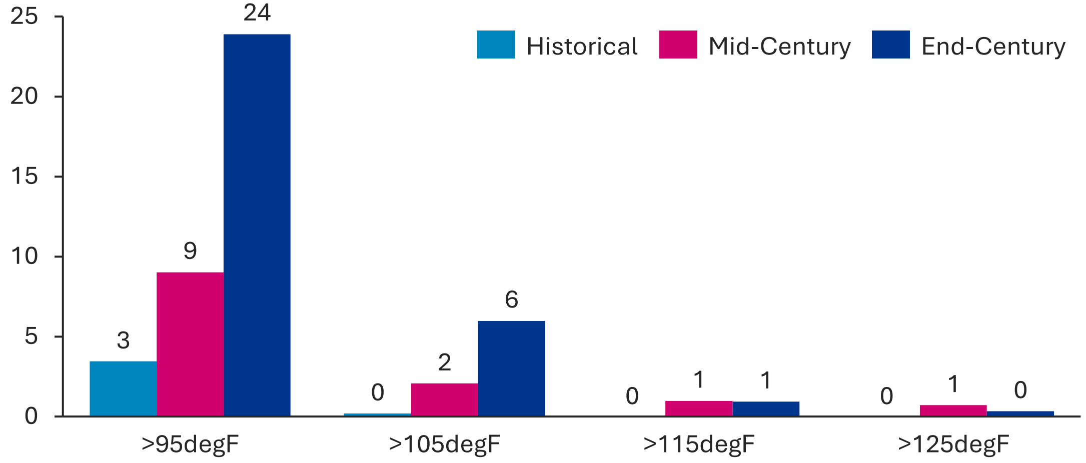
Key Highlights	Analysis
Thermoelectric	• Thermoelectric generators (Natural Gas, Coal, Nuclear) that rely on water-based cooling methods (once-through, cooling ponds, towers) will **experience production derates** as extreme heat raises average water temperatures. • This is due to both **cooling inefficiencies** and **environmental regulations** around temperature of released water.
Transmission	• A cluster of **Tx lines in Benton, Franklin, and Walla Walla Counties are highly exposed to extreme heat**, which contributes to line sag, derating, and potential failure.
Hydroelectric	• The majority of large hydroelectric plants in the state face **above average extreme heat exposure** (>85 °F avg. summer max). • High air temperatures can result in reservoir temperatures that can stress native aquatic organisms and increase likelihood of harmful algal blooms.

Extreme heat days will become more common in Washington, increasing peak load and contributing to derating and capacity violations across all asset classes

Washington Average Annual Cooling & Heating Degree Days (CDD & HDD)
Population-Weighted by County [RCP-8.5]



Washington Average Annual Days Exceeding Daily Max Heat Index Thresholds
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- Between historical and mid-century, **the ratio of CDD to HDD increases,** with the share of average number of CDD jumping from about 23% to 31% across historical and mid-century.

KEY OBSERVATIONS

- This results in **increased summer asset utilization and degradation**, but impacts to winter utilization remain unclear depending on heating electrification trends.
- Increase in days >105 °F poses a **substantial risk to distribution transformers and switchgear**, which can fail after two consecutive days above 104 °F.

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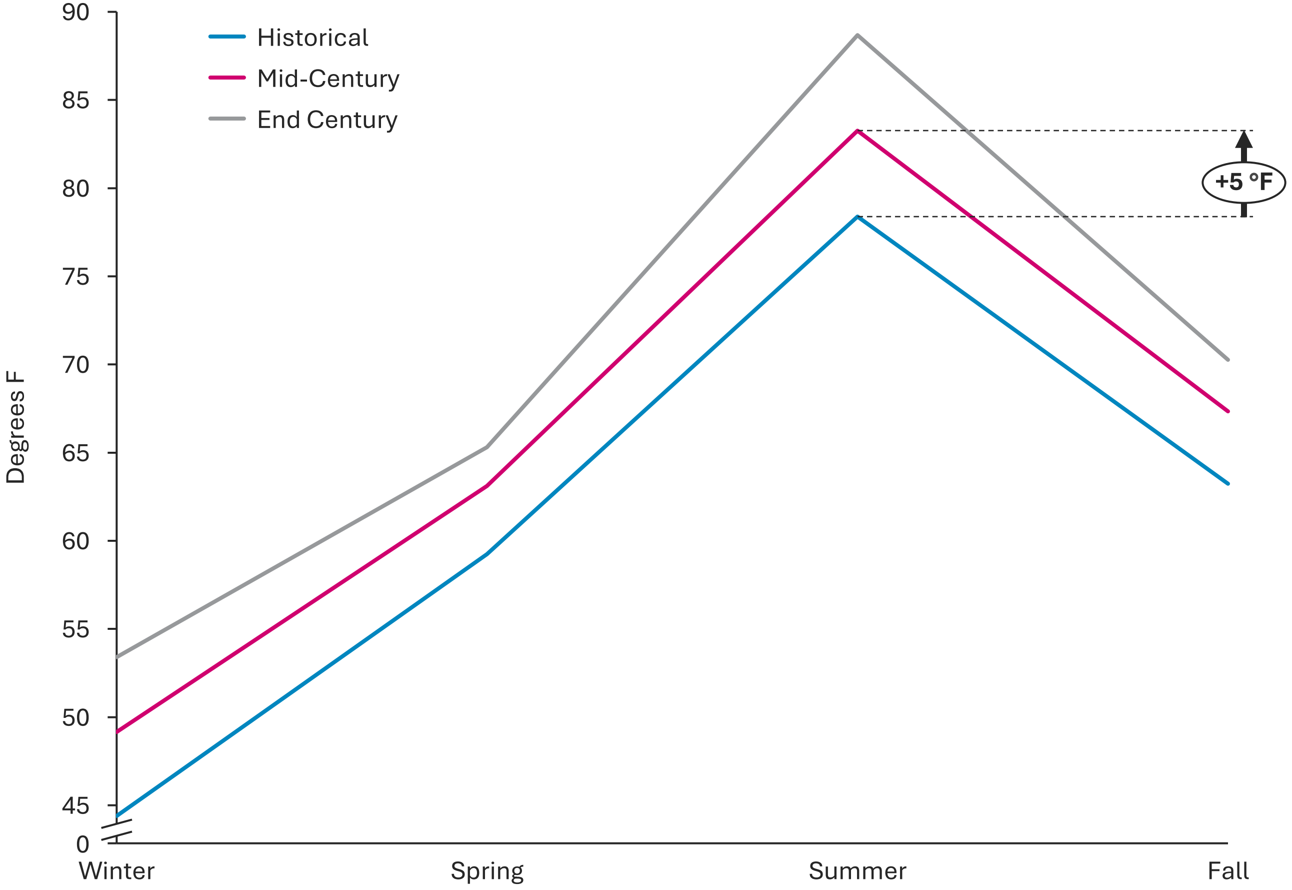
Average seasonal maximum temperature increases by 5 °F in mid-century, increasing system utilization and contributing to asset degradation

Washington Average Seasonal Maximum Temperature (°F)
Population-Weighted by County [RCP-8.5]



Key Highlights	Data Analysis
Temperatures are rising every month	• Heat risk **increases most drastically in summer**, with a 5 °F increase in the average seasonal max by mid-century, increasing system utilization and degradation. • Less pronounced warming in shoulder seasons; increased spring and fall temperatures may reduce heating load.
Hot season both lengthens and intensifies	• **Longer summers:** By end-century, summers will have extended as more months will have average temperatures >70 °F. • **Shortened maintenance season:** Off-peak months for maintenance shorten. • **Accelerated asset degradation:** Prolonged heat accelerates asset degradation.
Peak intensifies, but does not shift	• **Summer remains the hottest season** on average across the state. • Timing of **summer peak capacity warnings** should remain the same.

