TOWN OF WINDSOR

COMMUNITY VULNERABILITY ASSESSMENT

July 2021

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The Climate Change Consensus

The Town of Windsor is on the front lines of dealing with the impacts of the climate crisis. Wildfires are becoming hotter, more frequent, more severe, and more deadly.[1] In addition, extreme rainfall and associated flooding, prolonged periods of drought and extreme heat, and impacts to people as well as the human and natural environments are likely to get worse. All of these extreme weather events affect local and regional transportation systems, evacuation and emergency response plans, and the health and vitality of our community.

General Climate Science and Projections

Human activity, such as burning fossil fuels, is emitting greenhouse gases (GHGs) - primarily carbon dioxide and methane - into the atmosphere and warming Earth's surface and the oceans. This warming is caused by the GHGs that build up in the atmosphere and absorb sunlight and solar radiation that bounces off the Earth's surface. Normally, this radiation would escape back into space, but these gases trap heat and warm the Earth's surface much like a blanket traps heat and warms someone when they are sleeping; this is what's known as the greenhouse effect.[2] The average warming of the Earth brings more energy into the total climate system causing changes in patterns and increased variation at a local and regional level. The impacts of this warming and of climate change are being felt and observed across the globe, but the specific impacts vary regionally due to a multitude of factors.

Climate is the long-term average of weather over a given area; whereas *weather* is what is happening in the atmosphere at a given place and time. For example: in Windsor, the temperature and amount of rain on a given day is the weather, while the average temperature and precipitation in December (typically over a 30-year span) is the climate. Climate can be calculated across different spatial scales: globally, regionally, and locally. Each scale is useful for understanding different components of the climate system.

The exact amount of greenhouse gasses the world will emit over the next century is unknown, so scientists have to create climate change projections using several different scenarios based on plausible societal responses to climate change and other factors. The multiple emissions scenarios describe future trajectories of GHG emissions that capture the relationship between human decisions, global population growth, economic development, technological advancement, and global temperature change throughout the 21st century.

There are standard scenarios used across the scientific climate modeling community. Most recent emissions scenarios are the Representative Concentration Pathways (RCPs) created in 2010. The different scenarios are related to emissions trajectories until 2100 and are named based on the increase in radiative forcing, or the climate "warming influence", in watts per square meter on the Earth's surface at the end of the century. The scenarios are bounded by RCP 2.6, a stringent mitigation scenario that achieves net negative emissions by the end of the century and RCP 8.5, a higher-end scenario with no effort to constrain current emissions trajectories (Figure 1). RCP 2.6

[1] Bedsworth et al. (2018)
[2] Rosen (2021)

is representative of a scenario that would keep the average global warming to below 3.6°F (2°C) above pre-industrial temperatures and is extremely unlikely given current emission levels and lack of global political will to take action on climate change. The RCP 8.5 scenario corresponds to a future where carbon dioxide and other GHGs continue to rise over the rest of the century.[3] Average temperature is likely to increase by at least 3.6°F (2°C) under RCP 8.5 and lead to substantial warming across the planet and especially in the Arctic and northern latitudes. This warming is likely to cause rapid and extensive melting of glaciers and land ice, with global implications and consequences. The current emissions trajectory more closely follows RCP 8.5, so climate exposures and projections throughout this work will be based on RCP 8.5, with other scenarios offered to illustrate the range of potential future conditions.

It is important to take action to reduce emissions and limit the long-term impacts of climate change. The more emissions are reduced (globally), the less severe climate change exposures will be over the long term. So, while reduction of greenhouse gas emissions is important and it is still possible that the world will take action to limit the worst impacts of climate change, that is not the direct focus of this project. Mitigation (actions that reduce greenhouse gas emissions) and adaptation (actions that reduce the impacts of climate change) should be undertaken simultaneously and do have areas of intersection.

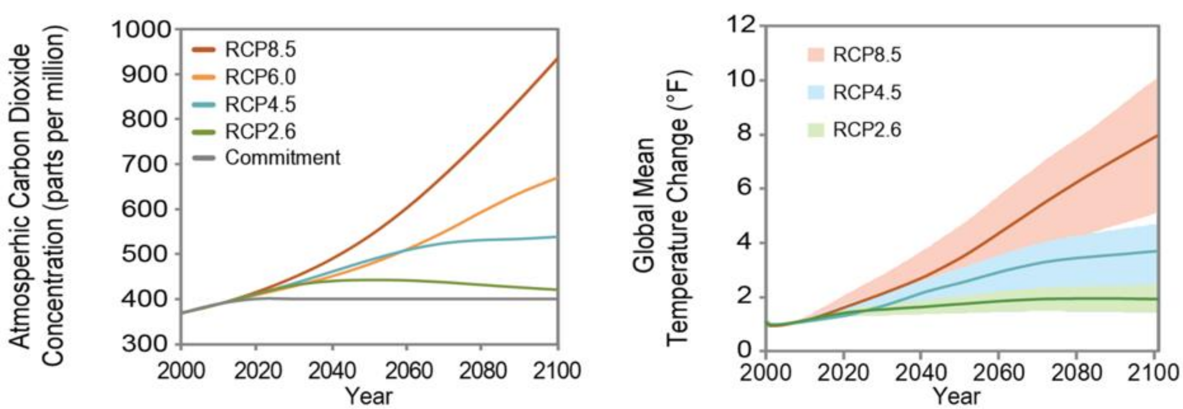


Figure 1. Future scenarios of global atmospheric concentrations of carbon dioxide and global temperature. Future scenarios of atmospheric carbon dioxide concentrations (left) and global temperature change (right) resulting from several different emissions pathways, called Representative Concentration Pathways (RCPs), which are considered in the fourth and most recent National Climate Assessment (Source: https://science2017.globalchange.gov/chapter/4/).

[3] Hayhoe et al. (2017)

Windsor's Climate Factors

SCALES OF ANALYSIS

Climate projections can be analyzed at multiple scale, and the appropriate scale depends on the climate exposure and the particular topographical and geographical features of the surrounding environment. When climate models are produced, climate scientists divide the area of study into a grid, and the model produces point estimates for each individual cell within that grid. These outputs can then be visualized on a map. In climate model projections, for any given snapshot in time, each grid cell is represented by a single value for the climate variable of interest (e.g., temperature, precipitation). Most global climate models are made of very large grid cells, from 100 to 600 square kilometer (about 38 to 230 square miles; for reference, Windsor's municipal area is ~7 square miles). This scale is useful when scientists study the global climate patterns or run complex global models, but it is not useful when trying to understand impacts on a more localized scale. In order to create finer-scale models for localized projections, scientists use various techniques to "downscale" global models. The data used in this climate analysis is taken from Cal-Adapt and downscaled to about a 6-kilometer resolution.[4]

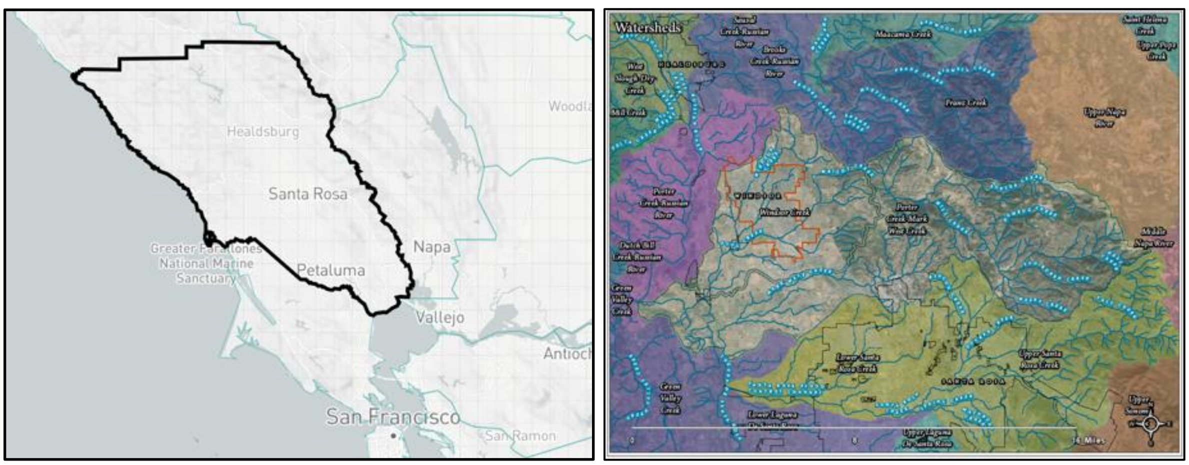


Figure 2. Map of different climate projection scales of analyses. The map on the left shows the Sonoma County boundary, which is used as the geographic scale for temperature and precipitation projections for Windsor (summaries provided through CalAdapt). The map on the right shows the outline of Mark West Creek Watershed (neutral color), one of the many watersheds around Windsor that have an impact on the Town (boundaries show in orange) and that can be used to discuss projected changes in other climate hazards such as flooding and wildfire. Map sources: CalAdapt (left), USGS National Hydrographic Dataset HUC12 designations hosted by the State of California (right).

While "downscaling" can help to analyze more localized climate projections, the spatial extent of the areas analyzed matter when considering particular climate exposures. The primary climate exposures, such as temperature and precipitation, can be averaged across the county-level to provide a more accurate representation of the projected changes for Windsor over the rest of the century. However, secondary exposure such as wildfire and flooding require a different - and larger - spatial extent due to topographical and landscape features (such as the watershed boundaries) that impact different environmental processes. While Sonoma County extends from

[4] Cal-Adapt (2018)

the ocean in the west and the valleys and mountains in the east, the county-level average for temperature and precipitation can still provide useful information on projected changes in magnitude of these climate drivers for the Town of Windsor.

EXTREME TEMPERATURES (HISTORICAL AND PROJECTIONS)

We all know that temperatures in Windsor vary daily and seasonally. Summers are warm (sometimes hot), winters are chilly (but rarely freeze). Historical average annual maximum temperatures for the Town of Windsor (modeled historical baseline 1961-1990) were 72.6 °F (range 72.2 °F - 72.9 °F), with most years seeing fewer than 10 extreme heat days (where temperatures rose above 100.5 °F) per year.[5]

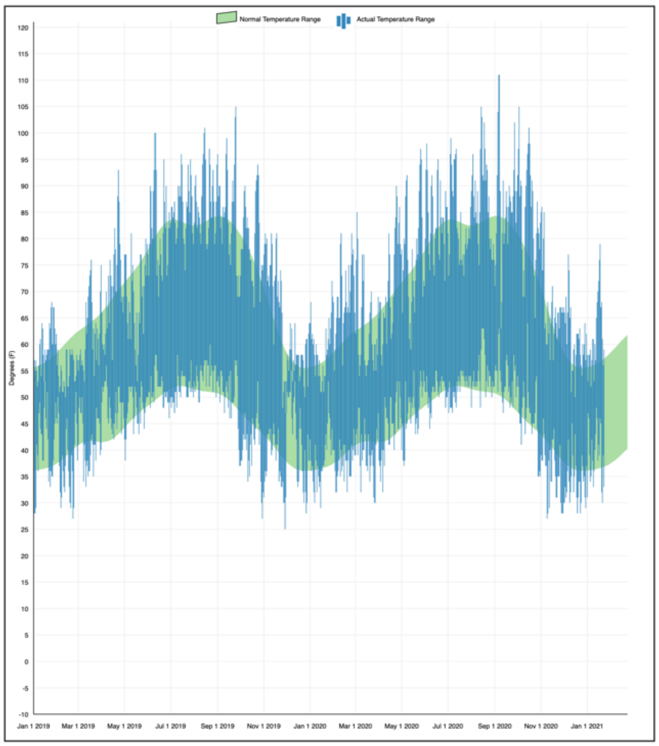


Figure 3. Observed temperatures for Santa Rosa between 2019 and 2021. Daily temperatures from the Santa Rosa Weather Station (# USW00023213) shown in the green shaded area. Actual daily temperature range for the last two years (Jan 2019-Jan 2021) shown in the blue bars. Temperature (in Fahrenheit) is listed on the vertical axis from -10 degrees to 120 degrees, and dates are listed on the horizontal axis from January 1, 2019 through January 1, 2021. Data provided by the U.S. Climate Explorer - https://crt-climate-explorer.nemac.org - Accessed January 24, 2021

The climate is changing; temperatures are increasing, and precipitation patterns are changing. Average annual maximum temperatures in the Bay Area region have increased 1.7 °F from 1950 through 2005 and are projected to continue to increase.[6] Using the RCP 4.5 and RCP 8.5 climate scenarios, average annual maximum temperatures in Windsor are projected to increase 3.3 °F *(RCP 4.5 average)* to 4.1 °F *(RCP 8.5 average)* by the mid-century *(2035-2065)* and 4.1 °F *(RCP 4.5 average)* to 7.2 °F *(RCP 8.5 average)* by the end of the century (2070-2099). In Sonoma

[5] Cal-Adapt (2018)
[6] Ackerly et al. (2018)

County as a whole, similar changes are projected, with average annual maximum temperatures expected to increase between 3.2 °F *(RCP 4.5)* and 3.9 °F *(RCP 8.5)* by mid-century and 4.2 °F to 7 °F (depending on the greenhouse gas scenario) by 2100.

Average annual maximum temperatures in the Bay Area region have increased 1.7 °F from 1950 through 2005 and are projected to continue to increase.

As part of this broader trend of increasing annual average maximum temperatures, the number of extremely hot days in a year is also projected to increase, with the potential to increase to up to three weeks per year under a high-emissions scenario by the end of the century. For this analysis, a daily temperature over 93.9 °F is considered an extreme heat day for Sonoma County.[7]

Table 1. Observed and projected changes in temperature for the Town of Windsor. Average historical (modeled) and projected changes in average annual maximum temperature and average number of extreme heat days a year (above 93.9 Degrees Fahrenheit) for Sonoma County. Projected increases are for the higher future scenario (RCP 8.5) for both the mid-century (2034-2064) and the late-century (2070-2099) (Source: Cal-Adapt.org).

Changes in Temperature in Sonoma County					
	Historical[8] (1961-1990)	Mid-century (2035-2064)[9]		Late-century (2070-2099)[10]	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Average Annual Maximum Temperature	69.2°F	+ 3.2°F	+ 3.9°F	+ 4.2°F	+ 7.0°F
Warm Nights (nights where temperatures do not fall below 55.4 °F)	4 nights/year	24 nights/year	32 nights/year	34 nights/year	74 nights/year
Extreme Heat Days per Year (above 93.9 °F)	4 days/year	10 days/year	12 days/year	13 days/year	23 days/year

Similarly dramatic increases are also projected under both scenarios for the number of warm nights, in which temperatures overnight do not fall below 55.4 °F. Under RCP 4.5, the county as a whole may see 20 additional warm nights by mid-century, and by late century, an additional 30 warm nights. Under RCP 8.5, mid-century warm night occurrence may increase by 28 nights per year, and by 70 nights per year at the end of the century. Likewise, the Greater Windsor area - whose vineyards rely upon night-time cooling - will likely see a similar trend. What all of this amounts to is a town, valley, and county whose climate is notably warmer.

[7] For purposes of this analysis, an extreme heat day or warm night is defined as a day in a year when the daily maximum/minimum temperature exceeds the 98th historical percentile of daily maximum/minimum temperatures based on observed historical data from 1961–1990 between April and October. (Source: Cal-Adapt)

[8] The historical baseline (1961-1990) average is chosen to represent a period in which the majority of California's critical infrastructure was developed. This 30-year period represents the period in which anthropogenic climate change signals were beginning to be felt and can be used as a standard baseline to discuss future projections. Thirty years is the traditional length of record used in climatological studies and is considered the minimum number of years needed to characterize a regional climate and for applying statistical tests. (Source: Cal-Adapt)

[9] This mid-century projection (2035-2064) is calculated using a 30-year projected average centered around the middle of the 21st century (2050). This period is selected to be coincident with the timelines developed for the Fourth National Climate Assessment. (Source: Cal-Adapt)

[10] This late-century projection (2070-2099) is calculated using the average of the last 30 years of the 21st century and is centered around 2085. This period is chosen to be coincident with the timelines developed for the Fourth National Climate Assessment. (Source: Cal-Adapt)

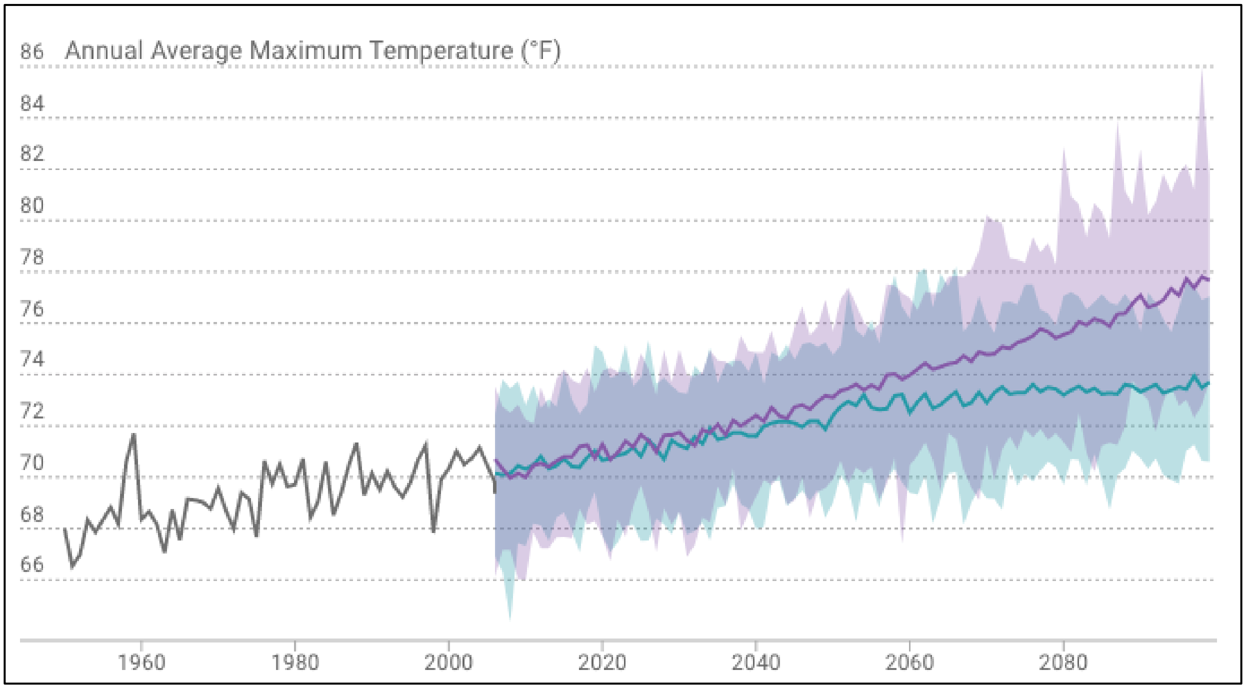


Figure 4. Graph of observed and projected annual average maximum temperature for Sonoma County. Observed temperatures are shown in the dark grey line and show an increasing trend from 1950-2005. Future projections for two different emissions scenarios are shown in the colored lines and shading. A medium emissions scenario (RCP 4.5) is shown in teal, while a high emissions scenario (RCP 8.5) is shown in purple. Both scenarios show significant warming over the course of the century and there is very little difference between the scenarios through the 2050s, after which they start to diverge.

EXTREME PRECIPITATION (HISTORICAL AND PROJECTIONS)

Windsor is no stranger to highly variable precipitation patterns with extremely wet years and extremely dry years. In fact, the last two years are perhaps the perfect example of this swing from wet to dry. 2019 was extremely wet with large amounts of rainfall in the spring and early winter with a total accumulation of nearly 52 inches of precipitation. 2020 was very dry with only slightly more than 10 inches of precipitation over the course of the year. Both years show little or no precipitation between May and November.

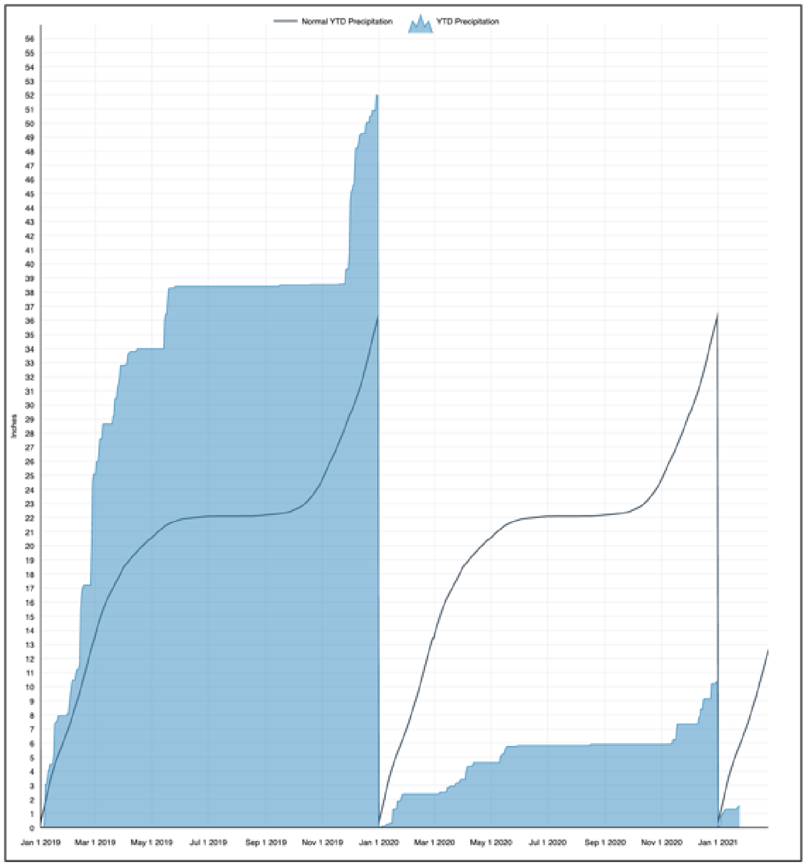


Figure 5. Graph of observed precipitation patterns for Santa Rosa weather station between 2019 and 2021. Daily and accumulated precipitation for 2019 and 2020. The long-term average water year accumulation curve is shown in the dark blue curve. Observed precipitation from the Santa Rosa Weather Station (# USW00023213) shown in the blue shaded area. 2019 was extremely wet with large amounts of rainfall in the spring and early winter with a total accumulation of nearly 52 inches of precipitation. 2020 was very dry with only slightly more than 10 inches of precipitation over the course of the year. Both years show little or no precipitation between May and November. Data provided by the U.S. Climate Explorer - https://crt-climate-explorer.nemac.org - Accessed January 25, 2021

Research suggests that these cycles of wet and dry years will continue for much of the State of California.[11] While overall average annual precipitation may remain fairly constant, there will likely not only be a continuation of the wet/dry cycle, but there will be more intense storms and more precipitation will come in a shorter rainy period. Precipitation in the Bay Area will continue to exhibit high year-to-year variability - "booms and busts" - with very wet and very dry years.[12] This "boom and bust" cycle is readily apparent in the precipitation records from the Santa Rosa station over the last decade. The middle part of the 2010s (2013-2015) saw three generally low water years in a row, followed by four years with average or above average precipitation.

[11] Cal-Adapt (2018)
[12] Bedsworth et al. (2018)

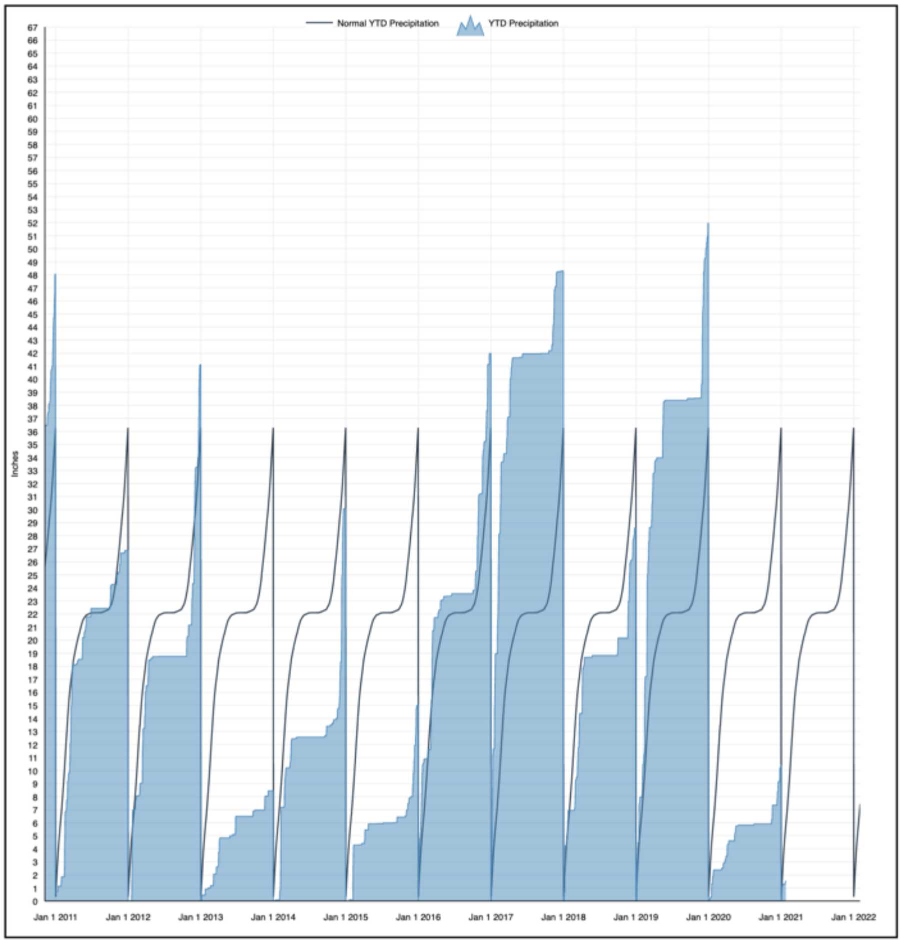


Figure 6. Graph of observed precipitation patterns for Santa Rosa weather station between 2011 and 2022. Accumulated precipitation for January 2011 through January 2021. The long-term average water year accumulation curve is shown in the dark blue curve each year. Observed precipitation from the Santa Rosa Weather Station (# USW00023213) is shown in the blue shaded area. 2013-2015 was extremely dry with only 2014 approaching average precipitation. 2016, 2017, and 2019 had significantly higher than average precipitation with 2018 only slightly below average. Data provided by the U.S. Climate Explorer - https://crt-climate-explorer.nemac.org - Accessed January 25, 2021

It is possible to see these highs and lows of precipitation in the overall average annual precipitation values for the last 50 years. The 30-year average (1961-1990) is 37.7 inches with lows of about 10 inches a year and highs of more than 80 inches a year. Rainfall is the most variable factor in climate models and projections for Sonoma County and the broader North Bay region. This wide variation in modeled rainfall projections is the greatest source of uncertainty in projected future conditions.[13] Climate projections show very little change in average precipitation over the course of the century, though there is likely to continue to be a high amount of variability and a continuation of wet years and dry years.

[13] Sonoma Water County Agency (2015)

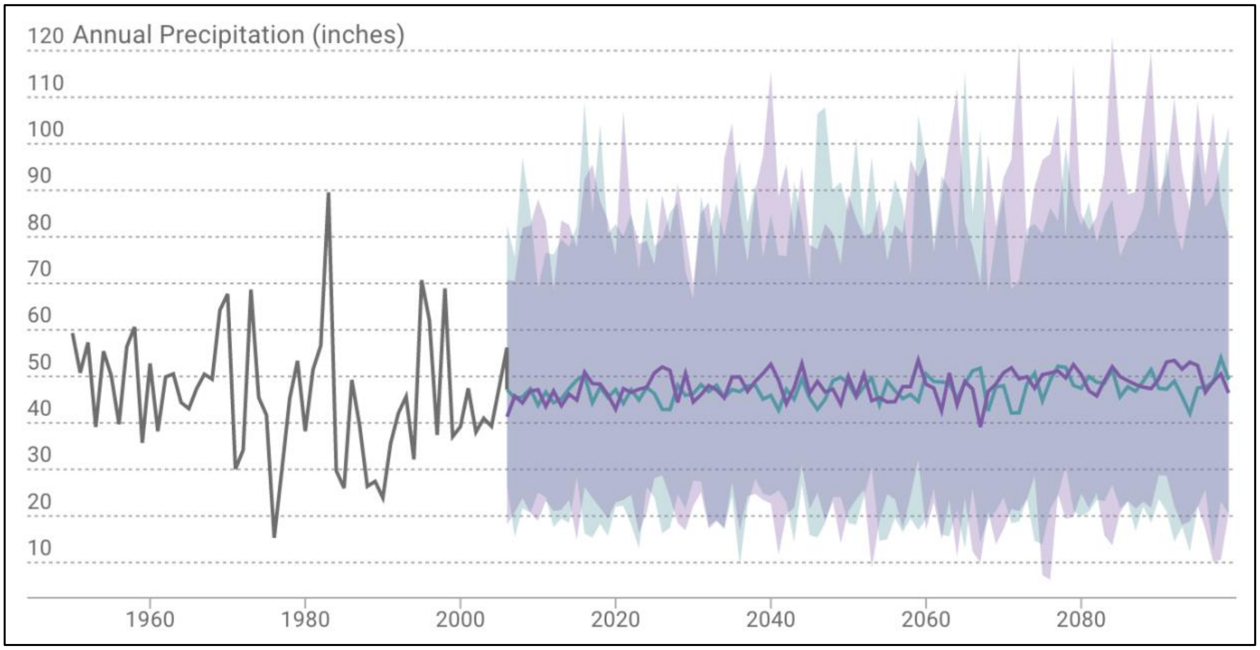


Figure 7. Graph of observed and projected annual average precipitation for Sonoma County. Average annual precipitation for Sonoma County shown in inches. The 30-year average (1961-1990) is 37.7 inches with lows of about 10 inches a year and highs of more than 80 inches a year. Observed annual precipitation is shown in the dark grey line. Future projected annual precipitation for two different emissions scenarios is shown in the colored lines and shading. A medium emissions scenario (RCP 4.5) is shown in teal, while a high emissions scenario (RCP 8.5) is shown in purple. Both scenarios show very little change in average precipitation over the course of the century, though there is likely to continue to be a high amount of variability and a continuation of wet years and dry years.

Table 2. Changes in Precipitation. Changes in average annual precipitation for Sonoma County based on modeled historical observations and future projections for 2050 (2035-2064) and the 2080s (2070-2099) under the RCP 4.5 and RCP 8.5 scenarios.

Changes in Precipitation in Sonoma County					
	Historical (1961-1990)	Mid-century (2035-2064)		Late-century (2070-2099)	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Average Annual	46.2 inches	+ 0.7 inches (+ 1.5 %)	+ 1.6 in (+ 3.5 %)	+ 1.9 inches (+ 4.1 %)	+ 3.7 inches (+ 8.0 %)
Dry Spells	99 Days	+ 5 days	+ 8 days	+ 6 days	+ 10 days
Max 1-Day	3.02 inches	3.24 inches (+ 7.3%)	3.31 inches (+ 9.6%)	3.34 inches (+ 10.6%)	3.60 inches (+ 19.2%)

Another way to look at this boom-and-bust cycle of rainfall is to look at extreme precipitation events and dry spells. It is difficult to project changes to extreme precipitation events. Scientists do know that a warmer climate holds more moisture, and it is likely that extreme precipitation events will increase as the climate warms. For Windsor, the extreme (1% annual chance) 1-day rainfall event brings 2.66 inches of rain[14]. It is unclear from the climate projections whether the intensity of these events will increase, but projections do show that they will likely become more

[14] Cal-Adapt (2018)

frequent. The specific impacts of a given extreme precipitation event will depend largely on where exactly precipitation falls and when, it does highlight the fact that increased atmospheric water holding capacity will in turn lead to the potential for more dramatic precipitation events, which in turn may yield more dramatic and destructive outcomes for people living on the ground.

Climate projections show very little change in average precipitation over the course of the century, though there is likely to continue to be a high amount of variability and a continuation of wet years and dry years.

At the same time as dynamics surrounding extreme precipitation events transform, seasonal precipitation patterns in the region are also likely to change. In both Sonoma County and Windsor, summers are typically very dry, with more than 111 days a year in a row with less than measurable precipitation (< 1 mm of precipitation a day). The length of those dry spells is projected to increase as the climate warms. Expanding by about a week by the middle of the century and on average an additional 9 days by the end of the century[15]. At the same time, these dry spells will be characterized by increasingly hot days and nights, further heightening the intensity of the region's dry summer seasons. As a result, while overall annual precipitation will likely remain similar or even increase, combination of longer dry spells, higher temperatures, and other factors will accelerate evaporation as well as transpiration from plants, resulting in less surface water and drier soils which can affect both agriculture and the functioning of natural ecosystems in the region.

[15] Cal-Adapt (2018)

Vulnerability Assessment

Background and Overview

As the climate continues to change, there are four main climate hazards that will likely affect Windsor: wildfire, flooding, drought, and extreme heat. All of these hazards are discussed and addressed in the Sonoma County Hazard Mitigation Plan[16] and annex for the Town of Windsor[17]. While many of the same findings and discussion occur in this chapter of the Resilience Plan, this plan provides additional perspective on the Town's vulnerability to these hazards particularly in light of changing climate conditions. Each of these hazards has the potential to impact people, buildings, infrastructure, natural systems, and the economy in different (as well as compounding) ways. Some hazards can create immediate threats to human health and safety, whereas other hazards can be chronic and more slowly degrade quality of life, the built environment, natural systems, and aspects of Windsor's economy. All of these hazards have direct and indirect effects on the physical, emotional, and mental health of those affected. Understanding how these climate hazards have already impacted Windsor as well as how they are exacerbated due to climate change is an essential step in working to become a more resilient community in the face of a changing climate.

This Vulnerability Assessment outlines the different hazards facing the community and analyzes how people, buildings, infrastructure, natural systems, and the economy are affected by these hazards. By better understanding who and what will be affected in these hazards, the assessment can help the Town prioritize efforts that will most effectively and efficiently address Windsor's climate vulnerabilities.

[16] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*
[17] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*

Windsor's Climate Hazards & Concerns

Changes in temperature and precipitation are the main climate drivers to multiple climate hazards. The graphic below describes the main relationships between extreme temperatures and precipitation, the four climate hazards, additional considerations, and the subsequent impacts to Windsor's people, assets, and resources.

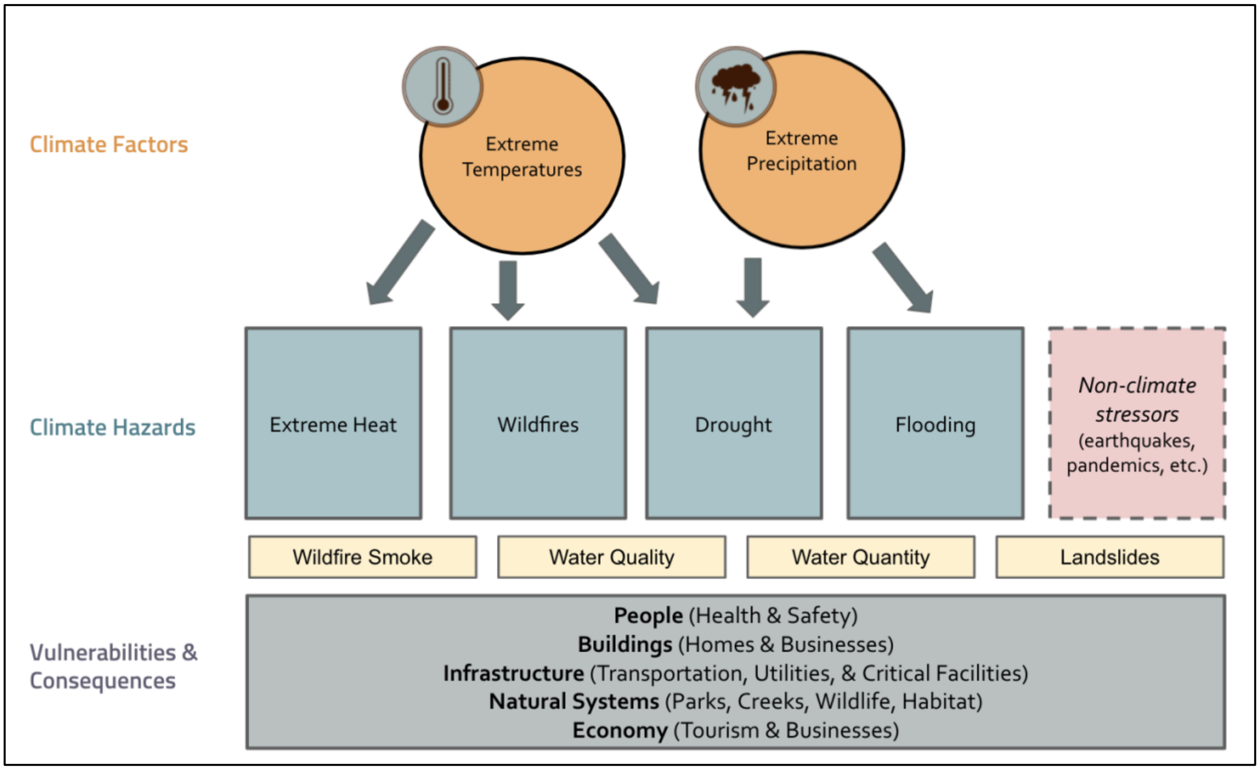


Figure 8. Graphic depicting the relationships between climate factors, hazards, and vulnerabilities. A graphic representation of the relationships between climate factors (extreme temperatures and extreme precipitation), climate hazards (extreme heat, wildfires, drought, and flooding), and the vulnerabilities and consequences to assets for Windsor.

The methodologies used to analyze and discuss each hazard varies, due to the quality and scalability of the data available. In general, a climate hazard will be introduced and discussed in the context of historical, current, and projected exposure for the Town and surrounding region using the best available science and information. It is important to understand that climate hazards are interconnected and influence each other in complex ways, many of which are known but also in ways that are still somewhat uncertain. The following sections of this plan pull together and summarize the plethora of information from local and regional sources, ongoing projects and planning efforts, as well as additional analyses unique to this project.

WILDFIRE

Wildfire is a familiar current and present danger across the region and state. Climate change is exacerbating the frequency, intensity, and severity of wildfires in California,[18] yet fire suppression policies at different levels of government,[19] and the continued expansion of development into the Wildland Urban Interface (WUI)[20] are also increasing the risk of wildfires in the region. Local wildfires can threaten the lives and safety of residents, as well as buildings and other resources. Smoke from regional wildfires can affect daily life (especially for those with existing respiratory conditions) and stress residents, negatively affect natural resources, and impact the economy. The characteristics are changing, and areas outside the traditional WUI are vulnerable to ignition by ember cast and firestorms from wildfires burning miles away.

The wildfire assessment focuses on changing environmental conditions, shifting characteristics of wildfires and new ways of discussing wildfire risk for Windsor. This analysis focuses on human health and safety and discusses wildfire-specific evacuation vulnerabilities within the transportation network. This analysis does not go into detail on the vulnerabilities at a structure-level but does highlight particular sensitivities that make certain buildings and homes more vulnerable to ignition.

FLOODING

While flooding is the second most financially devastating hazard facing Californians,[21] it may not be a hazard that many residents think about or deal with frequently. However, as precipitation in the region becomes more and more "flashy" and variable, people and infrastructure within Windsor and the surrounding area are increasingly vulnerable to damage from fluvial (Russian River) and creek flooding. Traditional 100-year and 500-year flood events may become more frequent and cover areas that previously did not flood. Atmospheric river events can dump incredible amounts of precipitation in areas that can cause river and creek swelling or flooding that can lead to overtopping of critical roadways, reduced efficiency of utility infrastructure, and lead to standing water in low-lying neighborhoods. While flooding is generally temporary, impacts to the quality of Windsor's consumptive water resources can be much longer lasting and felt by many more people.

The flooding assessment highlights areas within the Town and the surrounding areas currently vulnerable during a 100-year and 500-year flooding event. Current flood maps, created by the Federal Emergency Management Agency (FEMA), use only historical data and do not incorporate projected change in precipitation amount, duration, or frequency; due to limited data, the scope of this assessment, and high levels of uncertainty in precipitation projections, the analysis of future impacts of climate change on flood vulnerability takes more of a qualitative approach to highlight areas and assets currently at risk and factors that may exacerbate flood risk under changing climatic conditions.