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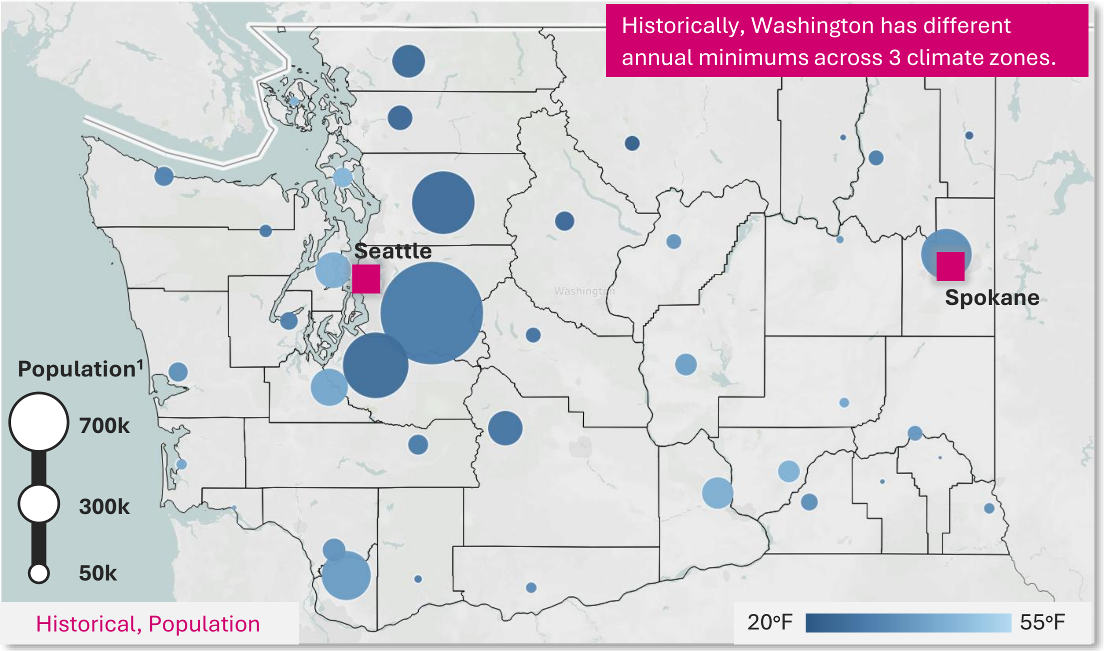
Extreme Cold

Asset Analysis

Average annual temperature minimums are projected to increase by about 9°F in end-century, yet extreme cold exposure remains in northwestern counties

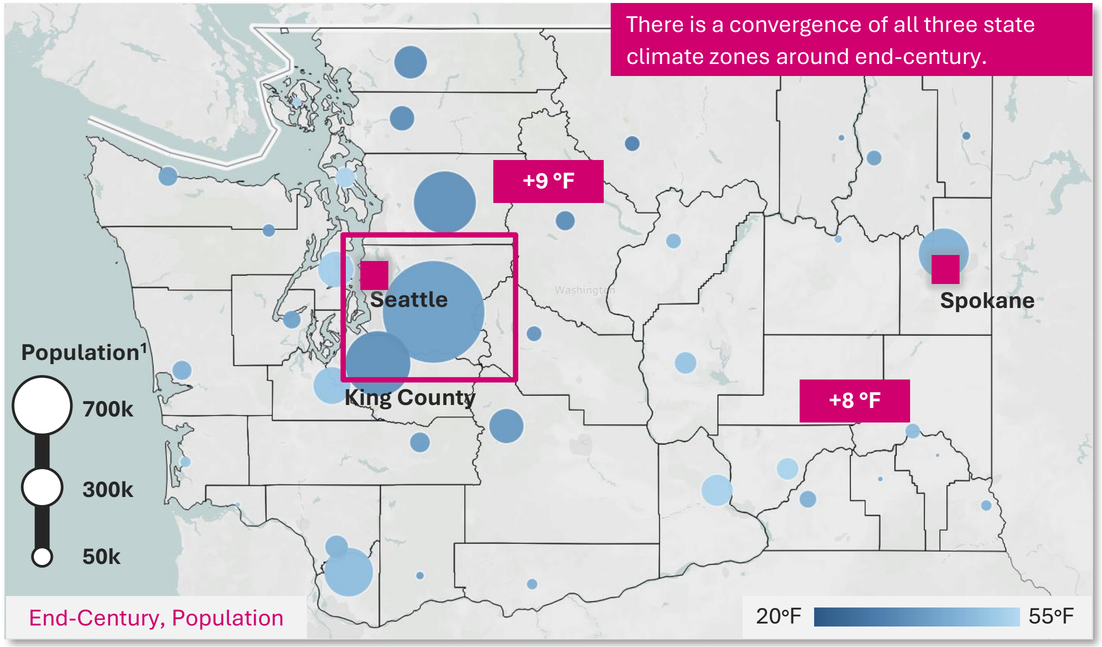
Washington Average Annual Minimum Temperature (°F)
Distribution Assets, (Population) Historical [RCP-8.5]



KEY OBSERVATIONS

- Most acute cold exposure lies in the northwest portion of the state, **coinciding with large population centers.**
- The high volume of distribution assets in these areas are exposed to icing, **impacting substation equipment** and causing **Dx and Tx line galloping.**

Washington Average Annual Minimum Temperature (°F)
Distribution Assets, (Population), End-Century [RCP-8.5]



KEY OBSERVATIONS

- Climate projections cannot predict acute extreme events like polar vortices and winter storms, **underrepresenting cold exposure.**

King County

King County is exposed to average annual minimum temperatures of about 35 °F, indicting potential **icing and freezing exposure for distribution assets**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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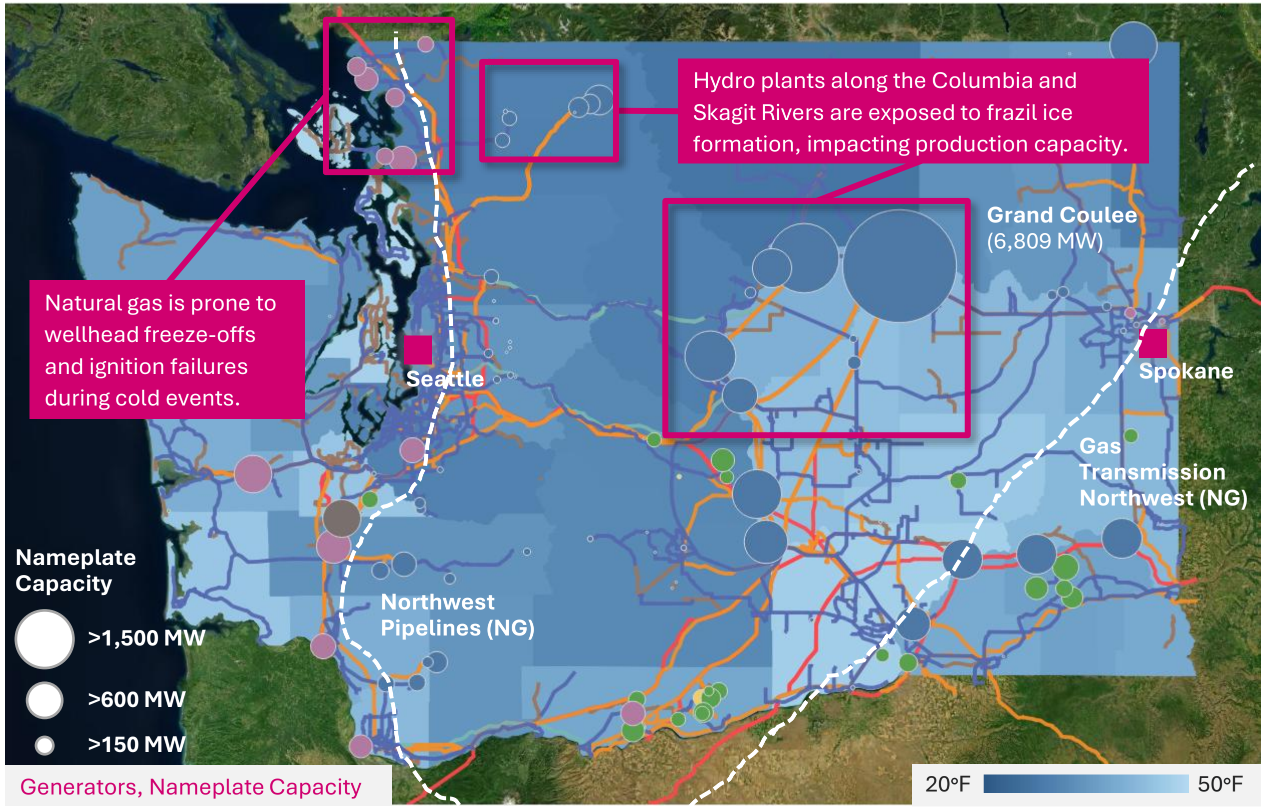
Despite warming, sub-freezing annual minimum temperatures persist in many counties throughout the state with generating assets, maintaining exposure to freezing/icing events

Washington Average Annual Minimum Temperature (°F)

Generators, Mid-Century [RCP-8.5]



Onshore Wind | Coal Plant | Hydroelectric | Nuclear | Solar Photovoltaic
Biomass | Natural Gas Plant | Pumped Storage | Batteries | Other
500kV | 345kV | 220-287kV | 100-161kV | DC

Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Hydroelectric	• Many hydroelectric assets on the **upper Colombia** and **Skagit Rivers** are exposed to sub-30°F temperatures mid-century. • Frazil ice formation and maloperation of spill gate motors can result in **plant faults or production derates.**
Natural Gas	• A pocket of natural gas plants in the **northwest corner** of the state are exposed to average minimums of about 29 °F, which could cause **ignition failure or other performance issues.** • Large pipelines in the NW and E counties that support transmission of natural gas into the state could be impacted by frost heaves and depressurization under severe extreme cold and supply scarcity.
Wind	• Average annual minimums in Klickiktat and Columbia counties are about 36°F and 38°F respectively, **posing a regular threat of icing to wind farms** in the region.
Freezing/Icing	• A high density of **Tx assets are exposed to cold in NW counties and could be prioritized for weatherization.**