[18] Bedsworth et al. (2018)
[19] Plumer, B., & Schwartz, J. (2020)
[20] Pierre-Louis, K., & White, J. (2018)
[21] Taylor (2017)

EXTREME HEAT

Excessively warm temperatures and heat rank as one of the deadliest natural hazards, yet heat-related illnesses and deaths can be largely prevented.[22] Windsor "feels" the California heat differently, in that it is typically cooler than many other locations throughout the Bay Area and southern California; however, how humans and the natural world react to increased temperatures is all relative. Residents and native species have adapted to historical temperature ranges, yet the projected increase in annual and seasonal average can cause significant health stress on organisms at the top of their specific temperature thresholds. The number of excessively warm days in Windsor are expected to increase as are the frequency and duration of extreme heat events (back-to-back days of extreme heat). Although life-threatening impacts are preventable, it will take preparation and planning for Windsor to prevent significant impacts to people, natural systems, and critical infrastructure.

DROUGHT

Another all-too-familiar hazard for Windsor is drought. Longer and more pervasive droughts are projected for California with significant implications for natural resources.[23] Due to the characteristics of regional water dynamics, droughts occurring in areas outside of Windsor and Sonoma County can impact residents of Windsor - especially during extended and extreme periods of drought. The projected increasing temperatures and drying trend will likely lead to increased regional wildfire risk and exacerbate the frequency, duration, and severity of wildfires.

Assessing Vulnerability

Vulnerability to changing climate conditions and the associated extreme weather events of climate hazards is generally dependent on three key factors: climate exposure, sensitivity, and adaptive capacity.[24] Figure 11 depicts the relationships between climate exposure, sensitivity, adaptive capacity. When climate exposure and sensitivity interact, the potential impact of an asset, resource, or system will experience due to climate change is defined. When that combined potential impact interacts with an assets adaptive capacity, the relative vulnerability of the people, assets, resources, or systems of the Town are defined.

> ***Climate Exposure*** **-** Long-term changes to temperature and precipitation patterns along with the associated changes to extreme weather and climate related hazards (e.g., wildfires, extreme heat, drought, flooding).
>
> ***Sensitivity*** **-** The degree to which a key asset, resource, or system is affected by a climate exposure or hazard.
>
> ***Adaptive Capacity*** **-** The ability to adjust to potential impacts, take advantage of opportunities, and respond to extreme weather events and changing climate conditions.

Climate Change exposures and hazards discussed describe, and in some cases quantify, the climate and weather conditions that the Town currently faces and will need to be prepared to face

[22] California Climate Action Team (2013)
[23] Public Policy Institute of California (2021)
[24] California Adaptation Planning Guide (p. 282). (2020).

in the future. Since human systems are generally designed to meet the needs of the current environment, these future exposures and hazards may extend beyond the limits that our systems are prepared for or able to address. Intuitively, systems, assets, resources, or community members that are more sensitive to these exposures and less able to adapt will be more vulnerable to these changing conditions. Similarly, systems, assets, resources, or community members that are less sensitive or can adapt easily will be less vulnerable to these changes. Ultimately, relative climate related vulnerabilities can help determine and inform the allocation of funding and planning support to reduce those vulnerabilities. Since the Town has only a finite number of resources, budget, and staff time, the higher vulnerability items are ones that could be addressed first while lower vulnerability items could be addressed in the future. Thus, making strategic use of these investments to reduce vulnerability and enhance resilience.

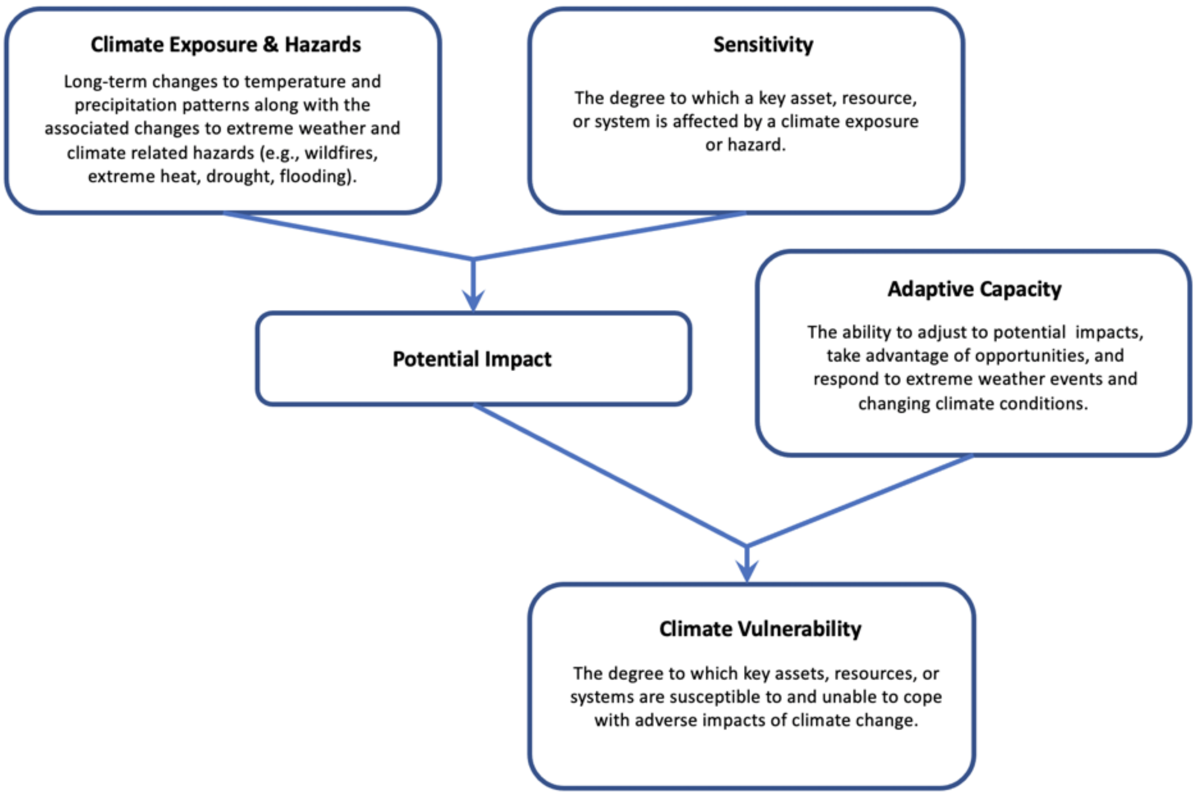


Figure 9. Graphic depicting the definitions and relationships between climate exposure, sensitivity, adaptive capacity, and climate vulnerability. Definitions and relationships of Climate Exposure, Sensitivity, and Adaptive Capacity, all of which contribute to climate vulnerability. Adapted from the California Adaptation Planning Guide, 2020.

Throughout the assessment, the project team considered the climate exposures and then assigned each main area of potential consequence a sensitivity and adaptive capacity ranking. These rankings ranged from low to very high on a five-point scale (0-4). Sensitivity rankings ranged from S0 (the component will not be affected by projected weather and climate conditions) to S4 (the component will be greatly affected by projected weather and climate conditions). Adaptive capacity can range from AC0 (the component is not able to adjust to projected weather and climate conditions) to AC4 (the component can adjust to projected weather and climate conditions in a beneficial way). These rankings were then combined to determine the overall vulnerability of the area of consequence. Areas that are highly sensitive to extreme weather and climate events and had limited ability to adapt were highly vulnerable, while those that are less sensitive or had greater ability to adapt were less vulnerable.[25] The adaptive capacity ranking process and results are discussed in detail for each of the climate in the following sections.

Asset Categories

The Town looked at five main asset areas: people, buildings, infrastructure, natural systems, and the economy. A *consequence analysis* helps to illustrate to what extent people, buildings, infrastructure, natural systems, and the economy are projected to be affected by a hazard - or multiple hazards. Focusing on these areas makes it easier to better understand the range of depth of potential impacts that climate change will have on the community and identify the priority action areas where the Town and the community can focus to reduce climate related risk and enhance resilience. Within each category, the assessment identifies key areas of concern or differential vulnerability.

While analysis focuses mainly on the assets within the jurisdiction of the Town of Windsor, the people, places, and things that give the town character and provide resources for the community extend beyond the jurisdictional border of the Town. Because of this, some of the assets discussed include those that fall beyond the Windsor town boundaries and are considered to be within the "Greater Windsor" area. While this is not strictly defined, this is assumed to include hillside communities to the north and east in the Bald Hills and blow Chalk Mountain, the Windsor Airport and the surrounding industrial parks, agricultural and residential areas to the west between Windsor and the Russian River, and the various residential areas and critical connections just outside of the town's limits.

PEOPLE (HEALTH, SAFETY, AND WELLBEING)

Windsor prides itself on being a family-oriented community with a diverse population, small-town character, and welcoming atmosphere. The Town values cultural diversity and promotes opportunities for all residents to "share their unique heritage and engage in the life of the community".[26] Windsor is currently home to 28,248 residents (Windsor Annex to Sonoma County Hazard Mitigation Plan), representing approximately 5.73% of Sonoma County residents. The Windsor population is roughly 34% Hispanic, 57% European Ancestry, and 9% Black, Asian, Mixed-Race, or Native American. When compared to Sonoma County as a whole, the average Windsor household is more likely to own their own home, to have a higher household income, and to live in a slightly larger home.[27] English and Spanish are the primary languages spoken in Windsor.

Community health and wellbeing are a major focus of the Windsor 2040 General Plan, which facilitates healthy development by including and encouraging active design strategies that

[25] Data from the CA Department of Finance, Estimated population from January 1, 2020. Retrieved from https://scta.ca.gov/wp-content/uploads/2021/01/8.4-Measure-M-LSR-LBT-Annual-Allocation-Estimates.pdf
[26] Town of Windsor (2018b)
[27] Town of Windsor (2018a)

encourage stair climbing, walking, bicycling, transit use, active recreation, and healthy living for Windsor residents.[28]

All of the climate hazards have the potential to affect all Windsor residents. However, decades of research on disasters and climate change have demonstrated that social factors such as individual characteristics (age, gender, existing medical challenges, etc.), social status, capacities, networks, and resource availability can lead to distinctly different outcomes.[29] These "Communities of Concern" often experience the first and worst impacts of the extreme weather events and other changing climate conditions. In order to better understand which portion of the Windsor community might be disproportionately affected by current and future climate hazards, this analysis includes a review of an array of socio-demographic and health indicators that have been demonstrated to have implications for impacts of these event, either by heightening sensitivity to hazards or by limiting the ability of these communities to proactively prepare or adapt after the hazards occur. **In this context, *social vulnerability* is the disproportionate sensitivity of some segment of the community or groups to the climate exposures or hazards.**

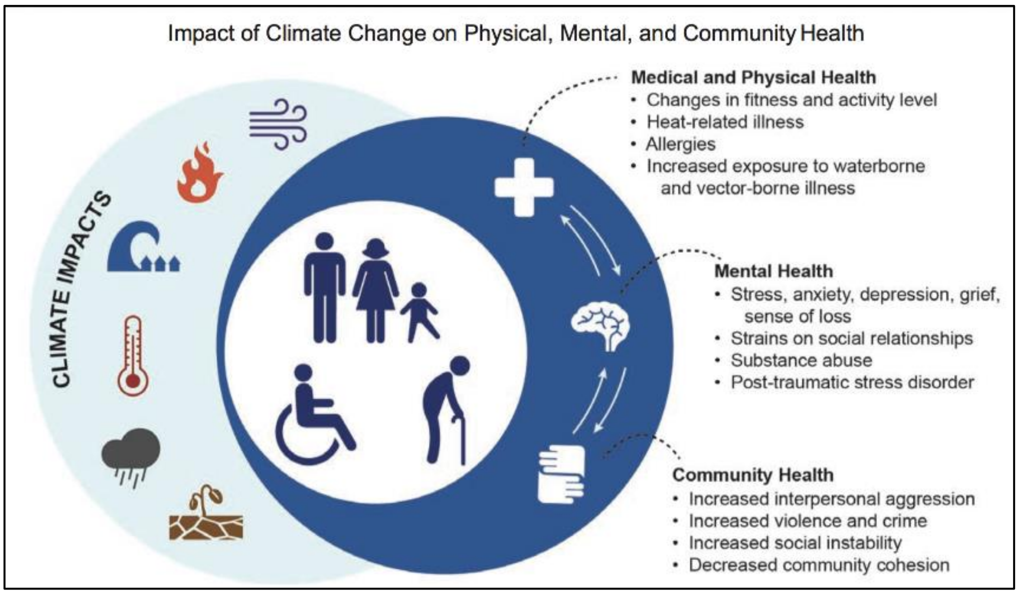


Figure 10. Graphic depicting the impact of climate change on physical, mental, and community health. The myriad of health impacts from climate change. Source: https://www.psychiatry.org/patients-families/climate-change-and-mental-health-connections.

This analysis included examining factors that:

- Increase the likelihood of severe negative outcomes during and after hazard events, such as poverty, economic burdens associated with housing costs;
- Are known to result in disproportionate post-exposure impacts due to societal discrimination, disenfranchisement, and such as race, ethnicity, and linguistic isolation;

[28] Town of Windsor (2018b)
[29] Cutter et al. (2009); Thomas et al. (2013); Fatemi et al. (2017); USGCRP (2016)

- Heighten the immediate negative impacts of certain hazards like smoke, e.g., asthma and cardiovascular disease;
- Hinder or preclude the ability to evacuate quickly in the event of an emergency, such as physical disability, age, English as a second language, and a lack of automobile access; and
- Limit the ability of individuals to incorporate new information about risk into their daily lives and make appropriate adjustments at the household level.

The Centers for Disease Control and Prevention's Social Vulnerability Index[30] program, the State of California's CalEnviroscreen program,[31] the California Healthy Places Index, and Headwaters Economics Neighborhoods at Risk System[32] each utilize data gathered by the U.S. Census Bureau, Environmental Protection Agency, and other authoritative sources. These data are compiled and aggregated to identify those areas or segments of the community that are more likely to face social, political, economic, or cultural challenges to extreme weather events and changing climate conditions. While it is not possible to pinpoint the vulnerability of specific individuals or households, the composite indices highlight census tracts that are most likely to be home to individuals and households with heightened sensitivity to hazard and disaster events and that may be limited in their capacity to prepare for, respond to, recover from, and adapt to hazard exposures. These community members are the ones that are most likely going to be affected more intensely by hazards now and within a transforming climate and environment.

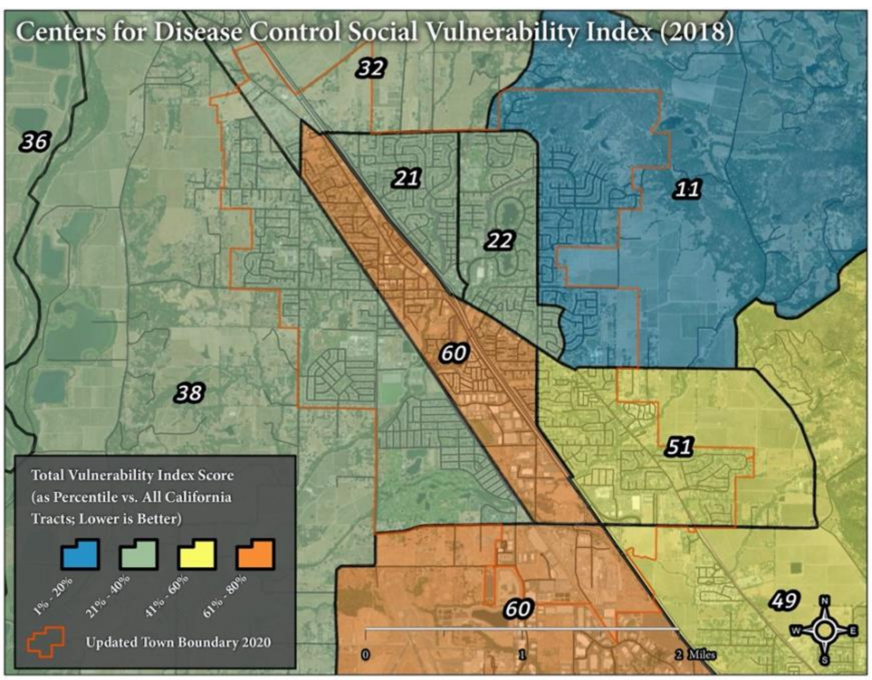


Figure 11. Map of Social Vulnerability Index (SVI) for the Town of Windsor. Relative social vulnerability index scores for census tracts in Windsor using data compiled by the Centers for Disease Control and Prevention (CDC). This compilation of 15 factors that are known to affect the ability of households and individuals to prepare for and

[30] ATSDR (2021)
[31] California Office of Environmental Health Hazard Assessment (2021)
[32] Headwaters Economics (2021)

respond to extreme weather events. Percentile rankings are relative to other census tracts in California where higher numbers (and warmer colors) are more vulnerable, and lower numbers (cooler colors) are less vulnerable to these events.

The project team collected ranking scores and raw information compiled by the state and federal agencies and created maps of specific vulnerability indicator variables for Windsor census tracts to help understand which neighborhoods/subdivisions are most likely to be home to individuals and households with heightened sensitivity to hazard and disaster events. The relative social vulnerability index does not identify who lives in which areas but highlights generally conditions that make these areas more exposed, more sensitive, or less able to adapt to the climate hazards. Some of the key socio-economic and demographic factors that go into these indices are described below. More detailed information can be found in Appendix A.

OLDER ADULTS

People over the age of 65 are also more likely to have underlying health conditions or experience health and age-related issues that may heighten their sensitivity to specific climate-driven hazards such as smoke, post-flood mold, extreme heat, and interruptions to water and electric/gas supply. In Windsor, many neighborhoods exist with average ages much higher than the surrounding areas in the County, including both neighborhoods tailored to independent senior living as well as areas where assisted living facilities are located. Numerous home-based care facilities are also present within otherwise purely residential neighborhoods. In general, the east side of town shows higher proportions of persons over 65, as do the communities just east of Windsor in the surrounding forested hillsides.

CHILDREN

Young children and infants have higher metabolic rates, spend more time outdoors, and get dehydrated more easily which can make them more sensitive to hazards related to smoke inhalation and extreme heat. During the day, schools and other facilities that house large numbers of children (such as day care facilities) present unique challenges for emergency response planning and evacuation. People under the age of 16 are unable to legally drive in California and will generally require assistance from public services or family members during evacuation events. Children live in every part of Windsor, making up between 20% and 24% of its residents depending upon the specific area. The town's elementary-, middle-, and high school facilities are located outside of wildfire and flood risk areas for the most part but are near to both in all but a few cases.

LINGUISTIC ISOLATION (ENGLISH AS SECOND LANGUAGE/LIMITED ENGLISH PROFICIENCY)

Effective communication is critical to any preparation, response, recovery, or adaptation effort, and language differences can create a barrier to effective communication. Since most government communication during emergencies is conducted in English, understanding where community members have limited English proficiency or primarily speak Spanish (or other languages) can inform planning and interactions with these community members. In the central Windsor census tract along the 101 corridor, an estimated 1 in 10 people speak English less than well and may require additional assistance from interpreters or native language translations of documents and public communications. Spanish is the second most spoken language in Windsor and the surrounding area, but others are likely as well.

PEOPLE OF COLOR

Historical legacies of racial discrimination, marginalization, and under-allocation of resources to communities of color have resulted in a constellation of factors that enhance these communities' experience of negative outcomes during both disaster processes and within the planning, preparation, and rebuilding efforts seen in many U.S. communities. Windsor is a multi-racial and multi-cultural community and is home mainly people of Caucasian ("white") and/or Hispanic/Latino descent with small populations of people with black, Native American, Asian American, and mixed-race heritages. Windsor, similar to Santa Rosa to the South, is made up of a notably more diverse cluster of communities than the largely rural and largely white Sonoma County area.

POVERTY AND ECONOMIC STRESS

Community members with lower incomes, living in poverty, or under economic stress are generally less able to invest in disaster preparedness and have fewer resources at their disposal to respond to climate hazards if/when they occur. Also, they are more likely to live in substandard housing that is less able to withstand extreme weather events or creates chronic stressors on the families in those situations. Residents living in Windsor 101 Corridor, Windsor Southwest, and Southeast Exurbs experience the highest rates of poverty and thus may be less likely to own an automobile and require additional mobility support during a climate emergency.