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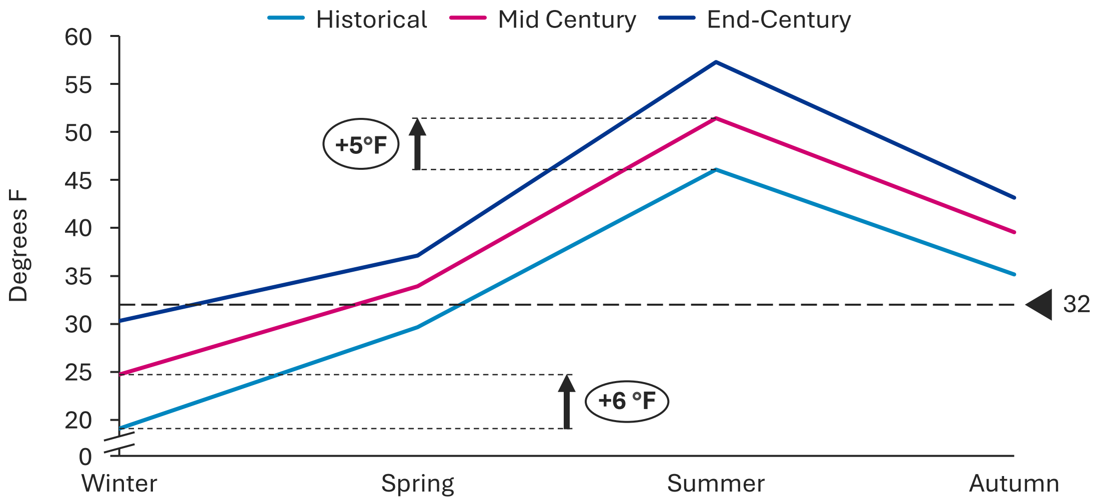
Seasonal and annual temperature minimums are projected to increase over time, but the ultimate effect on system utilization depends on the pace of heating electrification

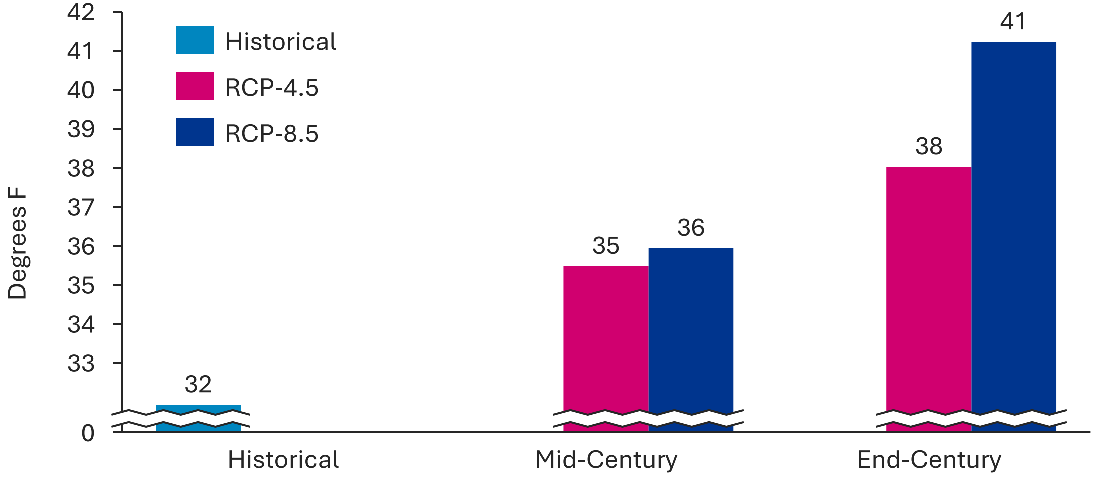
Washington Average Seasonal Minimum Temperature (°F)
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- Significant winter warming (+6 °F by mid-century) will decrease overall heating needs, but the **impact on electricity demand ultimately depends on the speed of heating electrification.**
- Downscaled climate data does not forecast acute temperature shocks, meaning assets could still face similar risk levels of cold-related failures.
- Warming effects are more significant in summer/winter compared to the shoulder seasons.

Washington Average Annual Minimum Temperature (°F)
Population-Weighted by County [RCP-4.5, RCP-8.5]



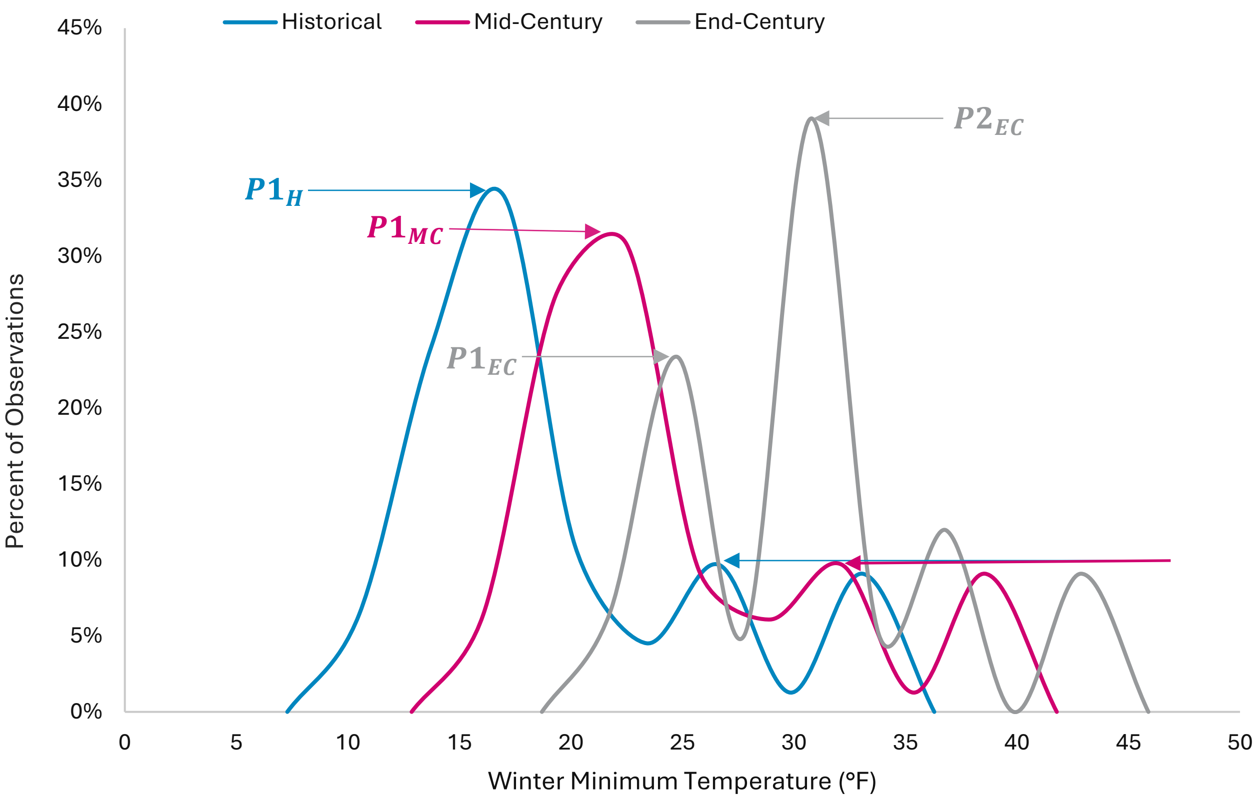
KEY OBSERVATIONS

- ~12% increase in average annual temperature minimum by mid-century indicates a reduction in heating load, but the impact on electricity demand ultimately depends on the speed of heating electrification.
- Regarding extreme cold, global climate models do not resolve for extreme cold events like polar vortexes, so **cold exposure is likely under indicated by the model.**

 |

Winter minimum temperatures are expected to warm over time, yet a similar percentage of the population is still exposed to sub-freezing minimums by end-century

Washington Average Winter Minimum Temperature (°F)
Population-Weighted by County [RCP-8.5]



Key Highlights	Analysis
Warming	• **Rightward shift of the curve indicates general warming** of average winter minimum temperatures over time, but impact on winter load depends on the pace of heating electrification.
Extreme Cold Exposure	• P1 decrease for end-century indicates that **fewer counties will be exposed to extreme cold minimums.**
Climate Zones	• Tri-modal curves for historical and mid-century shifting to a multi-modal shape indicates the **emergence of a 4th distinct climate zone by end-century.**
Freezing/Icing	• Increases in P2 by end-century demonstrates a **wider spatial extent exposed to winter minimums around 30°F,** maintaining relatively high levels of exposure to freezing and icing.