ACCESS TO AUTOMOBILE OR PERSONAL VEHICLE

People with limited or no access to a vehicle, either by choice or necessity, are more dependent on transit, if available, or friends, family, and private services to travel. While vehicle ownership in Windsor is generally high, lack of vehicle access can constrain mobility and limit access to key destinations.[33] While lower dependence on automobiles typically helps to reduce congestion, it is important to know where these residents live as they may need assistance evacuating during a disaster.

HEALTH CONDITIONS AND DISABILITY

Individuals suffering from cardiovascular and/or respiratory disease or stress, such as asthma and allergies, are more prone to experiencing complications from multiple environmental hazards, many of which are exacerbated by climate change. This population may need additional support during climate emergencies (especially evacuations or PSPS events) or extreme weather events. People with disabilities may be dependent on certain medical devices or need mobility assistance or help with transportation. This assessment considers the overall health and wellbeing of residents in the context of climate hazards and changing conditions, including general safety as well as characteristics of certain populations of residents that may make them more sensitive or less able to prepare for or adapt to climate hazards.

BUILDINGS (RESIDENTIAL, COMMERCIAL, PUBLIC AND CRITICAL FACILITIES)

For this assessment, buildings are considered the built structures within the Town of Windsor and include homes, businesses, public facilities (such as schools), and critical facilities (such as

[33] Blumenberg, E., & Schouten, A. (2020)

hospitals and fire departments). The built environment for the Town is centered around the Highway 101 corridor and Old Redwood Highway.

RESIDENTIAL AND COMMERCIAL STRUCTURES

The primary land use in Windsor is single-family residential. Many older structures are residential buildings that range in architecture from raised, wood slat homes with front porches to concrete and plaster homes with aluminum windows and asphalt driveways.[34] The more modern residential subdivisions are visually distinct from the older residences yet vary in design, color scheme, size of structures, and type of building materials; however, they are all single family detached homes that are one or two stories. Schools and a park are typically associated with single family residential neighborhoods. Areas of higher density multi-family development are located in the Station Area/Downtown Specific Plan area. Larger single-family developments are planned for the northern area of Town, north of Arata Lane, that was annexed to the Town in 2019.[35] Known in the region as a great place to raise a family, and despite increasing housing prices due to a general shortage of housing within Sonoma County, Windsor remains an affordable community compared to others in the region. Commercial buildings are generally focused in the Town Green area and in smaller commercial centers throughout town. The larger regional-serving commercial areas are located in the southeast part of town, and current and planned industrial developments are located in the southwestern part of Windsor.

CRITICAL & PUBLIC FACILITIES (FIRE AND POLICE DEPARTMENTS, HOSPITALS, SCHOOLS, ETC.)

Critical and public facilities - defined broadly - include both those facilities that support important town functions and health systems operations as well as key social functions and services. These are buildings, structures, or recreational facilities, such as schools and hospitals and those that function as community gathering sites. According to the 2018 LHMP, Windsor has 10 educational facilities (including administration buildings) schools, 3 urgent care or general medical care facilities, 11 registered senior care and/or assisted living facilities, 1 government center, and 4 community gathering sites.

[34] Town of Windsor (2018b)
[35] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*

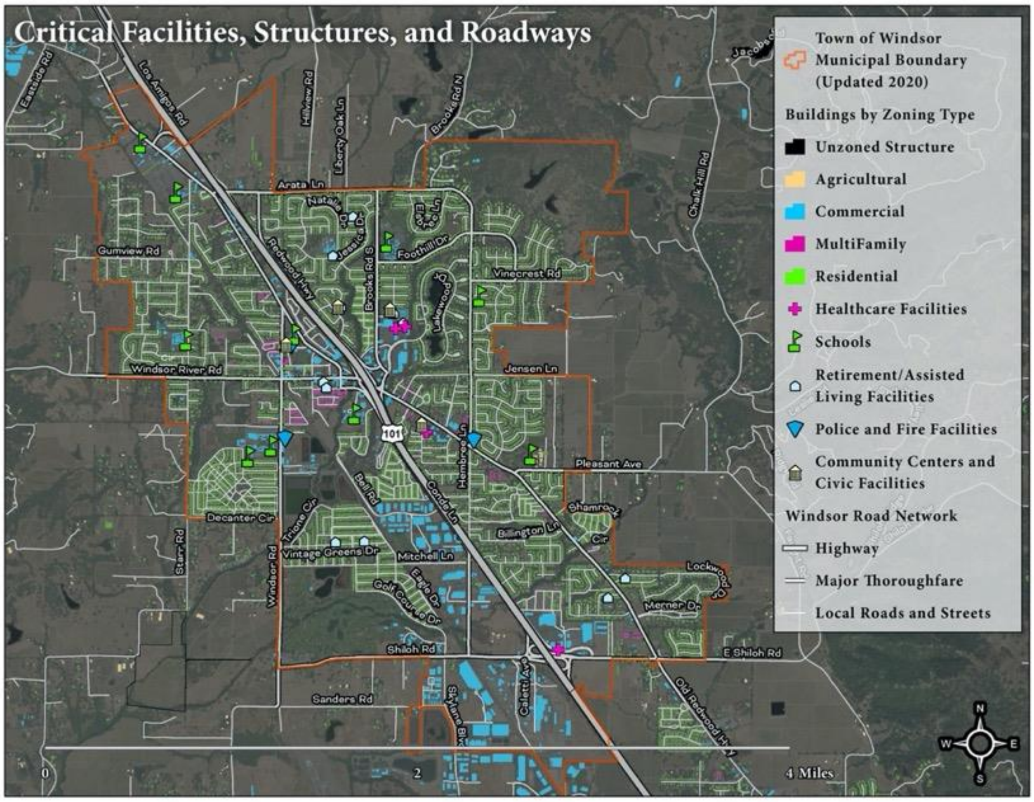


Figure 12. Map of critical facilities, structures, and roadways for the Town of Windsor. Overview of building location and building type in Windsor. Colors highlight residential, multi-family, commercial, and agricultural buildings by land use zoning type. Symbols identify various critical facilities, such as healthcare facilities, retirement/assisted living facilities, schools, police and fire facilities, and other public facilities and centers. Zoning designations are based on Sonoma County Parcel information as of late 2021, with mobile home parks (zoned commercially) converted where possible to residential visualization for the purposes of clarity for risk evaluation.

Where possible, this assessment will provide mostly a quantitative analysis of the number and types of buildings in climate exposure zones. It will also qualitatively discuss the changing nature of some climate and weather-related risks and the implications of those changes on the built environment.

INFRASTRUCTURE (CRITICAL SYSTEMS AND TRANSPORTATION NETWORK)

Windsor's infrastructure consists of multi-modal transportation assets and networks that provide a vital public service to residents and impact a wide range of issues including the economy, environment, health, safety, and overall wellbeing for Town residents. These systems are complex, expensive, and involve a wide range of stakeholders (some infrastructure may or may not be owned and/or operated by the Town). For this assessment, infrastructure is defined as multi-modal transportation assets including roads, bridges, and transit, as well as electric utilities, natural gas, telecommunications, water, and wastewater infrastructure. Climate hazards and extreme events can damage and/or destroy Windsor's infrastructure and disrupt vital services for the town, potentially leading to additional risk to health and safety of Windsor residents.

WATER INFRASTRUCTURE

The Town sources the majority of its potable water locally and from surface water sources.[36] Most of its water comes from the Russian River and the remainder is purchased from Sonoma Water. Direct sources include the Russian River Well Field (aka "riverbank wells"), local (off-river) groundwater wells, Russian River surface withdrawals (via the Santa Rosa Aqueduct), and recycled water.[37] The Windsor Water District (WWD) service area includes the entire Town of Windsor as well as portions of the surrounding areas. The water distribution system includes 136.6 miles of polyvinyl chloride (PVC) pipes, four storage tanks in the primary pressure zone (and 12 storage tanks in smaller, higher elevation zones), five river wells and five off river wells.[38] The majority of the system has been installed within the last 25 years, is buried at a range of depths from 32 inches to over eight feet deep, and is generally in good condition. The Town also has a recycled water system supplying water for irrigation. Recent studies have looked at the available water supply and projected future demand with population growth and determined that with some continued investment in the system it will be able to meet future demand. Calculations were based on daily and peak water demand including flows necessary for fighting fires.

Water can be produced and purchased during PSPS events. The Russian River Well Field is equipped with an auxiliary power supply (500 KW generator), which allows the Town to operate three of the five wells during such an event. In addition, there are also stationary and portable generators to push water within the outside agreement areas of the Shiloh Estates and Mayacama water systems.

The community responded well to drought contingency measures in the past and residents currently use on average 109 gallons of water per day per person. Forecast demand is based on an estimated 120 gallons per day per person. The Water Master Plan did an initial look at potential increase in water use due to climate change and determined that indoor water use was unlikely to change. Water needed for irrigation may increase with warmer temperatures, but even with a 20% increase in irrigation demand, the system would have excess annual water supply. Planning for droughts is a continued need for the effective management of the system. In addition, members of the Technical Advisory Group for this project mentioned that the Well Field has come close to being impacted by high water levels due to flooding events.

ELECTRIC UTILITIES INFRASTRUCTURE

Electrical providers in the Town of Windsor include Pacific Gas and Electric (PG&E) and Sonoma Clean Power (SCP).[39] SCP - a public nonprofit electricity provider operated by Sonoma County - is the default electricity provider of Windsor residents, although residents do have the choice of receiving service from PG&E. PG&E is a for-profit investor-owned utility company which services a large portion of the State. Both electric utility companies purchase electricity from power plants located across the State of California and in the broader Western United States (there are no power plants located locally in Windsor). In 2018, around 34% of the State's electricity was generated by renewable energy sources. In 2021, around 31% of the electricity in

[36] Town of Windsor (2018a)
[37] Town of Windsor (2011)
[38] Town of Windsor (2019b)
[39] Town of Windsor (2018a)

the State is currently being generated by solar power alone.[40] Additional energy sources include coal, nuclear, geothermal, liquefied natural gas, and other renewable energy sources (including wind, geothermal, solar, etc.).

The Town has been actively involved in installing solar photovoltaic power systems over the past decade including installations community centers and schools. Last year (2020) the Town installed and began operating a new 1.7 Megawatt floating solar power system at the Town's wastewater recycled water Pond 7. The array will provide power to the Windsor Wastewater Reclamation Facility, Public Works Corporation Yard, and the Geysers pump station, delivering about 90% of the water reclamation facilities' power needs, saving approximately $5 million dollars in energy costs over the next 25 years and reducing the Town's Greenhouse gas emissions by 350 metric tons a year.[41]

Two major electricity transmission lines - both owned by PG&E, and which connect distribution facilities in Santa Rosa and Healdsburg - service the Town of Windsor. In addition, Windsor's electricity is serviced by substations in Santa Rosa and Healdsburg as well as a substation on the north end of Town on Old Redwood Highway. All of the electric transmission lines that service the Town of Windsor are located above ground, while many neighborhoods have undergrounded lines. In addition, according to the Windsor General Plan and the Town's municipal code, all new electric utility distribution lines are required to be undergrounded.[42]

NATURAL GAS INFRASTRUCTURE

All of the Town of Windsor's local natural gas infrastructure is serviced by two high-capacity natural gas pipelines owned and operated by PG&E, Windsor's sole natural gas provider.[43] Both natural gas pipelines run through the middle of the Town, one running underneath the railroad tracks and another along Old Redwood Highway. At present, natural gas provides a significant portion of the power demands for the Town, but this reliance could present significant challenges if the pipelines are damaged.

TELECOMMUNICATIONS INFRASTRUCTURE

Telecommunications infrastructure includes all of the wires, cables, towers, satellites, and mobile network systems critical for supporting communication across the Town. There are a variety of services that provide internet, cellular, and landline services to homes in Windsor including AT&T, Comcast, Verizon, Frontier Communications, HughesNet, Dish Satellite, Sonic, and ViaSat.[44] Reliable, resilient, and redundant telecommunications infrastructure is critical to the health and safety of Windsor residents, particularly in the case of an evacuation.

TRANSPORTATION NETWORK

The transportation network for the Town is vital to the movement of people, goods, and services throughout the community and to/from the broader region. Broadly speaking, the transportation network includes roads, paths, trails, rail lines, and the airport. Within the Town boundaries this

[40] California Energy Commission (2021)
[41] Town of Windsor (2019a)
[42] Town of Windsor (2018b)
[43] Town of Windsor (2018a)
[44] Town of Windsor (2021c)

multi-modal network includes roadways, transit services, SMART rail services and a bicycle and pedestrian network that allows residents and visitors to walk, bike, take the bus or train, and drive around Windsor. Transportation vulnerabilities will affect the community when failures of transportation assets impede movement of people and goods and services.

ROADWAY NETWORK

The roadway network is the foundation on which all multimodal travel options operate. The Town of Windsor is located along Highway 101, a six-lane, limited access highway that bisects the Town of Windsor and connects it to Santa Rosa (and ultimately San Francisco) to the South and Healdsburg to the North. Although alternate, country road routes are available, Highway 101 and the two complete interchanges at the center and southside of town provide access to critical jobs, cultural activities, medical services, and in-coming tourism, workers, and raw materials. Old Redwood Highway, a two-lane roadway, runs parallel to and connects many local roads to Highway 101, as well as providing a critical alternative route to the north and south when Highway 101 is closed, temporarily congested, or lower-speed routes are desired. Old Redwood Highway can also serve as a secondary evacuation route if necessary.

Laid out in mainly fused grid and curvilinear patterns ("cul de sac" style) cut roughly in two by Highway 101, the local main roadway network extends throughout the town and up into the hills both to the east and west, and provides access to residential areas, shops, community facilities, and services. Every day, roughly 35,000 vehicles travel through the two critical interchanges with 101 on the south-side (101 and Shiloh Rd.) and center of town (101 and Old Redwood Highway). This traffic is due to both the high densities of regional travelers, substantial commuter traffic, and the growing flows of on-demand delivery retail operations and the constant truck and commercial vehicle traffic required from regional distribution centers to the south. Like almost all of the cities in Sonoma County, Windsor is heavily dependent upon raw goods and services accessible only by these limited roadway connections, highlighting the need to resolve critical bottlenecks and challenges along the greater Highway 101 corridor.

Built largely from the 1970's onward, most local roadways are functional, but many are in need of repair and upgrades due to their age. With limited points of rapid egress available, critical pressure is constantly placed on just two key exchanges and the three cross-town roadways (Arata Ln., Old Redwood Highway, and Shiloh Rd.) that connect the east and west sides of town. Although bypass routes along Skylane Blvd. and Windsor Rd. provide connections to the south, these two-lane paved roadways are highly sensitive to congestion slowdown. Routes to the east over the mountains also exist (as well as a handful of 4x4-only accessible routes), but these too are both highly sensitive to obstruction and congestion due to their rugged and windy conditions.

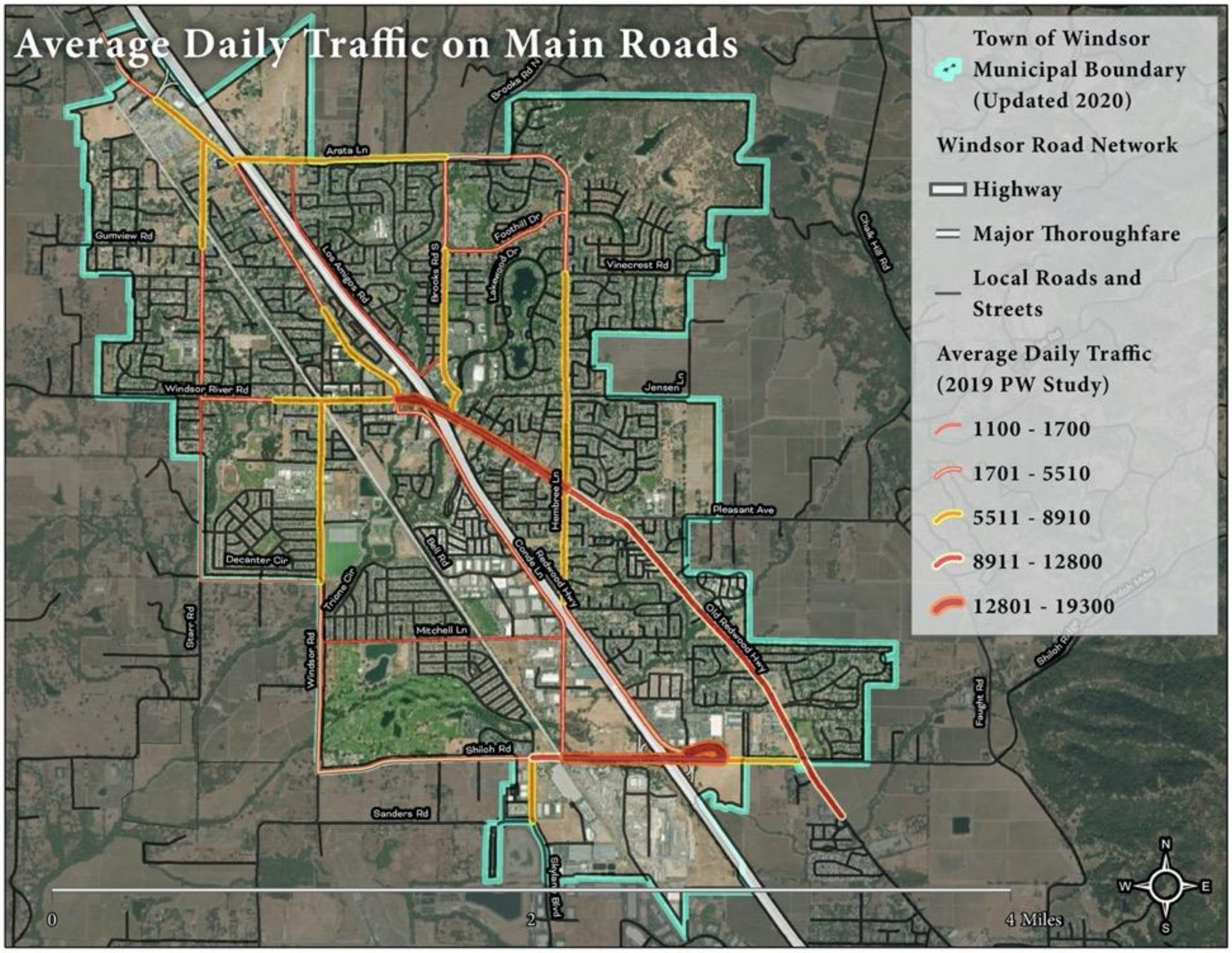


Figure 13. Map of the road network and average daily traffic counts on main roadways for the Town of Windsor. The Town of Windsor's Road Network shown with Average Daily traffic volumes. Traffic counts for local roads and streets not shown.

Windsor's current Local Hazard Mitigation Plan (LHMP) (2018) designates Highway 101 as the primary evacuation route and Old Redwood Highway as the primary surface street to support evacuations. The LHMP also identifies other potential evacuation routes that could support small-scale evacuations, including Windsor River Road, Starr Road, Hembree Lane, Conde Lane, and Shiloh Road. Neighborhood-level evacuation routes have recently been developed by the Town of Windsor to aid in the process of evacuation that delineate specific routes for residents and workers, as well.