Source: ClimRR, US Census Bureau, City and Town Population Totals

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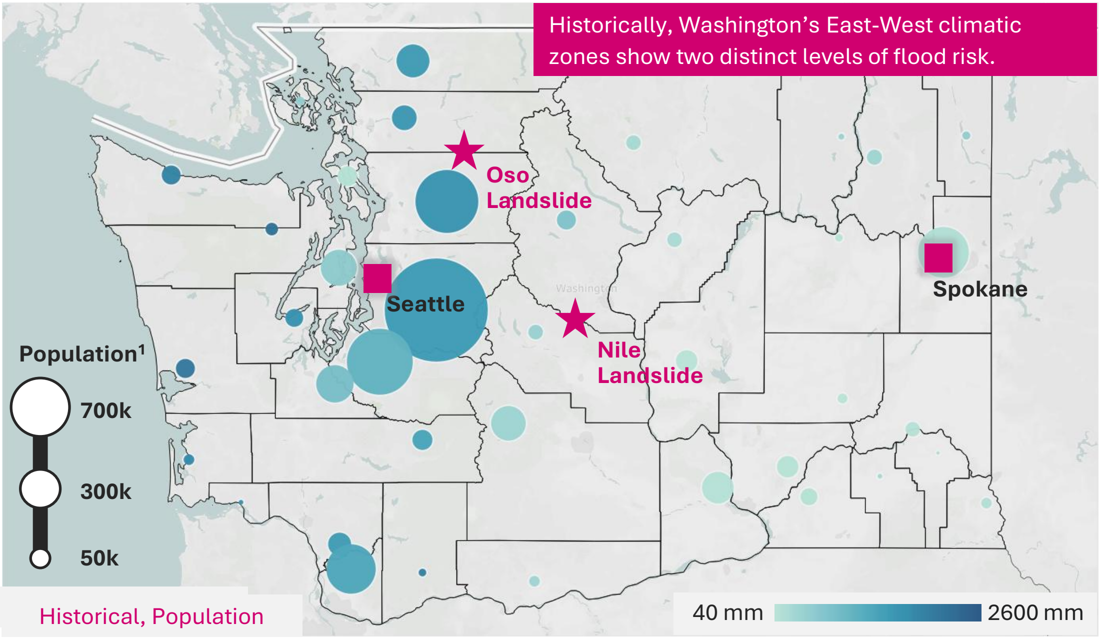
Flood

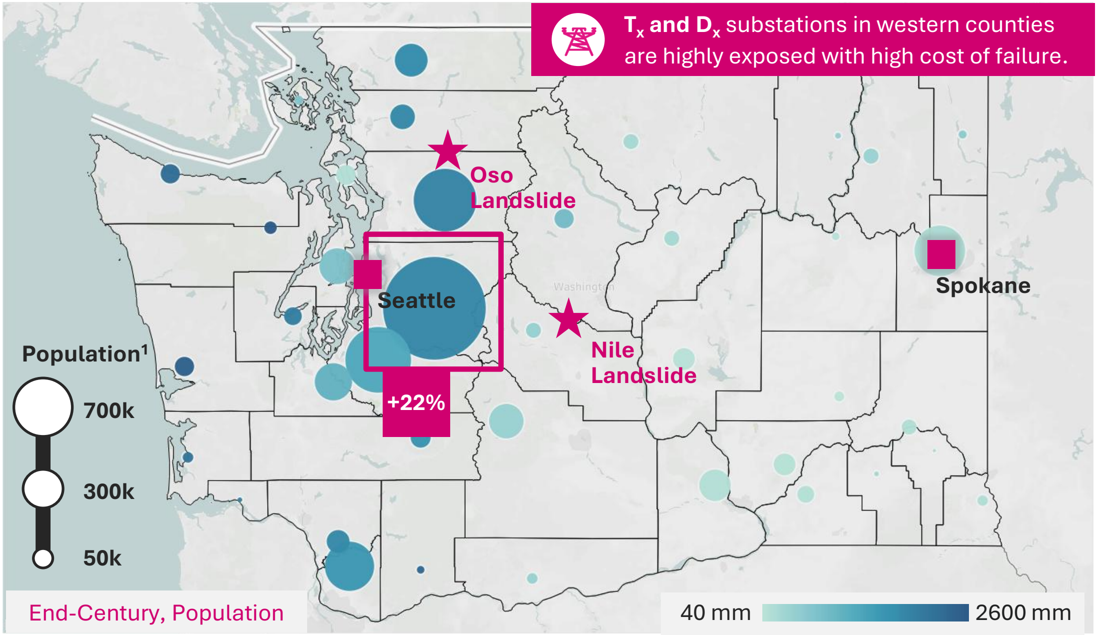
Asset Analysis

Flood exposure is significantly higher in western counties and is projected to intensify by end-century, posing a threat to low-lying substations and unfortified distribution assets

Washington Average Annual Surface Runoff (mm/year)
Historical [SSP5-8.5]



Washington Average Annual Surface Runoff (mm/year)
End-Century [SSP5-8.5]



KEY OBSERVATIONS

- Most flood exposure lies in the **northwest counties** given their relatively low elevations and proximity to the coast.
- **T_x and D_x substations in King and Snohomish counties** have a large volume of assets with high exposure given ground-mounted equipment.

KEY OBSERVATIONS

- Flood exposure is projected to **increase in western counties** by end-century but remains largely unchanged across eastern counties.

King County

Flood exposure is projected to increase by 22% by end-century, posing a substantial threat to low-lying substations and weak distribution poles.

Source: ClimRR, US Census Bureau, City and Town Population Totals

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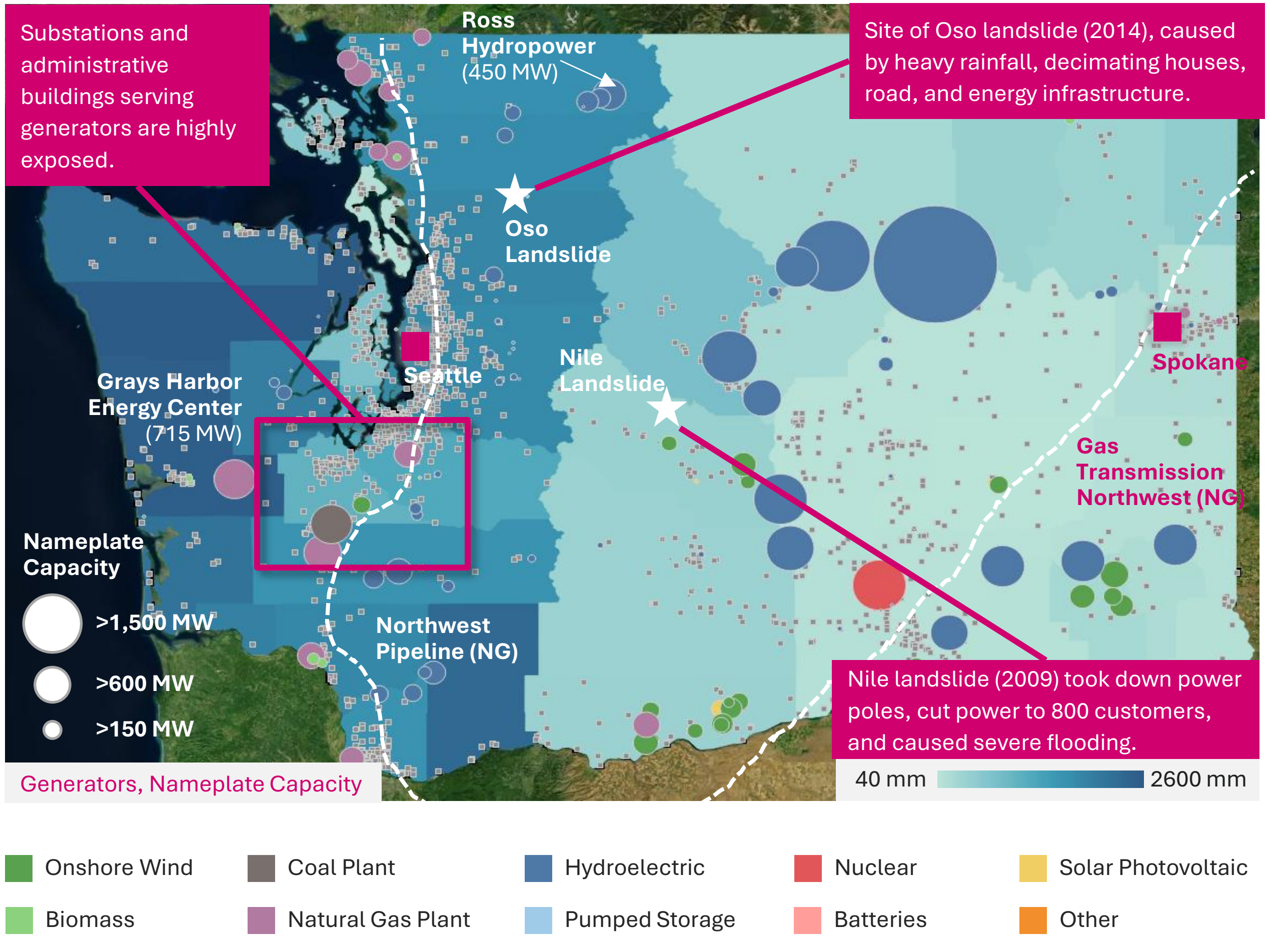
Flood exposure most acutely impacts generators located in western counties, especially hydro and natural gas assets in Whatcom, Grays Harbor, and Skamania counties

Washington Average Annual Surface Runoff (mm/year)
Generators, Mid-Century [SSP5-8.5]



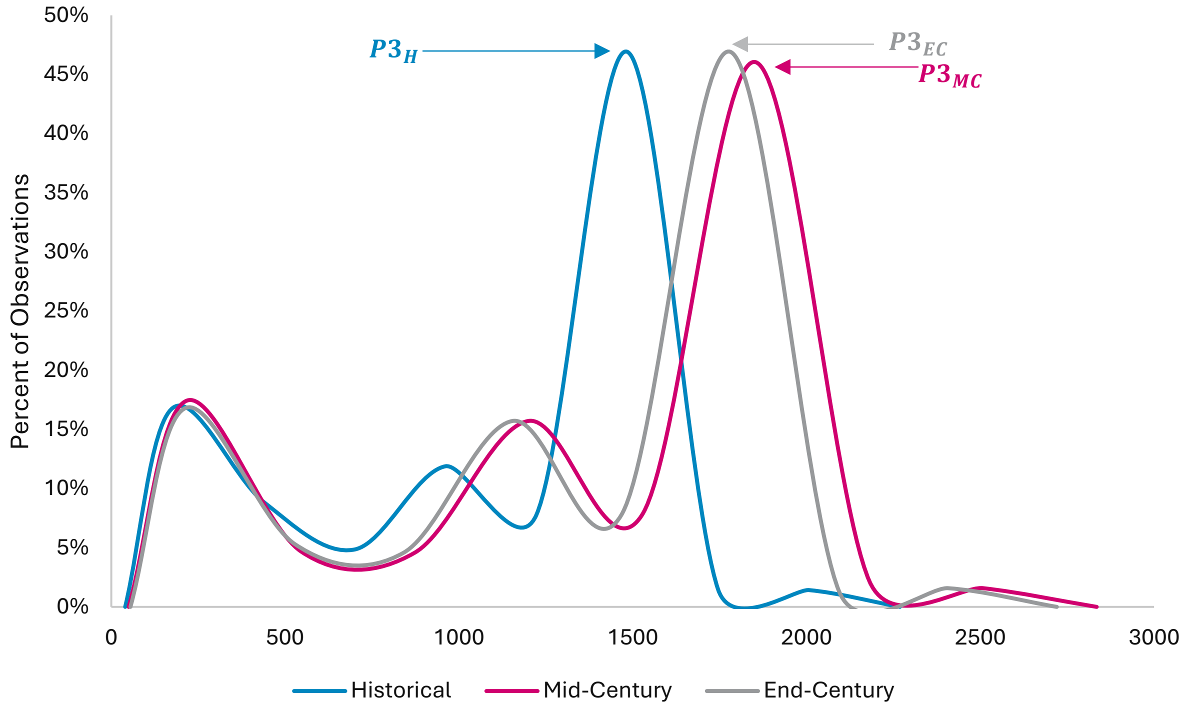
Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Hydroelectric	• Hydro plants in **Whatcom County will face high levels of flood exposure** given proximity to the Skagit River. • Hydro plants along Lewis River in Skamania County **are exposed to high flood levels** relative to the broader state. • Flooding can contribute to **dam overtopping/failure** and **pose operational challenges** to hydro assets.
Natural Gas	• The **Grays Harbor Energy Center is exposed to peak flood risk** in the state. • Flooding can **inundate critical equipment located at ground level or below** and cause plant failure. • **Northwest Pipeline** is exposed to elevated levels of surface runoff, leaving scouring or causing potential rupture due to landslides.
Restoration	• Flooding causes **ingress/egress complications** by washing out access roads, contributing to restoration issues. • Flooding can **affect on-site buildings or facilities**, making it more difficult to maintain adequate staffing for oversight and restoration.

 |

Flood exposure is projected to increase in severity, especially in high exposure areas, increasing the likelihood of failure for assets in almost half of the state

Washington Average Annual Surface Runoff (mm/year)
Population-Weighted by County [SSP5-8.5]



Key Highlights	Analysis
Increased Severity	• Rightward shift of the curve indicates a **general increase in the severity of flood exposure over time.**
Mid-Century Exposure	• **Mid-century flood exposure is generally more severe than end-century exposure** given its position to the right of the end-century curve.
Flood Zones	• Tri-modal shape of the curves represents **3 distinct zone of flood exposure within the state.**
Increased failure likelihood	• Rightward shift of peak 3 indicates significantly **more severe exposure for the most exposed assets,** increasing the likelihood of failure in these regions (almost 45% of the state).

Source: ClimRR, US Census Bureau, City and Town Population Totals

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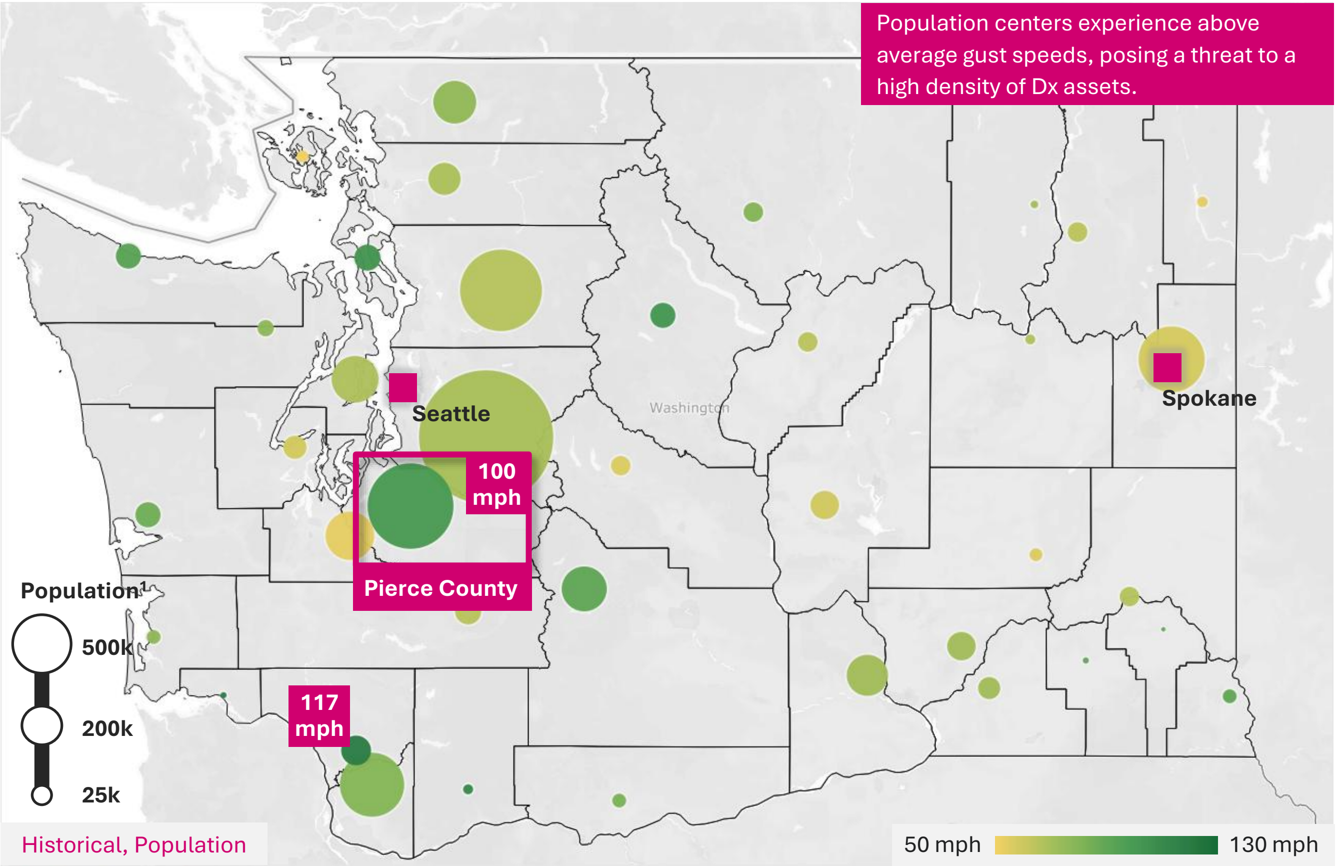
Wind

Asset Analysis

WSDOC could consider instituting upgraded design standards throughout the state to address wind exposure, especially in western counties that are highly exposed

Washington 100-year Wind Speed (mph)
Historical



Key Highlights	Analysis
Distribution	• Given weak climate signals, wind speeds are derived using historical data and do not vary at high spatial resolution. • Rather than targeted investments, wind exposure could be addressed through **upgraded design standards** across a utility service territory.
Pierce County	• Pierce County has a population of 900k and 100-year return value of 100mph, **indicating a high exposure area for Dx assets**. • Coincident extreme cold events put Dx lines at risk for galloping and sag.
Western Counties	• Gust speeds are generally highest among the western counties in the state, especially those on the coast. • WSDOC could consider funding projects including undergrounding, pole upgrades, decreasing spans, and vegetation management to address wind exposure.