LOCAL ACCESS AND NEIGHBORHOOD ROADS

Off the main network and highway are the streets, ways, courts, and lanes that terminate in the town's low-density residential neighborhoods and driveways, where the vast majority of Windsor's 28,000+ residents live and increasingly work, receive deliveries, and engage in home-based businesses. These roads vary highly in condition and layout type, although many are arrayed to serve cul-de-sac neighborhoods, with curvilinear street designs that limit connections to larger roads. This type of curvilinear street design poses several potential challenges for people who use the roadways, as they limit ingress/egress points into/from a neighborhood, increase the difficulty of navigating and wayfinding, and lead to few intersections and parallel roadways. Large, fused grid neighborhoods (such as the Jessica Way area and the north side of Mitchell Ln) provide significantly more flexibility for drivers and a more redundant transportation network. As a result of the conditions in many neighborhoods, people and vehicles must travel through a small number of the same major intersections, creating the risk of chokepoint effects occurring at every step of a person's journey towards the bigger arterials and the regional road network, be it for evacuation or other purposes. Furthermore, the street network in Windsor includes several narrow two-lane bridges that may act as chokepoints in the network during an evacuation. The Sonoma County Multi-Jurisdictional Hazard Mitigation Plan identifies two-lane bridges on the following roadways:

- Caletti Avenue (provides access to the Town's industrial area)
- Hembree Lane (provides access to Hwy 101)
- Conde Lane (provides access to Hwy 101 via Shiloh Road)
- Old Redwood Highway between Billington Lane and Deanna Place (provides access to Hwy 101)

BIKEWAY AND PEDESTRIAN NETWORK

Windsor's bicycle network consists of 2.5 miles of Class I pathways, 17 miles of Class II bike lanes, and 1.1 miles of Class III bikeways. According to the Bicycle and Pedestrian Master Plan, pedestrian activity in Windsor largely occurs in three major districts: Central Windsor, areas around schools, and areas around other public facilities. The Central Windsor pedestrian district is the largest district and covers a large section of central Windsor on both sides of the highway. The district includes the Town Green, the future intermodal SMART train station, high school, town hall, and other developments west of Highway 101, as well as the housing and commercial establishments on the east side of the highway.

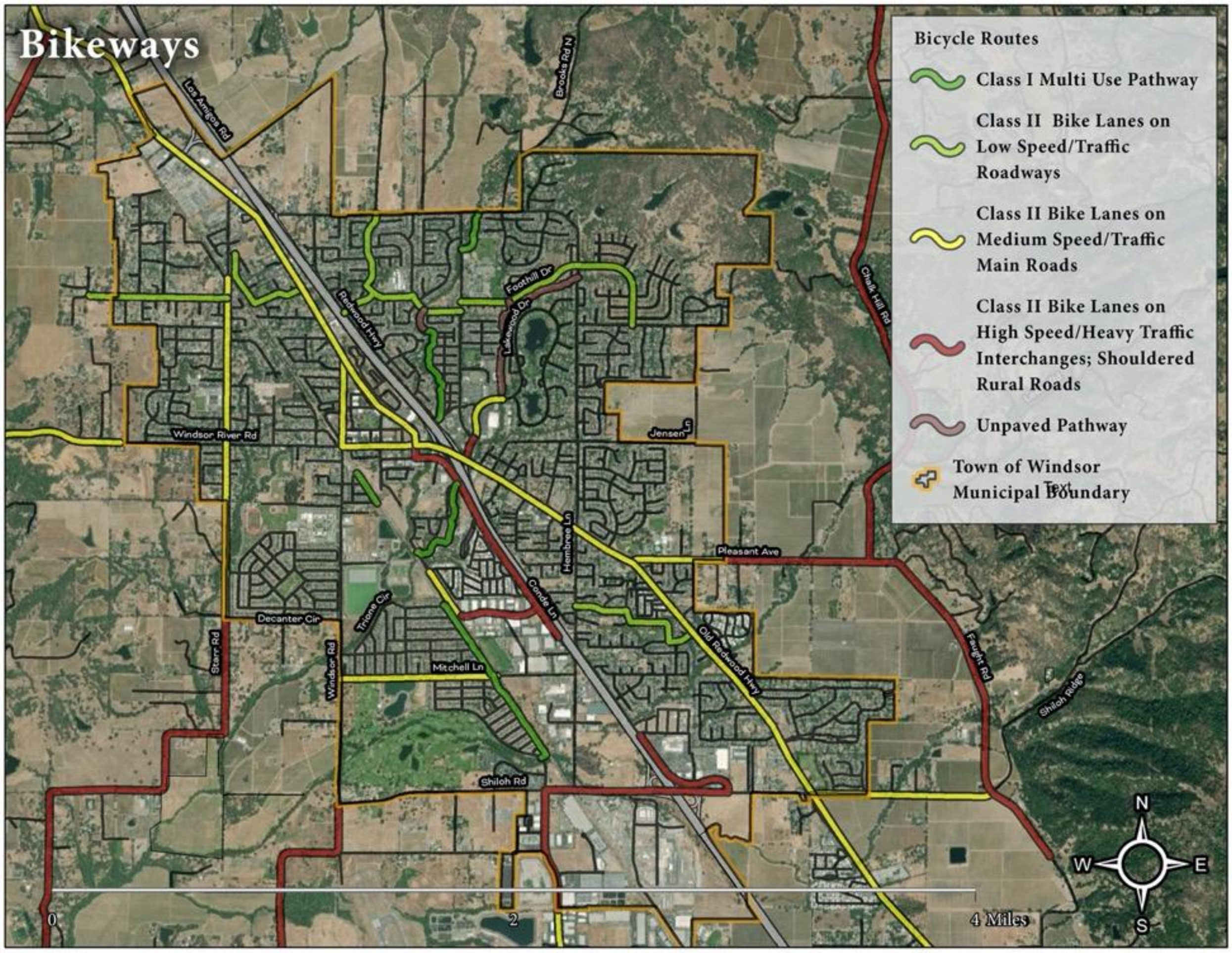


Figure 14. Map of bicycle routes for the Town of Windsor. This map shows the different bicycle routes by type and class within the Windsor Municipal Boundary and connecting routes to the surrounding areas. Class I pathways are separate from automobile traffic and provide the safest options for pedestrians and bikes. Class II bike lanes are alongside automobile traffic and require increased caution depending upon local traffic conditions, especially around interchanges. Rural bikeways may not be distinct bike lanes and may have topography that inhibits visibility or ready maneuverability for less than intermediately skilled riders.

One of the greatest challenges for people who walk and bike is limited connectivity between the east and west sides of town due to Highway 101. The Highway (which runs Northwest/Southeast through the center of the community, generally splits the Town in half and there are only a limited number of connections between the two sides of town. There are two underpasses and one overpass that extend across Highway 101 providing east-west connections for people, bikes, and cars. The Old Redwood Highway underpass (Figure 17) has dedicated pedestrian paths and bike lanes. However, these crossings also host the on/off ramps for the highway. While there is pedestrian signage and a painted bike lane, free right and left turns create unsafe crossing conditions for people who walk or bike.

Figure 15. Image showing the Highway 101 underpass at Old Redwood Highway. Note combination of dedicated bike lane, but also freeway on and off ramps that can create unsafe conditions for pedestrians and cyclists, making it less likely for them to use these crossings and limit East/West access across town. Source: Google Street View

The Arata Lane underpass (Figure 18) does not have dedicated pedestrian paths and bike lanes, which creates unsafe conditions for people who walk and bike and these conditions may influence the choices of individuals about their mode of transportation.

Figure 16. Image showing the Arata Lane and Highway 101 intersection. Note the lack of pedestrian and bicycle infrastructure. Source: Google Street View.

The community has already identified these limitations to the transportation network. The Windsor Bicycle and Pedestrian Master Plan (2014) recommends the expansion of both the pedestrian and bicycle network, including projects to bridge the gap between the east and west sides of town and to improve connectivity to schools, commercial centers, and parks to transit. While the focus of this assessment is on the impact to local assets, the way infrastructure functions regionally can have direct impacts to Windsor and its residents and should also be considered in future planning. When possible, quantitative data will be provided to elucidate the potential impact of different climate hazards to buildings within Windsor.

TRANSIT SERVICE

Sonoma County Transit (SCT) is the local transit operator. SCT provides a fare-free local transit service via Route 66 (Windsor Shuttle) which runs daily Monday through Saturday and creates a loop around town from the Windsor Depot around the Town center connecting a number of schools to residential areas. Intercity service on Route 60 and Route 62, which connect Windsor with downtown Santa Rosa (to the south) and Healdsburg/Cloverdale (to the north). Frequencies of these routes are low, with buses running every 45 to 60 minutes. Route 62 is the only route that runs on all days of the week; the other routes operate on weekdays only or have limited Saturday service. In addition to fixed-route service, SCT also runs an ADA paratransit program for qualifying residents; paratransit serves areas within ¾-mile of fixed-route SCT services during the same hours and days.

RAIL NETWORK

The railroad network - developed in 1872 through what is now the Town boundaries - was central to development in the region.[45] The San Francisco-Northern Railroad connected Windsor with San Francisco and facilitated the trade and distribution of agricultural products (including hops, grain, prunes, lumber and grapes) to the coast. The railroad system was owned and operated by Northern Railroad until the 1950's. In 2008, renovations and updates to the station building and rail facilitated the expansion of the Sonoma-Marin Area Rail Transit (SMART) service to the Town, which now provides regional connectivity and tourism along the SMART travel corridor. The rail is centrally located in the Town and parallels Highway 101. In 2020, the planned $65 million expansion project was initiated to extend the SMART rail Airport Boulevard to downtown Windsor. The project is currently on hold pending resolution of legal proceedings associated with one of the project funding sources, Measure 3.[46] The current bus depot along Windsor River Road next to the railroad tracks will be updated to accommodate the new service. In addition, all of the planned SMART rail corridor includes bike and pedestrian paths. Future SMART extension plans include extensions to Healdsburg and Cloverdale.[47]

AVIATION INFRASTRUCTURE

The Charles M. Schultz Sonoma County Airport - first developed as an airfield used to support an Army Base in WWII - services regional, interstate, and intrastate flights to scheduled commercial and private entities (private, business, corporate, and recreational planes). The County assumed operation of the airfield from the military in 1946 and has continued to expand since that time. Commercial airlines that operate out of the airport include United, Alaska Airlines, Avelo Airlines, and American Airlines and total passenger counts range from 15,000-40,000 annually in the last few years.[48] Guided by the Airport Master Plan, the airport is considering additional national and international service expansion in the coming years.[49] In addition to providing essential regional connectivity for people, goods, and businesses, the industrial and commercial area near the airport provides business opportunities and employment for Windsor residents.[50]

[45] Town of Windsor (2018b)
[46] Sonoma-Marin Area Rail Transit (2020)
[47] Sonoma-Marin Area Rail Transit (2021)
[48] Sonoma County (2021d)
[49] Sonoma County (2011)
[50] Town of Windsor (2018b)

NATURAL SYSTEMS (PARKS, CREEKS & WATERWAYS, FISH & WILDLIFE HABITAT)

The Town's identity is inextricably linked to its location and surrounding agricultural lands, oak woodlands, canyon's, rolling hills, evergreen forests, and beautiful recreation areas. Windsor's development standards encourage site design to preserve and enhance the natural and scenic beauty and resources of the area, its open spaces, and the agricultural lands just outside of the Town boundary which exist seamlessly with the more urban areas. The interconnected creeks and waterways within Windsor provide natural beauty that helps instill the collective community stewardship of natural resources that helps to benefit the needs and values of current residents as well as those of future generations. In addition, the open spaces of the Town not only provide valuable ecosystem services (e.g., floodplain management, scenic value, recreation) for Windsor residents, but also serve as critical habitat and movement corridors for fish, wildlife, birds, insects, and more.[51] In addition to the community, joint use, and neighborhood parks, Windsor is in relatively close proximity to three regional parks owned and maintained by the County including Foothill Park (located within Town limits), Riverfront Park, and Shiloh Ranch Park, which range from 211 to 845 acres in size.[52]

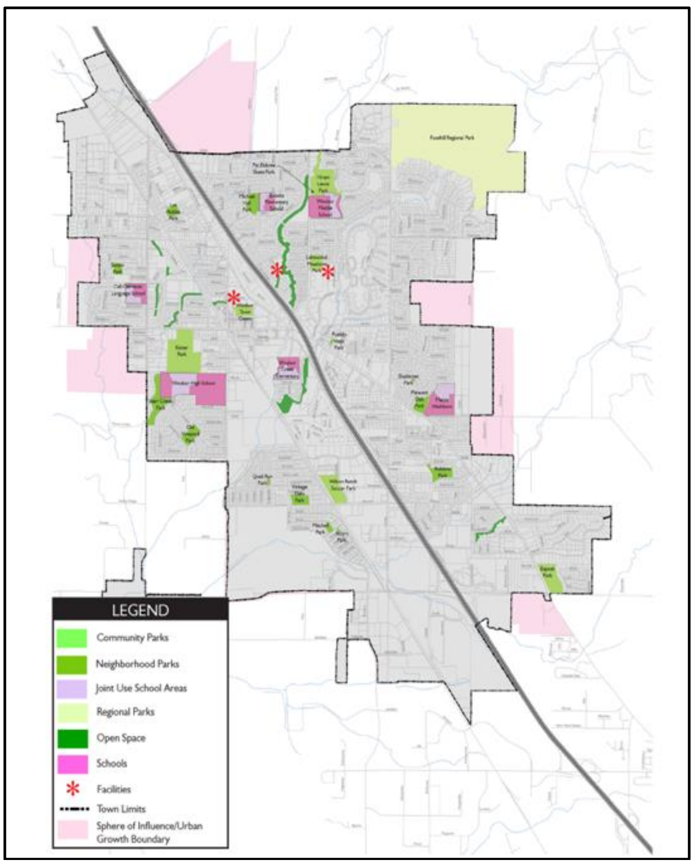


Figure 17. Map of parks, recreation spaces, open spaces, and facilities for the Town of Windsor. (Source: Windsor Parks and Recreation Master Plan, 2017)

[51] Town of Windsor (2018b)
[52] Town of Windsor (2017)

This assessment will provide mostly a qualitative analysis of the impacts of different climate hazards to the natural systems as well as discuss the complexities of compounding impacts to the environment and ecosystems under changing climate conditions.

ECONOMY

Windsor is economically and culturally tied to the larger region of Sonoma County and serves as an attractive location for visitors traveling along the Highway 101 corridor from the Bay Area and beyond. In close proximity to wine country and the nearby Russian River recreation area, Windsor has a diverse economy, supporting jobs in the largest economic sectors of retail trade, food service, educational services, and manufacturing. There are 50 wineries and vineyards within five miles of Windsor, and the surrounding area is considered a hub of three of the largest American Viticultural Areas (AVAs) in the country - Russian River, Dry Creek, and the Alexander Valley.[53] The Town has a mix of residential, commercial, professional, and industrial land uses that support the range of employment opportunities for residents. The primary commercial service areas of the town include the Downtown, Lakewood, the Shiloh Road corridor, and particular areas along Old Redwood Highway; the Town Green is celebrated as one of the Town's key economic assets.[54] Climate hazards impacting or interrupting the transportation network and natural ecosystems within and around Windsor have the potential to directly and indirectly affect Windsor's economy.

This assessment will generally discuss the qualitative impacts of climate hazards to Windsor's economy. When possible, quantitative information will be used to provide context to the potential magnitude of impact to the economy.

[53] Town of Windsor (2012)
[54] Town of Windsor (2018b)

“Exposure and Consequence” Analysis

This section summarizes the relative vulnerability rankings for each climate hazard and specific asset categories for the Town. Each section includes a more detailed analysis of the climate hazards and a discussion of the intersectionality of climate resilience and non-climate stressors. As described in the climate change projections section, rising temperatures and changing precipitation patterns influence and create climate hazards. Of primary concern for the town are wildfire, flooding, drought, and extreme heat. Some non-climate stressors (such as population growth, or dam failures) have indirect connections with climate change (for example extreme precipitation may raise reservoir levels and put additional stress on dams) are discussed as appropriate in the subsequent sections. Earthquakes are not directly related to climate change, but many of the actions developed in the Windsor Resilience plan will help enhance resilience to these non-climate hazards.

While this assessment is formatted to discuss the four hazards, their exposure, and consequences to assets separately, it is important to remember that climate hazards are often and very likely interconnected. They may happen simultaneously, in quick succession and/or may exacerbate the vulnerability of and impact to different assets. For example, extended periods of drought exacerbate the potential for a wildfire, and if a wildfire does occur, the dry soils and vegetation can increase the severity of a wildfire. Additionally, drought periods followed by a high precipitation event can lead to more severe flooding, as the soils are not able to absorb surface water, further exacerbating the impacts of flooding on the landscape and to infrastructure. This interconnected nature of climate hazards makes the conversation of vulnerabilities more complicated; however, the potential solutions to these challenges and vulnerabilities (as discussed later in the Adaptation section of this plan) can address multiple hazards while also providing benefits to residents in their everyday lives.

Wildfire

VULNERABILITY SUMMARY

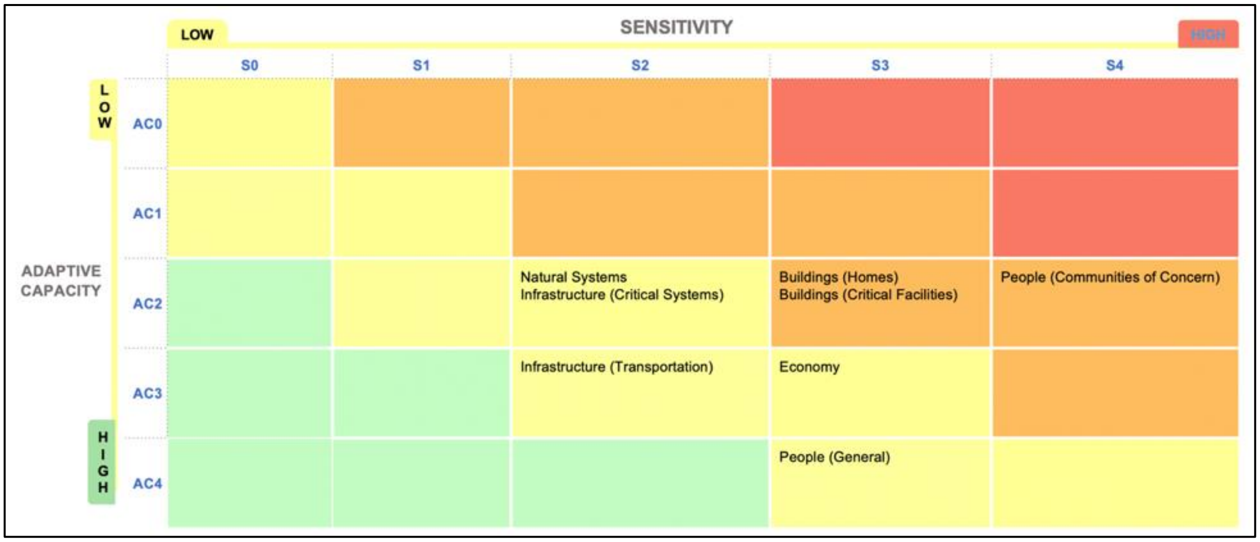


Figure 18. Relative vulnerability assessment of wildfire for the Town of Windsor. Vulnerability is shown by the different colors of the matrix (Red = Extreme Vulnerability; Orange = High Vulnerability, Yellow = Medium Vulnerability; and Green = Low Vulnerability). Given the climate hazards, relative vulnerability is based on the assessment of sensitivity (x-axis ranging from S0 = not at all sensitive to the projected changes to S4 = extremely sensitive to the projected changes) and adaptive capacity (ability to respond to those changes ranging from AC0 = no ability to respond to AC4 = ability to respond to projected changes in a beneficial way).

PEOPLE: **Windsor residents are highly vulnerable to wildfire** due to both the potential exposure of the Town and the potential impact to the health and safety of residents. Several subsets of the Windsor population are particularly sensitive to the impacts of wildfire. These Communities of Concern are more sensitive (S4) as they may have underlying health conditions and/or limited ability to evacuate (e.g., individuals with disabilities, older adults, individuals in assisted living facilities, among others). The general population is somewhat less sensitive (S3). In addition, limited evacuation options out of Windsor due to local and regional chokepoints and limited ingress and egress out of some neighborhoods increases the sensitivity of Windsor residents to wildfire. Some residents are more sensitive to the impacts of wildfire smoke caused by wildfires due to factors including pre-existing health conditions (such as asthma), limited access to air purification systems, employment that exposes residents to smoke, and other conditions. In general, adaptive capacity is medium for Communities of Concern (AC2) and high for the general population (AC4). This is due to local and regional emergency preparedness planning, enhanced wildfire behavior modeling, wildfire detection technologies, incorporating local and regional lessons learned from past wildfires, and wildfire preparedness education, increasing the adaptive capacity of Windsor residents to the impacts of wildfire.

BUILDINGS: Homes and critical facilities are highly vulnerable to wildfire. Exposure to wildfires continues to increase. Very few of the Town's buildings and homes are located in the WUI - a traditional indicator of sensitivity to wildfire. However, wildfire exposure is increasing due to climate change (among other factors) and expanding wildfire risk. The potential impact on homes and buildings in Windsor continues to increase. Under an extreme wildfire scenario, all Windsor homes and businesses are highly sensitive (S3) to the impacts of wildfire - particularly those in closer proximity to the wildlands, as evidenced by past regional wildfires (e.g., Coffee Park and Kincade). Adaptive capacity is generally medium (AC2) for homes and businesses in Windsor and depends on a variety of factors (e.g., vegetation management and fuel reduction efforts, landscape scale fuel breaks, wildfire detection capabilities, etc.) in addition to policy and program changes that support structural resilience to wildfire.

INFRASTRUCTURE: Windsor's infrastructure systems are moderately vulnerable to wildfire. Exposure to wildfires continues to increase and existing electric utilities, telecommunications, and water infrastructure, and transportation are somewhat sensitive to wildfire (S2). Adaptive capacity for Windsor's telecommunications, water, electrical and transportation infrastructure is moderate (AC2) as system components and capacity can be increased over time. For example, the communications system exhibits redundancies that allow for it to be functional even after a wildfire were to occur[55] and the Town of Windsor Municipal Code requires all new developments with existing overhead services along its frontage, including electrical lines, to be placed underground.[56] It is, however, not easy to relocate infrastructure once it is in place and upgrades will generally happen gradually over time. The transportation system does have built in redundancy though there are chokepoints and other bottlenecks that can exacerbate the impacts of certain hazards. In addition, secondary impacts of wildfire, including increased sediment, erosion, and landslides due to hydrophobic soils, can have significant impacts on transportation systems.

NATURAL SYSTEMS: Natural systems are moderately vulnerable to wildfire. Natural systems have evolved to rely on wildfire to survive and thrive in the region, therefore, they are not very sensitive (S2). Yet, the extent and intensity of wildfires continues to increase, therefore the sensitivity of natural systems and the ecosystem services that they provide to wildfires is also increasing. This is particularly true in extreme wildfire scenarios, particularly in sensitive ecosystems that support threatened and endangered species (e.g., California Coast Coho Salmon). Ecosystems with the highest sensitivity to wildfire are local stream and riparian habitats, and mature and old growth forests.[57] The secondary impacts of wildfire, including increased sediment, erosion, and landslides due to hydrophobic soils, can have significant impacts on aquatic environments. In addition, natural systems are more susceptible to increases in invasive species post-wildfire, which not only impacts ecosystem health and function, but increases the likelihood of additional wildfires. These species and ecosystems have a medium level of adaptive capacity (AC2). They have evolved over centuries and millennia and may not be able to keep up with the pace of change.

ECONOMY: The economy is moderately vulnerable to wildfires. Many businesses in town are dependent on tourism, agriculture, and viticulture. These industries are sensitive (S3) to wildfires, associated evacuations, and all business can be affected on a short-term basis by secondary impacts such as smoke or loss of power due to public safety power shutoff events. As

[55] FireSAFE Sonoma (2016)
[56] Town of Windsor (2018b)
[57] FireSAFE Sonoma (2016)

the wildfire season expands beyond historical norms due to climate change, and the perceived risk of wildfire increases, this will continue to increase concern of visitors and affect the local economy. Adaptive capacity varies based on the individual business but many businesses in the town have a medium or high degree of adaptive capacity (AC3).

WILDFIRE EXPOSURE FOR THE TOWN & REGION

Past regional wildfire risk assessments have classified wildfire risk for the Town of Windsor as being relatively limited. Yet, a variety of factors - including climate change - are requiring a new approach to understanding wildfire risk for the Town. Across the region and state, wildfires are becoming hotter, more intense, lasting longer, can now happen at any time of the year, and are proving more deadly. Today, nearly all of the Sonoma County is at risk to wildfire. According to the Sonoma County Multi-Jurisdictional Hazard Mitigation Plan (2021), “risks include, but are not limited to, extensive building in the Wildland Urban Interface/Intermix (WUI) areas, lack of vegetation management near homes and in wildland areas, structures not built or retrofitted with ignition-resistant building materials that can increase resistance to wildfire’s heat and embers, and a significant likelihood of high wind events during dry fall months” (p. 1-2).[58] As residents have quickly learned from recent experience, wildfire risk reduction and protection efforts are not just a matter of maintaining a sense of security, limiting property destruction, injuries, and death. For towns like Windsor, that maintain a reputation as a thriving tourism destination, as a viable place to build a business, and a stable community to raise a family or enjoy one’s retirement, changing wildfire risk presents a real threat to the community’s identity and vision for the future.

Reestablishing an accurate understanding of wildfire risk in Windsor requires a new approach to characterizing the hazard itself. The effects of firestorms, ember cast, and of wildfire smoke produced by wildfires (sometimes) hundreds of miles away, mandate a new hazard categorization that redefines the differences in exposure and risk. Hazard mitigation activities that target forward-looking (leading) risk factors are generally more effective at targeting future community resilience, but in lieu of accurate forecasting the tendency is to rely on the historical experience and other lagging data. While utilizing existing wildfire assessments remain an important indicator for planning purposes, several additional factors (including climate change) that exacerbate the size, intensity, duration, and frequency of wildfires must be considered in order to create accurate planning assumptions, accurately quantify appropriate mitigation and response resources, hone operational procedures for wildfire response, and build appropriate community coping capacities. The following section of this report will discuss the traditional ways of modeling and understanding wildfire risk, the factors that exacerbate that risk, and the new assumptions that need to be incorporated into wildfire resilience planning efforts moving forward.

TRADITIONAL (AND OUTDATED) WAYS OF UNDERSTANDING WILDFIRE RISK

Wildfire is a known hazard in Windsor, but wildfire risk has historically been under-classified in regional planning efforts. In 2018, as assessed in the Windsor LHMP, wildfire was classified as a

[58] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*

‘Medium’ level threat to the community. This placed it comparatively lower in terms of severity than drought or earthquake - both of which had received a ‘High’ threat designation.[59]

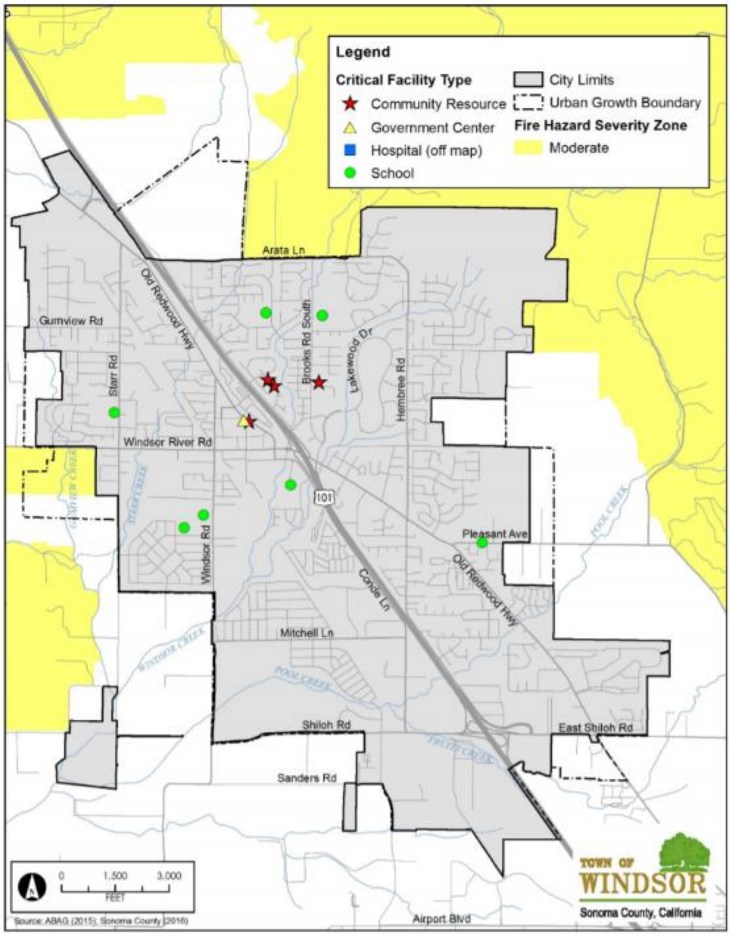


Figure 19. Map showing wildfire risk for the Town that appears in the 2018 Windsor Local Hazard Mitigation Plan. This map highlights the limitations of existing methodologies for quantifying actual wildfire risk for Windsor.

Like the LHMP, past wildfire risk assessments - which classified wildfire risk within the incorporated jurisdiction of Windsor as being medium or low - have traditionally provided the basis of planning in the emergency management, hazard mitigation, and community development sectors. Prior to 2017, wildfire risk assessments were drawn almost exclusively from two key data points: 1) a historical record of wildfires that only included three major fires over the course of 80 years in the proximity of the Town; and 2) a map of Fire Hazard Risk Zones maintained by the CAL FIRE Fire Resource and Assessment Program (FRAP). Because none of the three fires had any direct impact on the Town of Windsor itself, and the FRAP maps used in the assessment indicated no presence of wildfire risk zones within Town limits, wildfire risk for the Town of Windsor was classified between low to medium wildfire risk and a steadfast assumption of safety was established.

[59] Hazards which received a lower risk designation in the 2018 Windsor LHMP [Town of Windsor (2018a)] include flood and extreme heat, both of which are classified as ‘Medium’ threats, and dam failure, landslide, and liquefaction, each of which received a ‘Low’ threat designation.

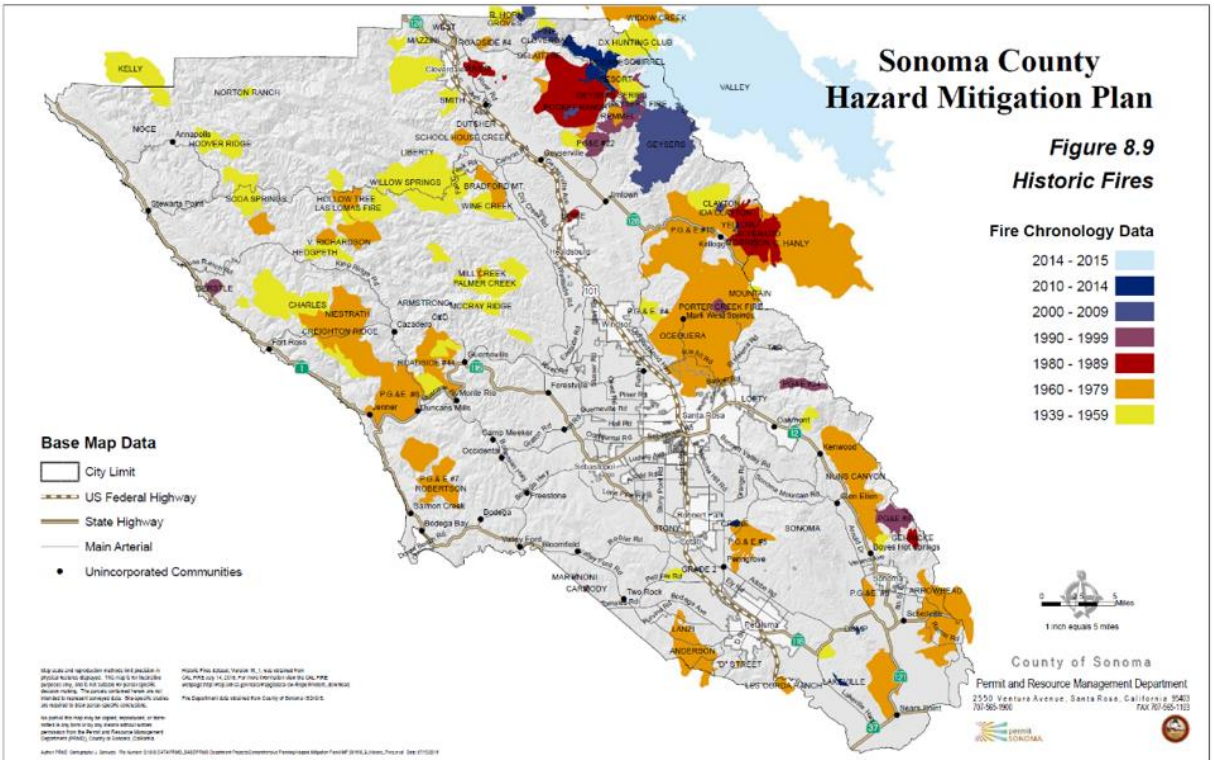


Figure 20. Map of historic fires in Sonoma County between 1939-2015 (Source: Sonoma County Permits, 2016 http://bit.ly/3oBTWOx)

Like many other California communities, Windsor has relied on CAL FIRE FRAP Wildfire Hazard Severity Zone maps to scope the exposure to, or potential severity of, wildfire risk. These maps are generally the most informative data available given the general absence of more locally relevant products and guide the development of local policies and codes (e.g., fire-resistant building codes). However, the maps carry two key limitations that limit the Town's capacity to accurately assess wildfire risk within its jurisdictional borders. The CAL FIRE FRAP maps do have value for local communities in terms of their capacity to indicate areas where exposure to trans-boundary transmission is likely or possible (e.g., areas where wildfires originating on State or Federal land may cross into the LRA). These maps, however, do not provide a level of detail for wildfire exposure and risk within the communities themselves to understand any level or risk below 'Very High', nor were they marketed as such (despite their widespread and prevalent use).

Windsor's multi-year effort to develop the Town's LHMP was completed in February of 2018. As the most complete and accurate information on wildfire risk at that time, the CAL FIRE FRAP wildfire hazard risk zone maps formed the basis of this plan's wildfire risk profile. Drawing on the data reported on this map, coupled with the Town's hazard history, exposure and risk in Windsor was depicted as follows:

> "There are no wildfire hazard severity zones within the limits of the Town itself. The area south of Windsor River Road near Gumview Creek, which is outside of the Town limits but within the urban growth boundary, is considered a moderate fire

hazard severity zone. There are also areas of moderate fire hazard severity along the Town's northeastern border." (Windsor All-Hazards Mitigation Plan, 2018; Page 41).

The map which appears on the left in the figure below is excerpted from this plan and is reflective of the description provided (*see Figure 22*). While sourced as being created in 2016, the depiction of fire hazard severity zones as indicated in yellow is nearly identical to what is reported on the 2008 CAL FIRE FRAP map for the County. The only notable difference is a small area in the northwest where an annexed area of land has been added to the incorporated areas. The risk zones as designated, however, remain unchanged.

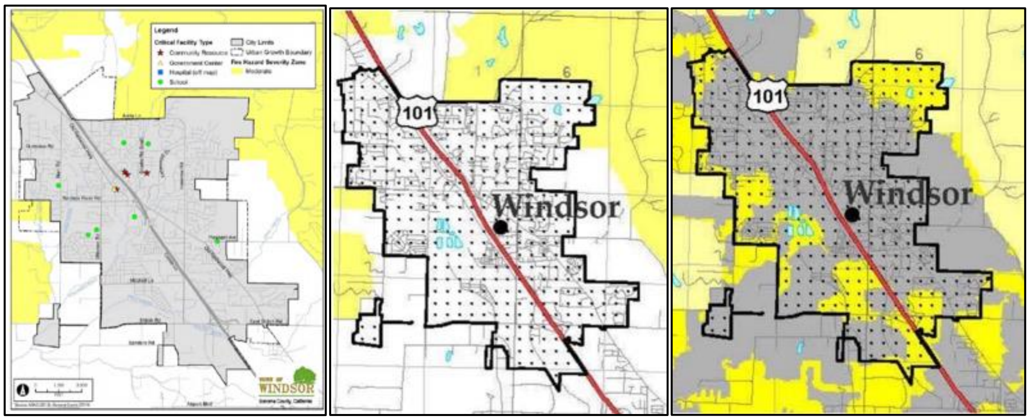


Figure 21. Maps of historic wildfire risk for the Town of Windsor. (LEFT) Wildfire Risk Map that appears in the 2018 Windsor Local Hazard Mitigation Plan. (CENTER) Detail of wildfire risk in the Town of Windsor as reported on the CAL FIRE FRAP 2008 release of Wildfire Hazard Severity Zones. (RIGHT) Excerpt of the Draft CAL FIRE Draft FHSZ Map showing multiple areas of 'Moderate' wildfire severity in Windsor Town. (Source: CAL FIRE)

Although CAL FIRE only endorses the approved final maps for which 'Moderate' and 'High' risk zone designations have been removed from the LRA, it provides access to the original 'draft' maps that contain all zones of severity. Provisional maps detailing risk in Windsor, released in 2007, provide significant insight into the extent to which wildfire hazard risk actually extends into the Windsor LRA. Despite the lack of CAL FIRE endorsement, this map nonetheless establishes a more informative reference point for a better understanding of the extent of wildfire risk within Town limits. And while the 2007 release date might be considerably old, it should be noted that the data included in the final map used in the current LHMP was drawn from essentially the same set of data (namely, the 2008 approved CAL FIRE FRAP map). The CAL FIRE risk assessment for the town indicates the town center is of limited risk while the surrounding hillsides face only a low level of risk. Accuracy can be increased by incorporating the information contained in the 2007 CAL FIRE FRAP map that details LRA Hazard Severity Risk Zones, although much of the town is still demarcated as having limited risk. Recognizing that limited risk is not zero risk, and that house-to-house spread is possible once a fire enters the town from this elevated risk, all areas and thus all structures must be rated for wildfire risk to achieve an actionable assessment.

Wildfire risk that is portrayed in older maps and planning efforts understate the appropriate wildfire risk for the Town.

It is important to highlight that the wildfire risk portrayed in older maps and planning efforts understate wildfire risk for the Town. Further, because they are based on traditional modeling techniques, these older maps are not necessarily representative of the changing wildfire risk due to the impacts of climate change, both in their intended use setting (public land forest management), nor for towns like Windsor at the wildland edge. It is important to note that an expected level of uncertainty exists in current modeling techniques. As a result, decision-makers often downplay, ignore, or misunderstand actual wildfire risk for a given area when relying solely on current or historical modeling techniques. [60] A variety of factors – including climate change - challenge the ability of existing modeling techniques to account for hyper-localized variations in wind, temperature, and precipitation changes and their impact on urban and suburban environments. Even with new, more detailed maps, it is critical that we understand that "low" risk is no reason for low levels of preparedness or caution, as recent years have borne out all too well. In the next section, we will explore this changing risk and the factors that require new ways of understanding and planning for increasing wildfire risk in Windsor.

THE NEW NORMAL FOR WILDFIRES

Among Town and Sonoma County officials, there is growing consensus that Windsor's wildfire risk is 'High' and continuing to increase. The 2021 update to the Sonoma County Operational Area Hazard Mitigation Plan (SCHMP) determined that wildfire risk should be recharacterized in Windsor as having a 'High' level of threat.[61] The 2021 update to the Sonoma County Multi-Jurisdictional Hazard Mitigation Plan classified wildfire risk across the county as 'High.'[62] In addition, the Sonoma County Community Wildfire Protection Plan update, completed in 2021, also classified the Town of Windsor as having a 'High' level of risk to wildfire.[63]

Among Town and County officials, there is growing consensus that Windsor's wildfire risk is 'High' and continuing to increase.

Wildfire risk factors for the Town of Windsor include, but are not limited to: 1) Climatic changes that are resulting in larger, more frequent, more intense, and more common wildfire events; 2) current and historical fire-suppression policies; 3) increasing population growth in the Wildland Urban Interface (WUI) and intermix; 4) vegetation and fuels (and lack of vegetation management around homes and in wildland areas); 5) structures not built or retrofitted with ignition-resistant building materials that can increase resistance to wildfire's heat and embers; and, 6) localized changes in wind patterns which fuel the formation of 'firestorms' and drive ember cast. These factors are altering the Town's hazard profile by creating entirely new hazards and increasing the severity and likelihood factors for others. A new understanding of wildfire risk, and subsequent appropriate planning response, must therefore be established to correct any outdated or inaccurate perceptions and assumptions. The following presents a forward-looking assessment reliant on leading data. It distinguishes between standard wildfire threats and more

[60] https://digital.lib.washington.edu/researchworks/handle/1773/46885
[61] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan* Recharacterization of wildfire risk in Windsor from Medium to High was the result of three factors: 1) Evacuation of the town in 2019 during the Kincade fire when it was determined the entire town was potentially exposed; 2) Evacuation of the northwestern part of town in August of 2020 during the Walbridge Fire; 3) a new understanding about wildfire behavior developed while developing this resilience plan.
[62] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*
[63] Sonoma County (PENDING). *Sonoma County Community Wildfire Protection Plan*

damaging firestorms, recognizing observed data and developing research on evolving wildfire behavior. It also acknowledges the profound effects that debris flows and prolonged wildfire smoke inhalation are having on the life, health, and property of Windsor residents.