Source: DRI, EIA860, HIFLD

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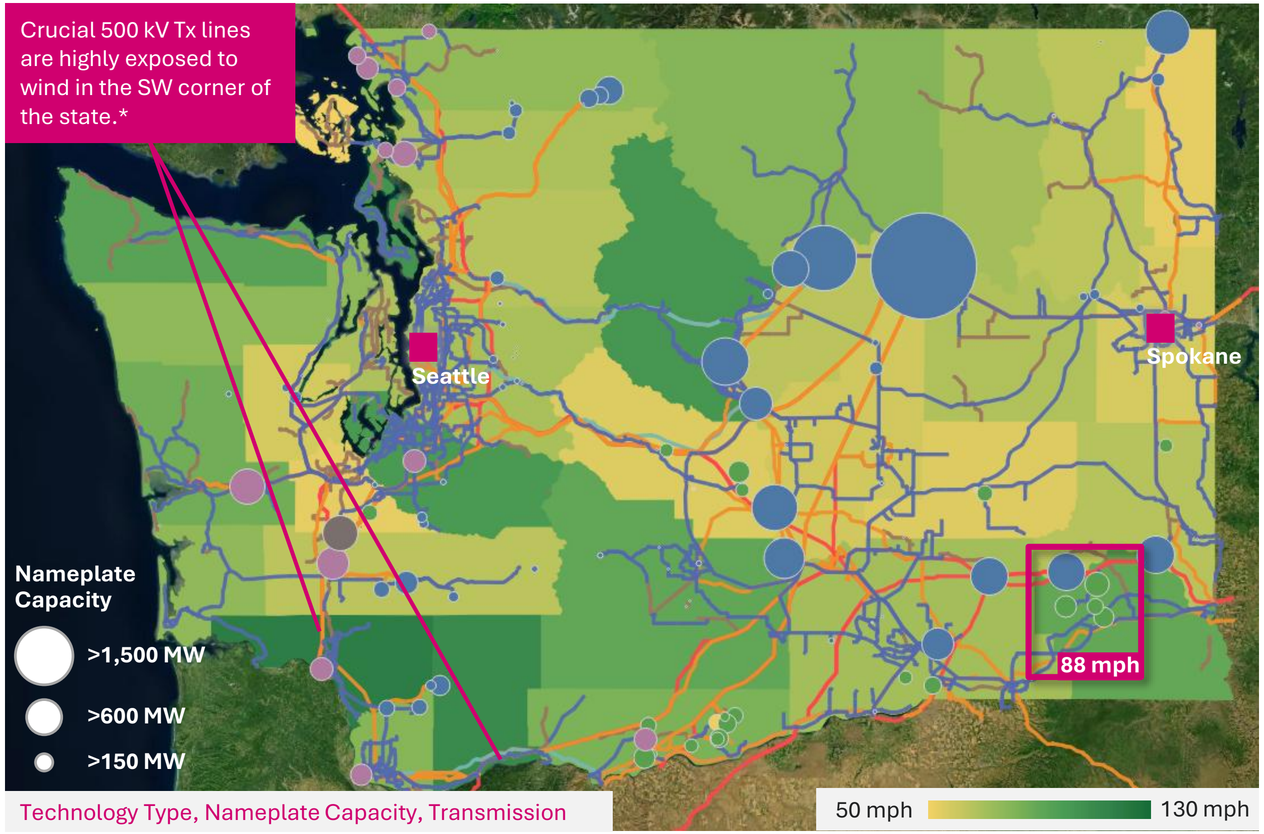
WSDOC could consider prioritizing HV Tx lines in SE counties for structure reinforcement, and hardening wind and hydro generators in counties exposed to high wind speeds

Washington 100-year Wind Speed (mph)

Historical



Onshore Wind | Coal Plant | Hydroelectric | Nuclear | Solar Photovoltaic

Biomass | Natural Gas Plant | Pumped Storage | Batteries | Other

500kV | 345kV | 220-287kV | 100-161kV

Source: DRI, EIA860, HIFLD

Key Highlights	Analysis
Transmission	• **A cluster of MV/HV Tx lines are highly exposed in Pierce County,** making them susceptible to failure. • **HV import/export lines running through Cowlitz and Skamania Counties are exposed to high wind speeds,** which could be prioritized for hardening given their crucial role during extreme weather events.
Wind	• Wind farms cutout speeds can vary between 45-70mph, indicating that in high wind speed events, the turbines stop producing. • Wind farms in Columbia and Garfield Counties are exposed to 100-year return period values far greater than the cutout threshold, **resulting in production curtailments.**
Hydroelectric	• Multiple hydroelectric plants along the Columbia River border counties with high levels of wind exposure. • High wind speeds can cause debris to accumulate in the water and **clog intakes or directly damage plant equipment.**

*These 500 kV lines are covered by lower voltage lines in the map

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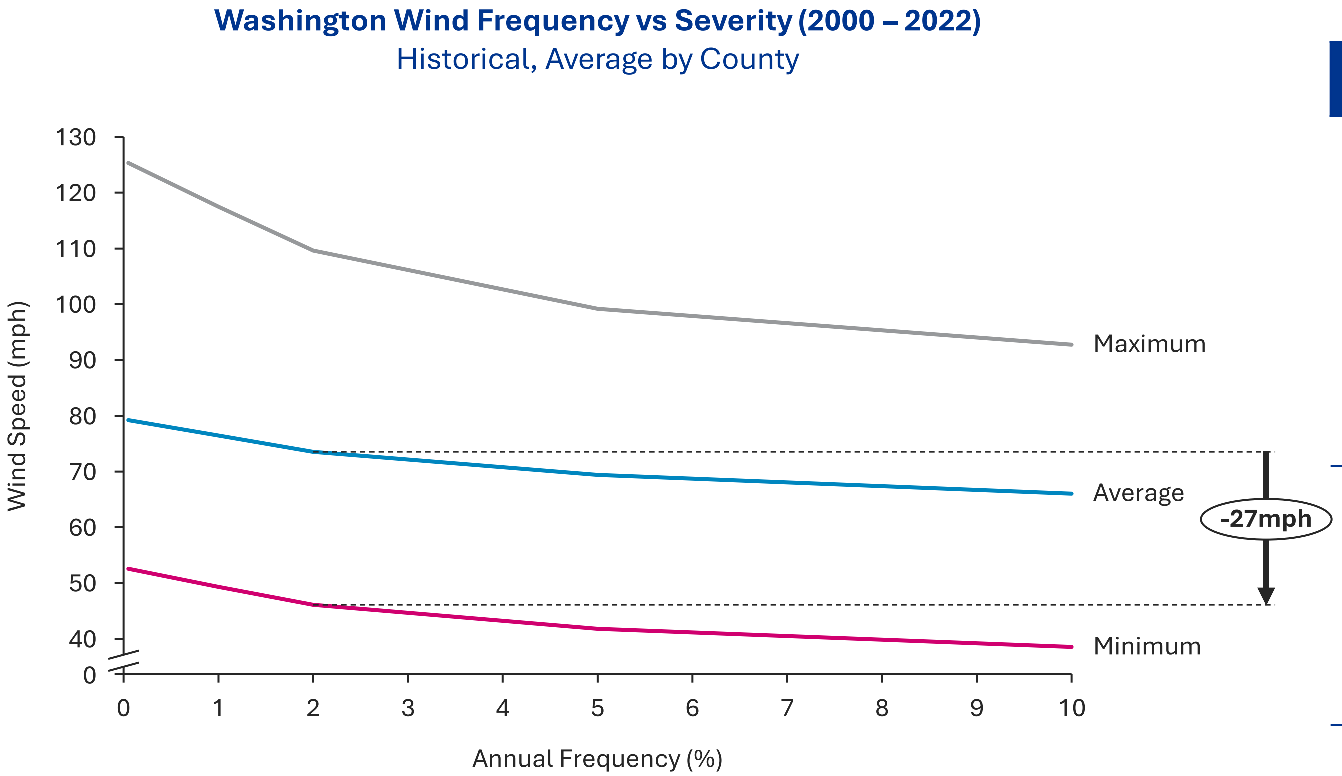
Historically, there is a 1% chance that the average wind speed seen across Washington counties is about 80mph annually.



Key Highlights	Analysis
 **High System Averages**	• Historically, there is a 1% chance that the average wind speed seen across Washington counties is ~80mph annually. • Further out on the curve, the 10% annual likelihood drops to 66 mph, indicating high system wind speeds are common across counties.
 **Volatility Across Counties**	• There is a wide band between the maximum and minimum counties around the mean. • This indicates that wind adaptations should be focused on a county basis rather than over large service territories.