CLIMATE CHANGE

Climate change is exacerbating the frequency, intensity, duration, timing, and severity of wildfires across the State of California.[64] In addition, wildfires are becoming hotter, more intense, and more deadly.[65] Important climatic factors like rising temperatures, changing humidity levels, longer and more severe droughts, and a reduction in annual snowpack compound the way climate change exacerbates wildfire risk. In the past few decades, there has been a significant increase in the number of wildfire ignitions, acres burned, and harmful impacts to humans and ecosystems in California.[66] According to CalMatters, of the 20 largest wildfires in California history, five burned in 2020.[67] In 2020, over 8,500 wildfires statewide burned more than 4 million acres and California experienced its first "Gigafire," a term used to denote a wildfire (the August Complex Fire) that burned over one million acres. According to the California Climate Assessment, projections show that the average area burned statewide could increase 77% by 2100 if greenhouse emissions continue to rise.[68] In addition, recent studies suggest that climate change has rendered the concept of a "fire season" in California obsolete — major wildfires can happen at any time throughout the year and areas previously considered to be low-risk can experience catastrophic wildfires. A 2019 study showed that, due to changes in the North Pacific jet stream, the correlation between winter rainfall and the severity of the fire season can no longer be made.[69] Studies suggest this disconnect between winter moisture and wildfire conditions coincided with federal historical wildfire suppression policies in the early 1900's and were all but non-existent after 1977.

CURRENT AND HISTORICAL FIRE-SUPPRESSION POLICIES

For more than a century, federal and state policies have shaped wildfire-suppression tactics as a means to reduce the negative impacts of wildfire on the built environment. Although these policies (and fire management practices) are slowly evolving, current and historical fire-suppression policies at the federal[70] and state levels[71] exacerbate the size, intensity, and duration of wildfires across the region and state. For millennia, fire has been a natural mechanism for cultivating healthy woodlands and forests across the West. Prior to European settlement, Indigenous peoples' used fire as a tool to manage forests and grasslands, protect their homes, and to support the regeneration of culturally significant foods and medicines.[72] Yet, as more Europeans moved West and began to build infrastructure that they wanted to protect, fire suppression policies solidified as a means of protecting those assets and timber for use in logging. Traditional Indigenous fire management practices were quashed as Native Americans were stripped of the right to manage the landscape that they had lived on for centuries and

[64] Bedsworth et al. (2019)
[65] Rincon (2019)
[66] California Department of Forestry and Fire Protection (2018)
[67] Hwang (2020)
[68] Bedsworth et al. (2019)
[69] Wahl et al. (2019)
[70] Plumer, B., & Schwartz J. (2020)
[71] Shogren (2021)
[72] Cowan (2020)

Europeans sought to protect valuable timber harvests.[73] Federal and state fire-suppression policies have shaped the way fire management is understood and practiced across much of the West, even as more fuels began to accumulate. When a wildfire escapes suppression, the increased fuel loads have resulted in bigger, more intense, and more destructive wildfires. Many of those policies and approaches remain today, despite increasing calls from scientists, Indigenous communities, and land managers to return to utilizing fire as a management tool (e.g., prescribed burns) on the landscape. In the Southeastern part of the US, where the conditions and landscape allow, prescribed burns are used regularly to reduce the risk of catastrophic wildfires.[74] Coupled with increasing population growth and the development of valuable properties in the WUI, dismantling fire-suppression policies or encouraging fire-adapted management practices presents a significant challenge for local and county governments.

INCREASING POPULATION GROWTH IN THE WUI AND INTERMIX

Population growth in the Wildland Urban Interface (WUI)[75] and intermix has been increasing for decades across the state despite the continuously increasing risk of wildfire.[76] Between 1990 and 2010, the US experienced an estimated increase of 12.7 million homes and 25 million people moving to the WUI.[77] In California, an estimated one million homes were built in the WUI between those two decades. Within the town boundaries of Windsor itself, 19% (2,541 of 8,313) of single-family and 27% (47 of 150) of multi-family residential structures are in a FRAPS-designated WUI zone. However, when including structures on a parcel that intersects WUI zones (classified here as the WUI Edge), 31% of multi-family and 31% of single-family structures are directly exposed. Despite these numbers being relatively low when compared with other communities in Sonoma County and the County as a whole, (leading to “low” and “moderate” fire risk scores in assessments at the county-scale), this should by no means be taken as a signal that the town of Windsor faces minimal exposure to wildfire risk. For example, the north and eastern borders of the Town directly border vast regions of woodland and forested lands characterized by sparse agricultural and residential development. In addition, the western edge of the Town also borders a large swath of forested lands and a continuous surface of agricultural and residential vegetation. More importantly, because Windsor’s green spaces, urban trees, and small-scale agriculture are all potentially flammable in the eyes of a floating ember, we cannot exclude them from our cataloguing of the potential sources of fire ignition and spread as has been done in many wildfire risk assessment approaches to date. As a result, it is critical that our planning, awareness, and mentality about fire looks beyond the type of discrete classifications used by wildland forest management agencies and takes an honest assessment of the true risks posed by Windsor’s specific geographic and ecological features.

[73] Cowan (2019)
[74] Fuller, T., & Pierre-Louis, K. (2019)
[75] Pierre-Louis, K. & White, J. (2018)
[76] Barringer (2013)
[77] Pierre-Louis, K. & White, J. (2018)

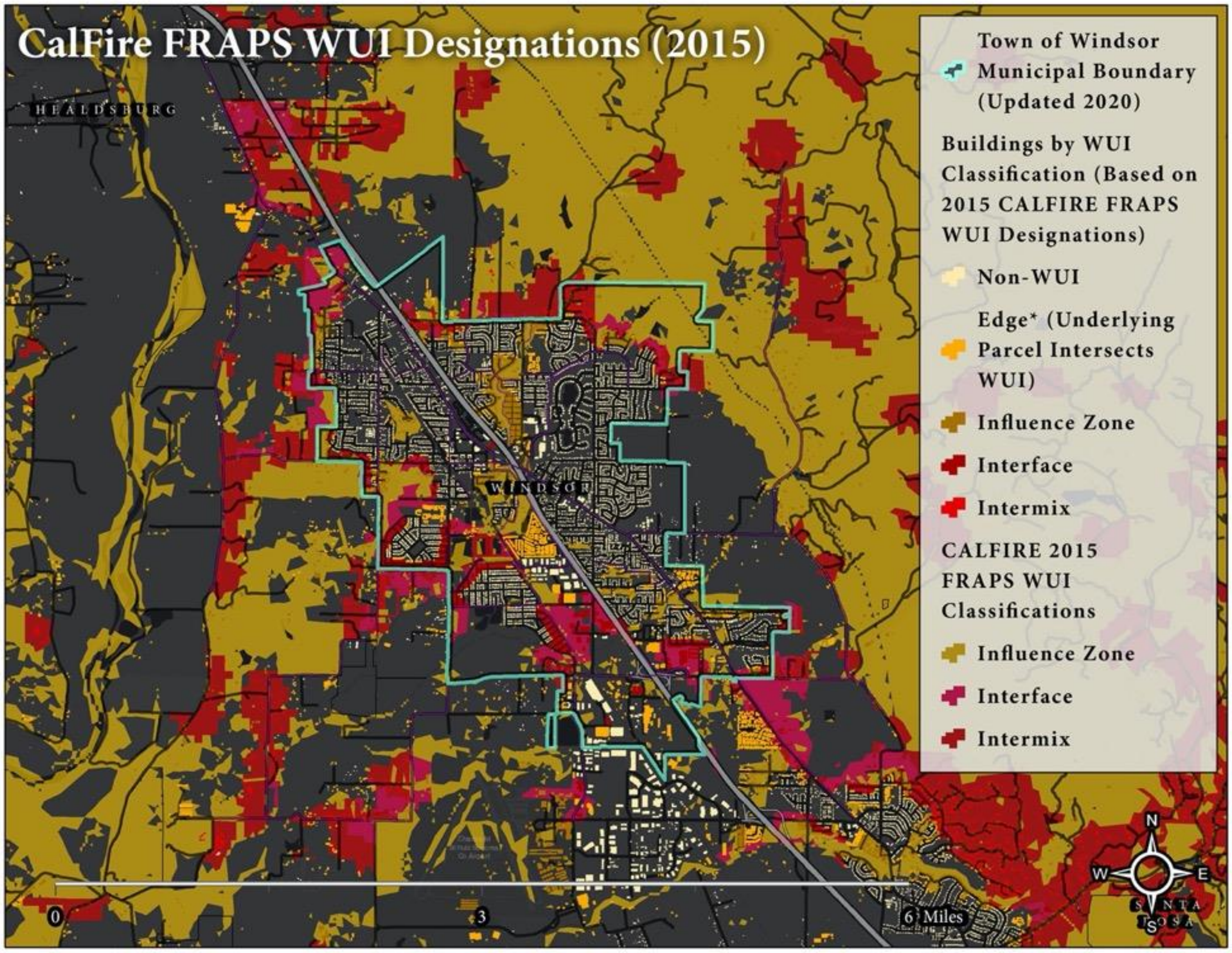


Figure 22. Map of the Wildland Urban Interface classifications for the Town of Windsor. Although much of the town's structures and parcels are not within traditionally recognized Wildland Urban Interface (WUI) areas, the town's small overall size puts all structures within catching distance of potentially intense wildfire activity, with multiple extensions of dense vegetation into and through the town's residential areas and commercial core. Difficult to control and rapidly growing fires in nearby WUI areas could readily induce heightened fire risk in non-WUI areas as a result. As seen in other maps, these types of classification schemes cannot be the final determinant for fire preparation, response, and adaptation planning. (Source: CAL FIRE, 2021)

VEGETATION AND FUELS

Other wildfire risk factors include vegetation cover, vegetation type, the probability that a fire will exist in a certain area to begin with, and if there, the degree to which a fire in that area will grow or spread. Several recently released datasets – developed for the 2021 update to the Sonoma County Community Wildfire Protection Plan - allow us to examine some of these factors with a more finely tuned eye to the local context in Windsor.[78] While the Town has historically been classified to have 'low' wildfire risk due to limited encroachment in the WUI and intermix compared to other parts of the county and the state as a whole, significant fuel sources exist within town boundaries in the form of vegetation and urban trees around homes, along roadways, and within parks. As shown in Figure 23, below, this vegetation creates a more

[78] Sonoma County (PENDING). *Sonoma County Operational Area Hazard Mitigation Plan*

or less continuous surface of ladder fuels from surrounding wildland hillsides and through the entirety of the town. When structures are added to this mix, the available fuel landscape of the town becomes almost total. Vegetation and trees provide a variety of ecological, social, and physical benefits to the Town (including shade for extreme heat days), highlighting the complexity of planning decisions and tradeoffs that need to be made to address multiple climate hazards (like wildfire and extreme heat).

Following the Tubbs Fire in 2017, the Town initiated the process of updating its landscaping requirements as a part of a broader Zoning Ordinance Update. This update will require hardscape within 5-feet of buildings in order to reduce fuels around structures that spread wildfires and damage property.

In addition, local and regional powerlines (highlighted in bright yellow here for the area's two 60kV and one 230kV transmission lines) – which are a common wildfire ignition source - further underscore the risk of wildfire to the Town.

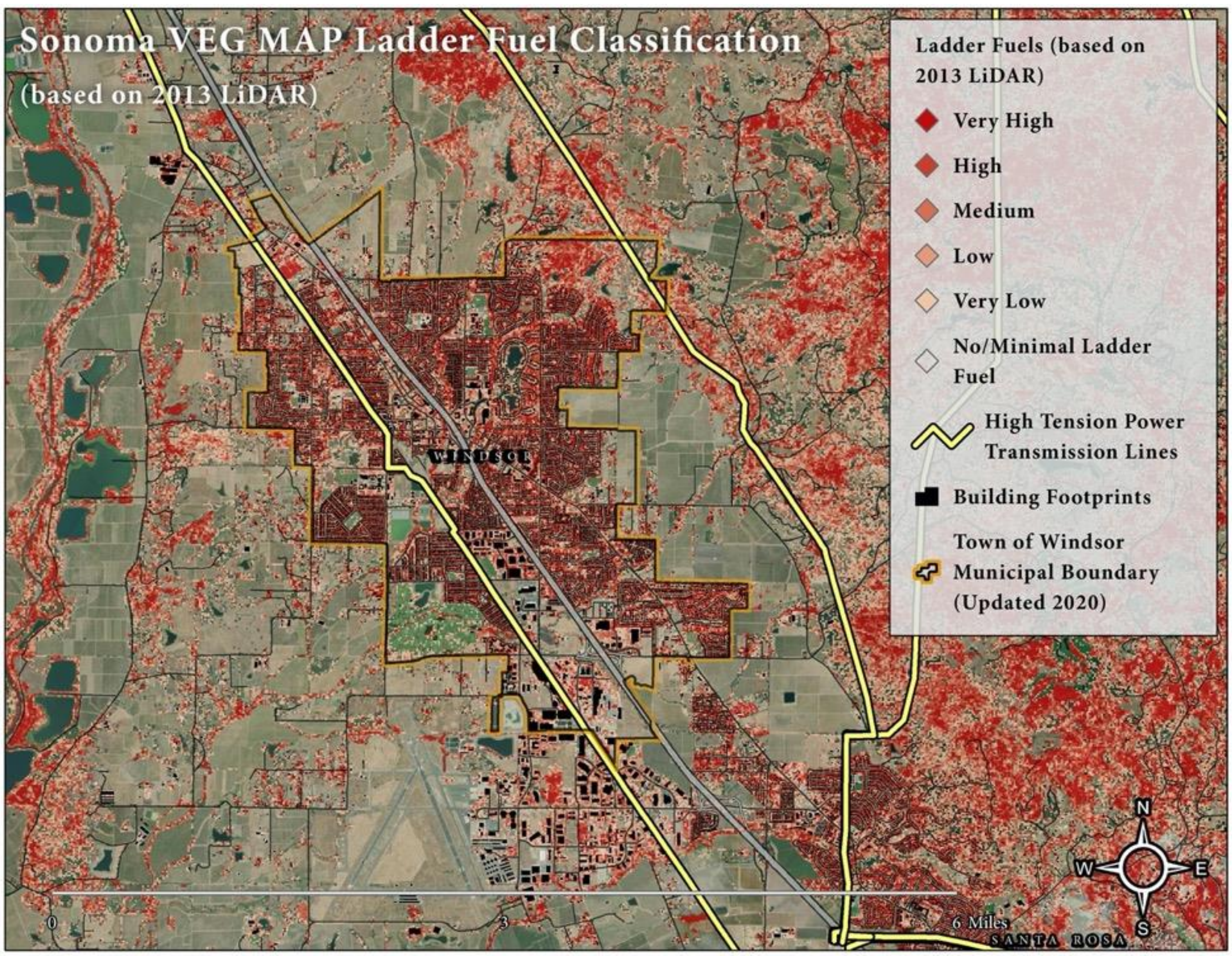


Figure 23. Map of ladder fuel presence for the Town of Windsor (i.e., vegetation within ~40 ft. of the ground, by height) based on 2013 LiDAR data and major electrical transmission line pathways. Note: not all transmission lines are shown, only those carrying 60 kV or more (max 230 kV on the line running over the Bald Hills). (Source: SonomaVegMap.org and CA Energy Open Data)

In the statewide Wildfire Hazard Potential Index (*see Figure 24*) provided by this same effort, the town and the areas surrounding it are, perhaps unsurprisingly, classified as low- to moderate risk in terms of the overall Wildfire Hazard Potential, with much of the town area classified as "non-applicable" due to the absence of wildland vegetation. However, as we have seen above, this distinction between "wild" vegetation and vegetation on the ground in the form of urban trees and green spaces can be somewhat misleading. This does not mean that this work is invalid – or that the component datasets that went into it are inaccurate – just that, relative to the potentially catastrophic risks faced by other parts of the state, Windsor is indeed on the low end of likely negative outcomes and the overall challenge of fighting fires nearby.

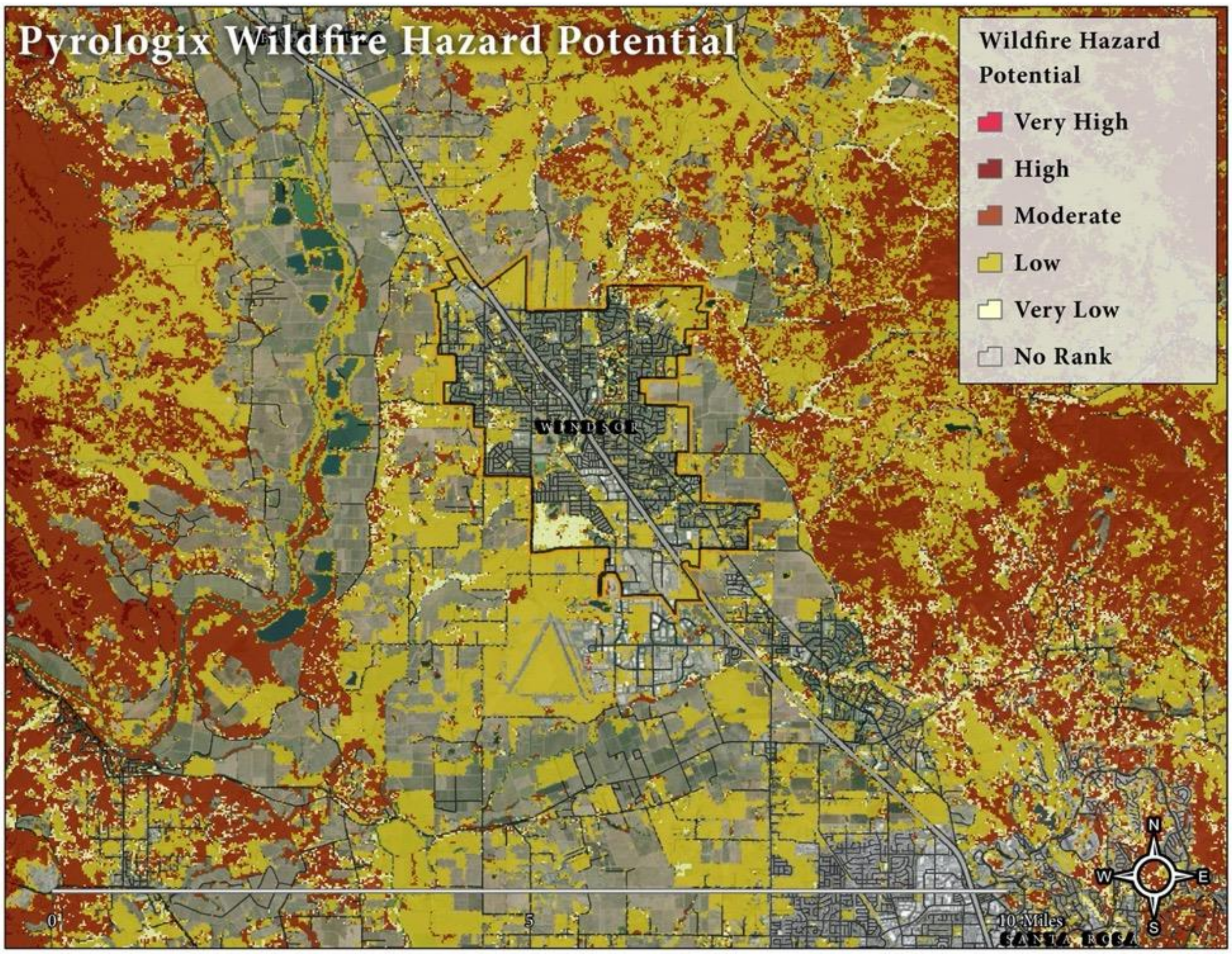


Figure 24. Map of wildfire hazard potential for the Town of Windsor (2021). Created by Pyrologix and based on modeling incorporating fuels, topography, fire weather, and an array of other factors, this model does not include structures or urban areas as a fuel type in its risk assessment, as it is focused on providing information for decision-makers in the public land management context and at the scale of the state of California as a whole. To wit: Coffee Park, which burned completely, is in a low-to-no risk zone in this classification scheme. (Source: Tukman, et al. 2021)

However, as is shown in Figure 25, when one's view is adjusted to a smaller scale of reference – in this case, Sonoma County – the relative risks faced by the town become somewhat clearer. In addition, because this map incorporates dimensions of the built environment like human-built structures and power transmission lines into its risk model, the severity of the situation around Windsor becomes more evident, with many areas within the town – some of which were entirely excluded from other risk assessments – falling in the high and moderate classifications for Wildfire Hazard Potential.