DRI

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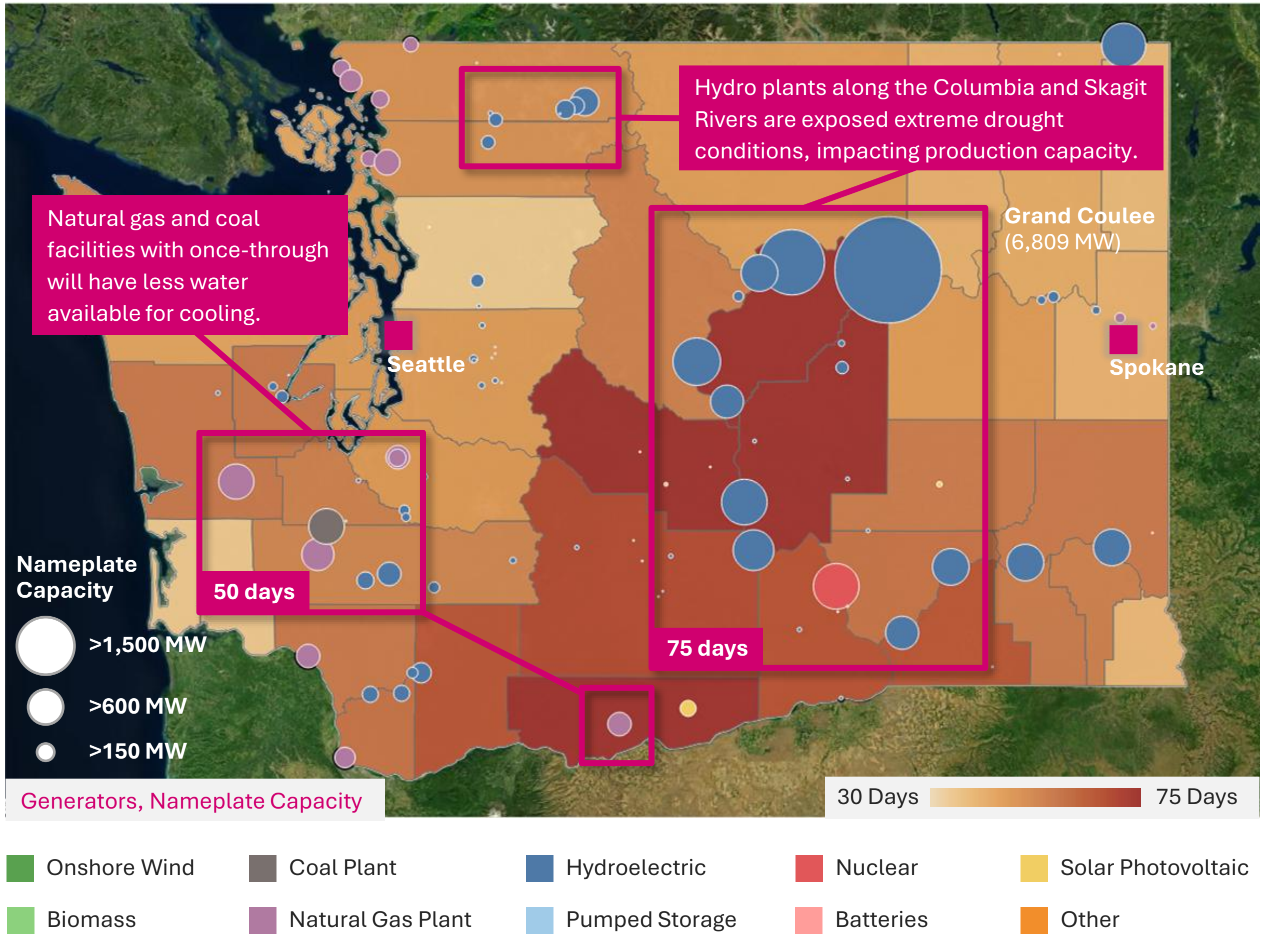
Drought

Asset Analysis

Increases in drought exposure in the central and southern regions of the state by mid-century will decrease hydro output and create cooling issues for nuclear and natural gas generators

Washington Consecutive Days No Precipitation
Generators, Mid-Century [RCP5-8.5]



Key Highlights	Analysis
Hydroelectric	• A string of **hydroelectric plants along the Columbia River** bordering Douglas and Grant Counties are exposed to peak state-wide drought levels. • Asset owners should be forecasting long-term production from these hydro facilities with **climate-adjusted inputs.**
Nuclear	• The Columbia Generating Station in Benton County will face drought exposure of about **66 consecutive days without precipitation** in mid-century.
Natural Gas	• In arid conditions**, air intakes for CCGTs and CTs can clog and degrade** due to dust and sand particles, decreasing efficiency and longevity of generator.
Cooling	• Lack of water availability can **reduce natural gas and nuclear plant cooling ability**, resulting in power production curtailments.

Source: ClimRR, US Census Bureau, City and Town Population Totals

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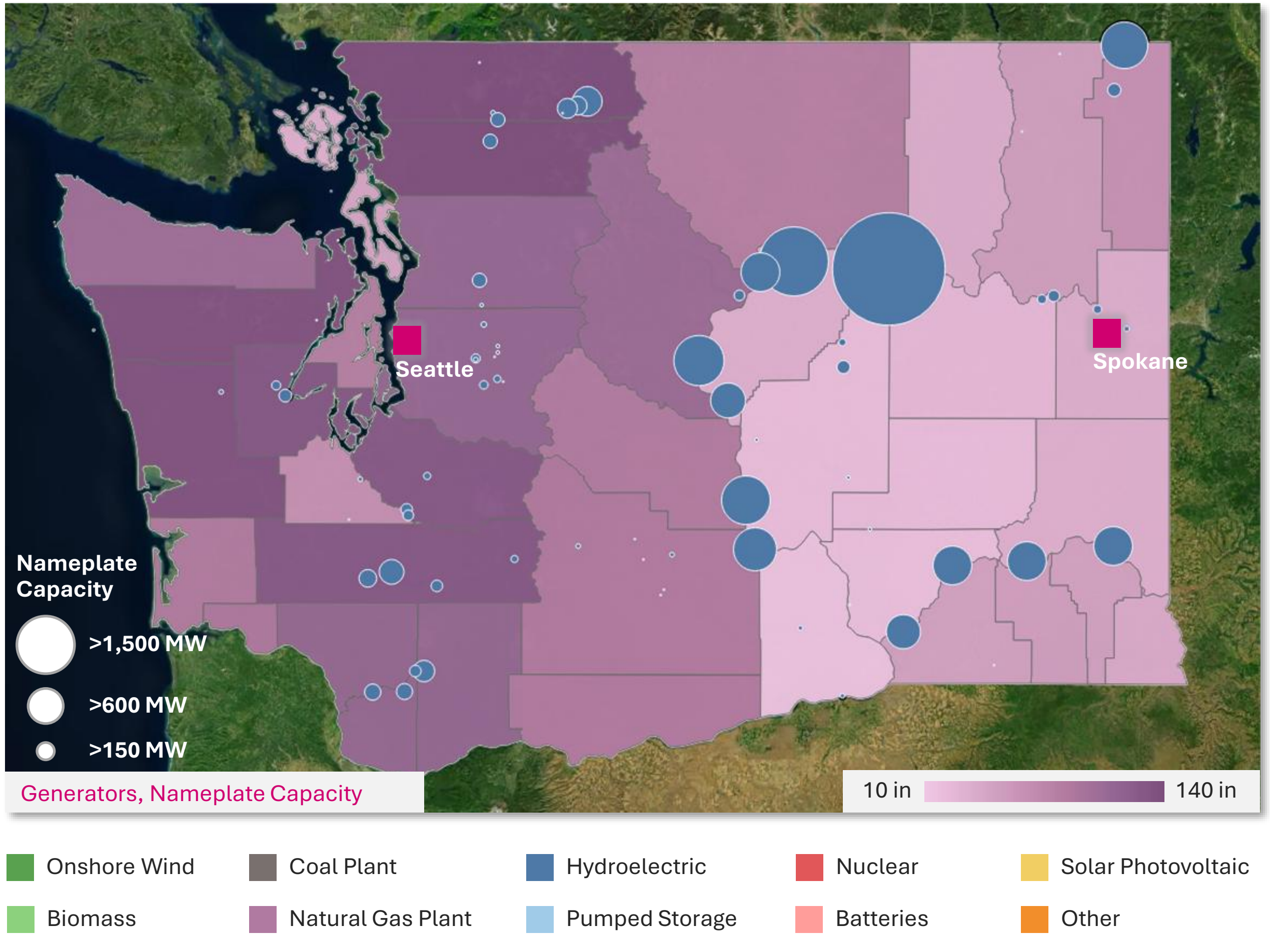
Precipitation

Asset Analysis

Hydro assets along the Columbia River border areas with low levels of projected precipitation, but the ultimate impact on output depends on upstream projections and timing

Washington Annual Max Precipitation (in)
Generators, Mid-Century [RCP5-8.5]



Key Highlights	Analysis
Columbia River	• Most counties with the **highest precipitation levels fall outside of the Columbia River Basin.** • Difficult to discern precipitation's impact on hydro generation along the Columbia River because it **largely depends on precipitation levels in Canada.**
Northwest Counties	• Hydro assets in **Whatcom and Skagit Counties** will be exposed to **annual max precipitation levels around 134 inches.**
Timing	• Timing of precipitation has an important impact of hydro output. • Extreme rainfall events may overflow reservoirs and put more pressure on dams, increasing risk of failure. • Projections of increased drought and annual precipitation indicate that **extreme precipitation events may become more likely over time.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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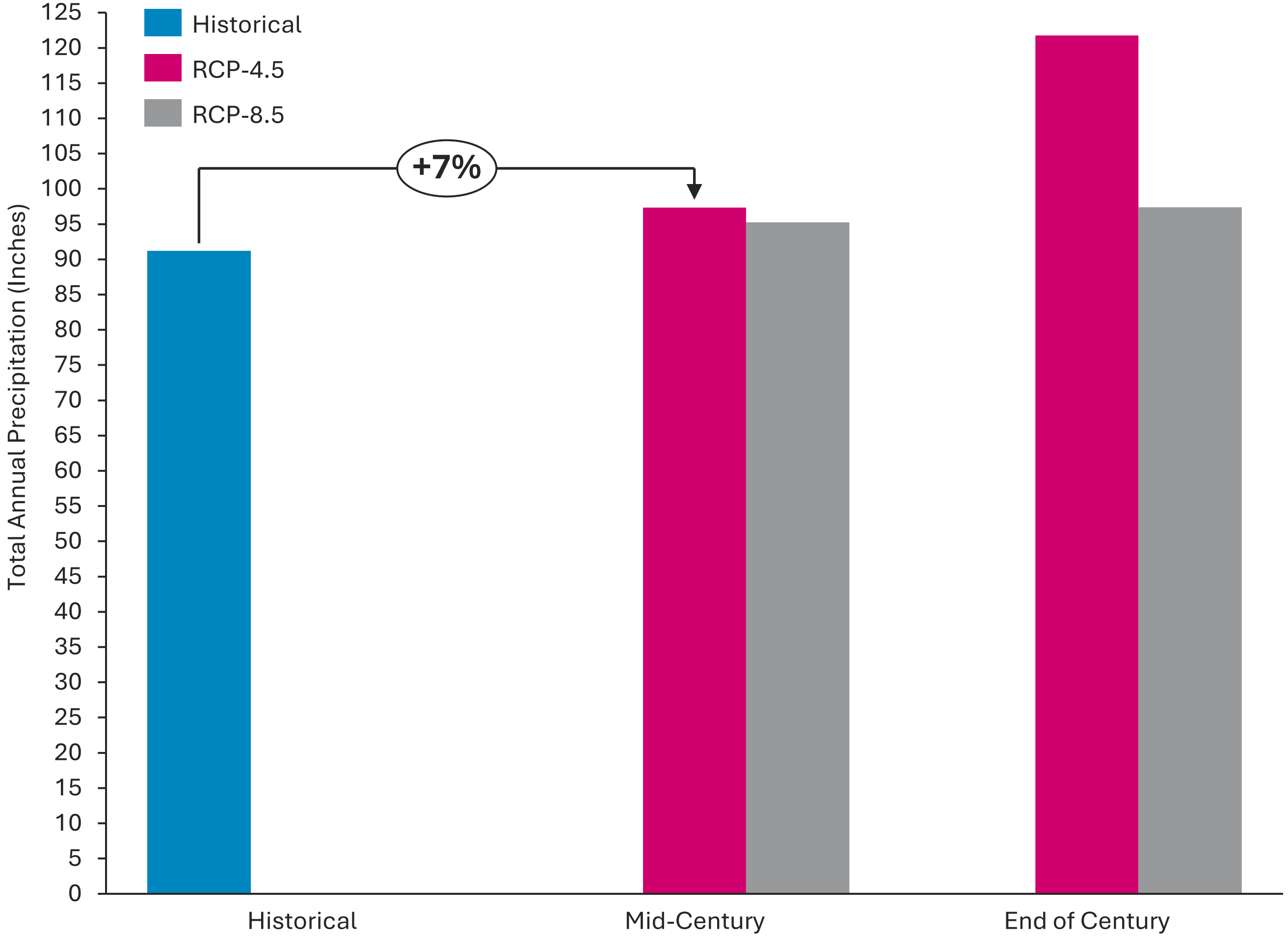
Total annual precipitation is projected to increase by 7% by mid-century (under RCP 4.5), and increases much more drastically under RCP 4.5 than RCP 8.5

Key Highlights	Data Analysis
Trends	• Projected **7% increase in average total annual precipitation by mid-century** (under RCP 4.5).
Major precipitation events	• Combined with drought increases, increasing annual precipitation indicates **more frequent major precipitation events and flooding.**
Warming and precipitation	• Precipitation increases much more drastically under RCP-4.5 than RCP-8.5, demonstrating a non-linear relationship between temperature and precipitation.

Washington Average Total Annual Precipitation (inches)
Population-Weighted by County [RCP 4.5, RCP-8.5]



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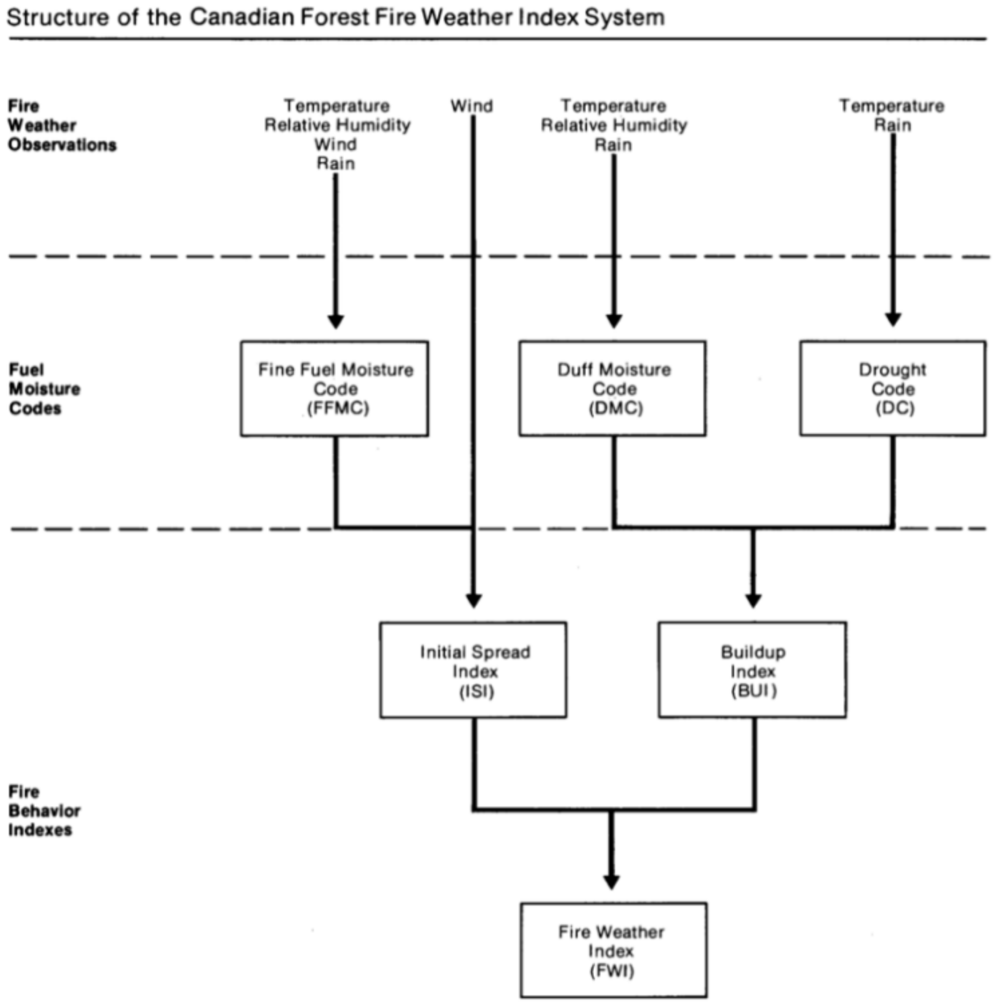
Appendix

Fire Weather Index synthesizes weather and moisture content data into a normalized value representing the danger of fire spread once ignition has occurred.



KEY TAKEAWAYS

- FWI is a useful metric for evaluating weather-based conditions that heighten the **danger of wildfire spread once ignition has occurred.**
- **Initial Spread Index**: Measures the **expected rate of fire spread,** based on wind speed and moisture content of fine fuels/forest litter (Fine Fuel Moisture Code).
- **Buildup Index:** Measures **the total amount of forest fuel available for consumption,** based on the **moisture content of intermediate organic layers**, such as decomposing plant matter (Duff Moisture Code), and the **moisture content of deep organic layers and soils,** which corresponds to drought measures (Drought Code).
- Daily FWI values were calculated using readings from Argonne's downscaled 12km climate data and averaged annually or seasonally across RCP-4.5 and RCP-8.5.
- Percentiles (below) were calculated based on **FWI values across all 12km grid cells in the contiguous U.S.**

FWI Class	Percentile range in historical period	FWI values in Class
Low	0–25th percentile	0–9 FWI
Medium	25–50th percentile	9–21 FWI
High	50–75th percentile	21–34 FWI
Very High	75–90th percentile	34–39 FWI
Extreme	90–98th percentile	39–53 FWI
Very Extreme	Above 98th percentile	Above 53 FWI

Source: ClimRR, US Census Bureau, City and Town Population Totals

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