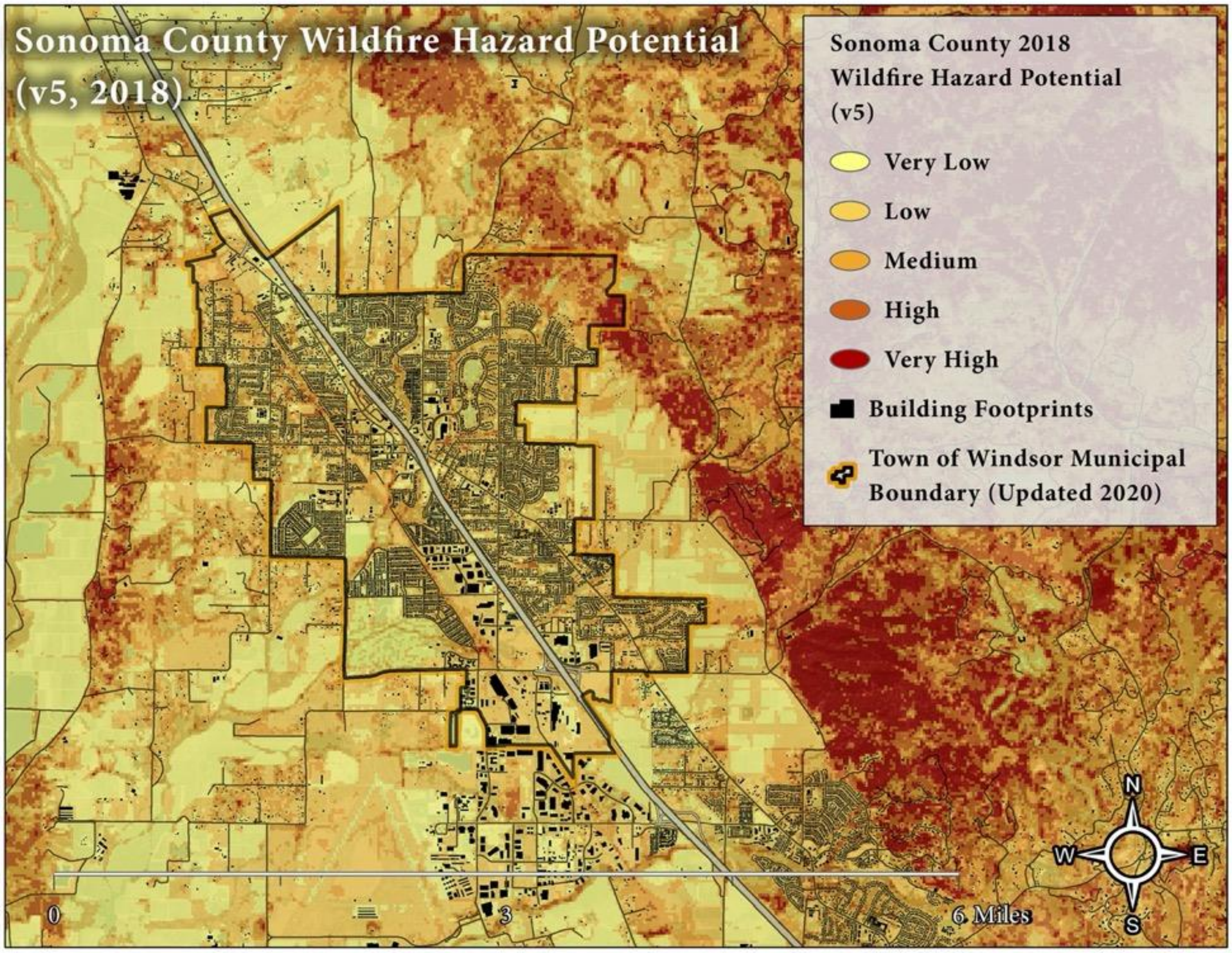


Figure 25. Map of wildfire hazard potential for the Town of Windsor. Operating independently from USDA and State efforts but sharing many project components, the recently updated Sonoma County Wildfire Hazard Index provides another valuable but limited view of the risk factors faced by the Town. Built from analyses of flame length potential, extreme fire weather potential, human development proximity, transmission line proximity, and suppression difficulty, this scheme also classifies much of Winsor and nearby areas as low- to medium severity, relative to all of Sonoma County. However, with much of the town within just a mile or so of potentially dangerous fire hazard areas, these classifications must always be presented in context. (Source: Pyrologix)

STRUCTURES NOT BUILT OR RETROFITTED WITH IGNITION-RESISTANT BUILDING MATERIALS

Land use and building codes are important tools for municipalities to use in reducing exposure to wildfire. The Town of Windsor's General plan[79] and building codes establish development, home hardening, and vegetation management regulations in the Town.[80] Most of the homes in

[79] Town of Windsor (2018b)
[80] Town of Windsor (2021a)

the Town of Windsor were constructed prior to 2008, the year that California's Building Code Chapter 7A - "WUI Building Code" was implemented. Despite only a limited number of homes located in the WUI, the Town of Windsor does have homes within its jurisdiction located in the edge, influence zone, and intermix (*see Figure 23*). Continued development in these areas have implications not only for the residents living in those areas, but also for the residents located in Town boundaries due to the ability and rate of wildfire spread under the appropriate conditions. New construction is required to abide by local, county, and state WUI codes. In addition, there are trigger mechanisms in place for older homes to become wildfire code compliant. Also known as home retrofits, these changes to existing homes that increase their resilience to wildfire heat and embers can be expensive and time consuming.[81] New builds and homes that have already undergone this process represent a small proportion of buildings located within Town boundaries. Land use and building codes are important indicators of adaptive capacity for aspects of the Town's vulnerability to wildfire and will be further considered in later sections of this document.

The primary determinants of risk beyond proximity to wildfire risk zones is the presence of fuels, housing construction type, topography, and distance from adjacent structures. The following map, produced as part of recent risk modeling work for the State of California by Pyrologix, provides a more granular assessment of standard wildfire risk in Windsor that considers some of these dimensions. It is based upon the relative risk to structures based on local fuel characteristics and simulated flame length ranges derived from local topography and winds, and shows that the majority of the town's structures – and all of the areas immediately surrounding the town – are at moderate to high risk of destruction should a wildfire occur near it. However, while this dataset depicts relative likelihood of serious impacts to structures, it does not adequately incorporate the actual existence of structures and/or their ability to act as fuel into consideration. It also does not fully capture urban vegetation with coverage of less than 10 square meters, thereby excluding many urban trees in central Windsor from its fuel load calculations. These are important considerations to factor in when examining existing modeling approaches to defining wildfire risk.

[81] Lorence (2021)

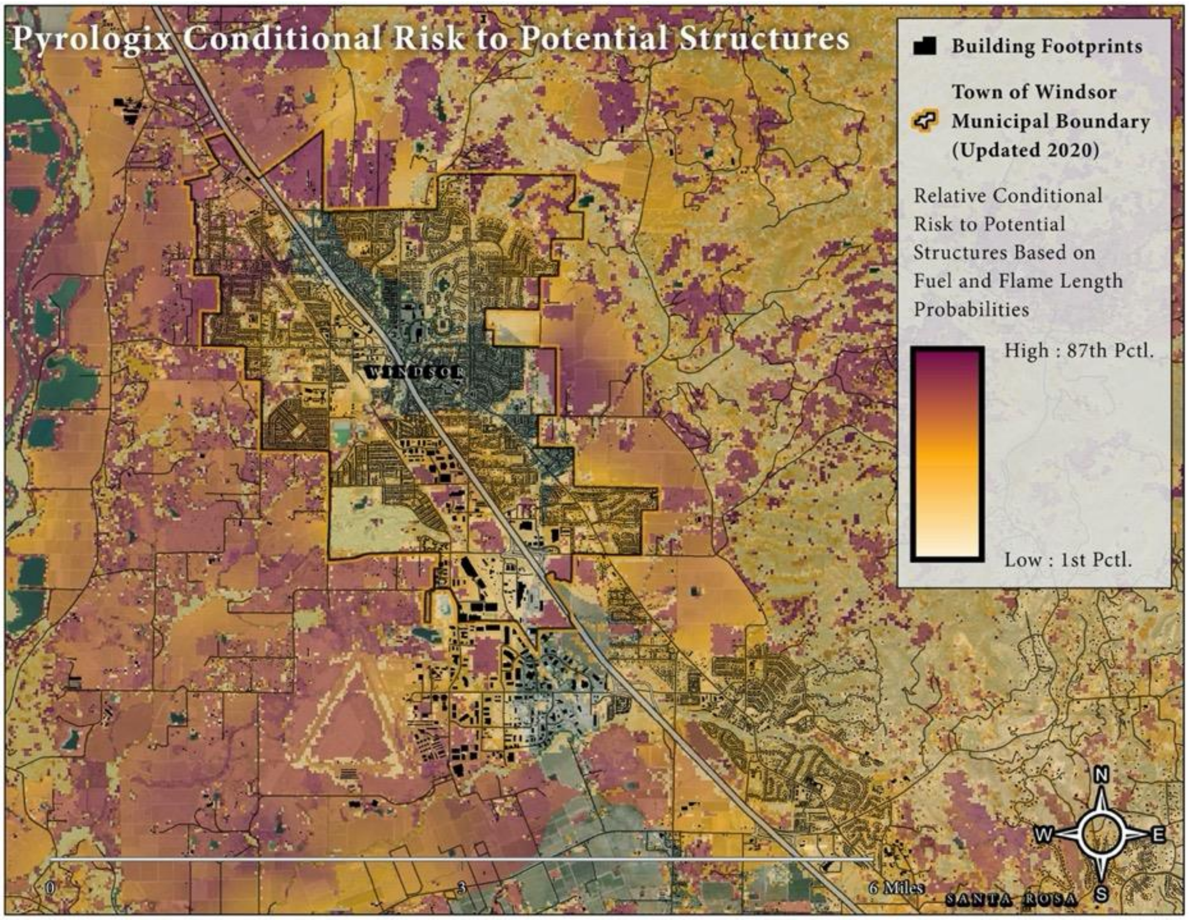


Figure 26. Map of building footprints and conditional risk to potential structures for the Town of Windsor. The higher the risk ranking, the more likely structures are to be destroyed during simulated wildfires occurring in the area. Note: this layer depicts relative likelihood of serious impacts to structures (relative to all CA lands) but does not incorporate the actual existence of structures and/or their ability to act as fuel into consideration. It also does not fully capture urban vegetation with coverage of less than 10 square meters, thereby excluding many urban trees in central Windsor from its fuel load calculations. (Source: Pyrologix)

FIRESTORMS AND EMBERCAST

Localized shifts in wind patterns and intensity shape wildfire behavior in important ways. For example, extreme wildfires have the ability to create their own weather patterns (firestorms) and/or distribute embers miles away (ember cast). A firestorm is created when a wildfire burns with enough intensity to draw outside streams of air into the blaze, thereby increasing heat and influencing weather. They often result in wildfire behavior that is more damaging, less predictable, and harder to suppress. Firestorms form because hot air rises, and the resulting vacuum pulls in surrounding air. As the hot air reaches the upper atmosphere, it condenses and forms pyrocumulous clouds which have the capacity to generate lightning and strong winds. Lightning strikes can ignite additional fires outside the areas impacted by the original firestorm, and the strong winds contribute to the spread of any and all fires. The strong winds also have the capacity to create ember attacks, which are streams of burning material (e.g., twigs, bark, leaves, pieces of wood) that help to ignite new fires. These ember attacks act like blow torches, striking from the side or above and traveling miles from their point of origin.

This issue is also seen in recent efforts to project relative wildfire hazard severity for the state of California by both the state (via Pyrologix) and Sonoma County. For example, model simulations of ember production – now recognized as a significant risk factor in future stand-replacing, high intensity fires – show a relatively low level of risk within the area immediately surrounding Windsor, as is shown in Figure 28 and Figure 29. However, because "low" risk of ember production relative to the extreme levels of ember production that might be found in dense, mountain forests is still quite a significant threat, it is critical that planners and community members take steps to understand the risks of fires travelling long distances in a non-linear fashion. Areas surrounding the town may potentially produce significant embers during a major fire event, creating the possibility of fires starting well behind the normal defense lines put in place during firefighting efforts. If local resources for fire spotting and control are taxed by these regional fires, the potential for fires to spread unchecked in or near the town may be relatively low, but cannot be ignored.

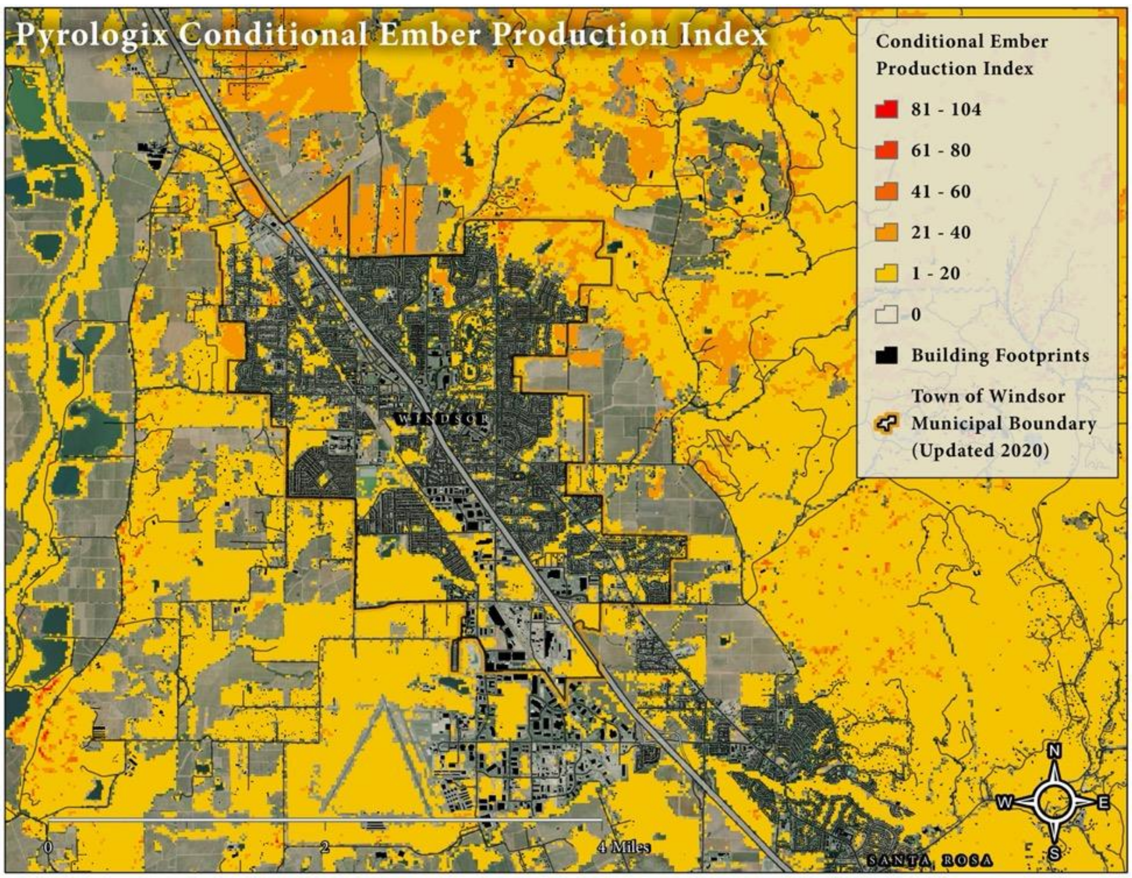


Figure 27. Map of conditional ember production index for the Town of Windsor and the surrounding area. Created by Pyrologix and based on existing fuels, average wind conditions, topography, and fuel type, this map represents model outputs of an effort to predict the relative volume of embers produced by potential fires in the area. Relative to all of California, the area immediately around Windsor faces low and moderate ember production risks on a percentile ranking basis. However, embers produced in distant areas can be carried significant distances, and given the extreme risks faced elsewhere, "low" ember production risk within the state is no justification for low levels of caution. Forests upwind of the town to the west have significant ember production potential. (Source: Tukman, et al. 2021)

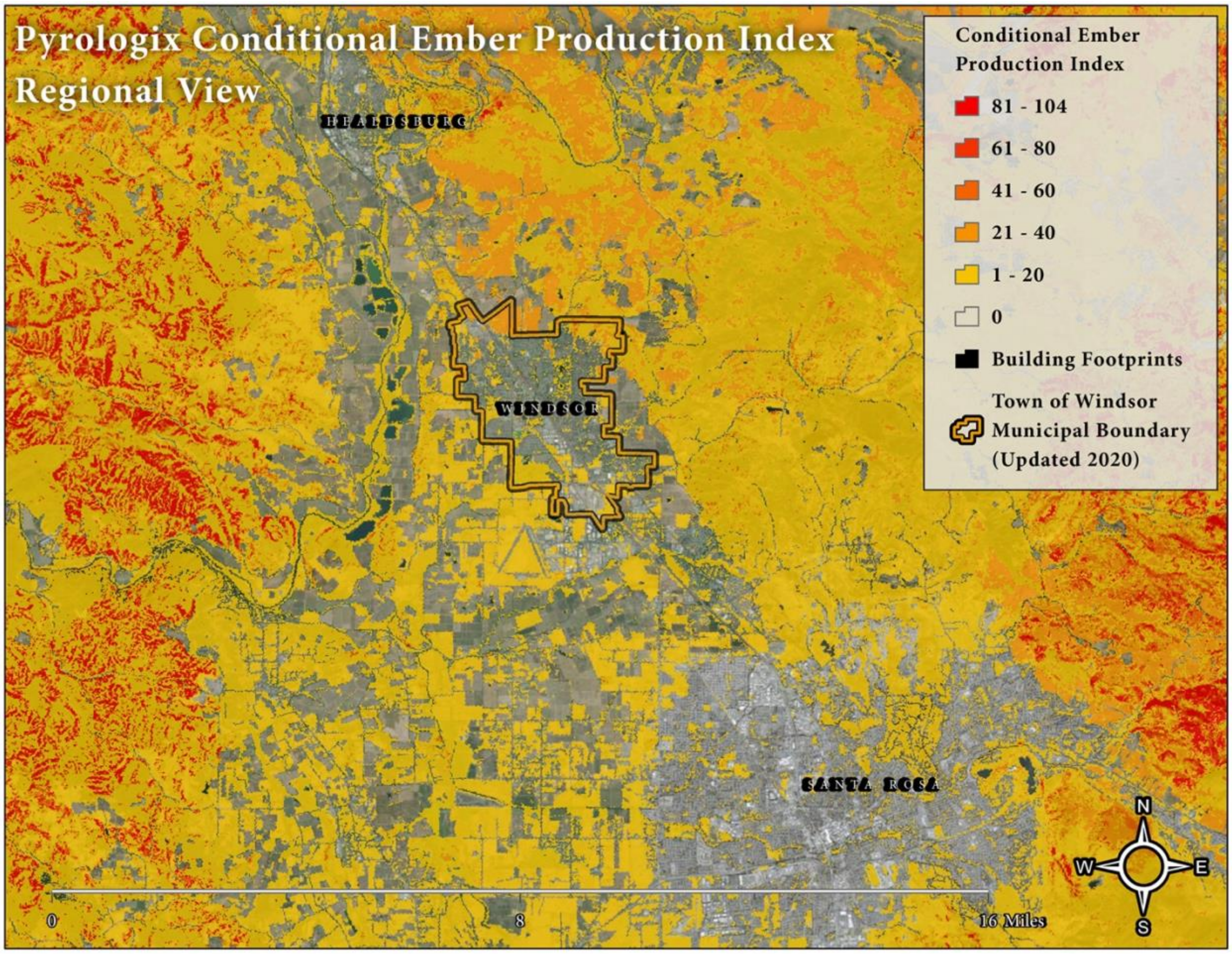


Figure 28. Map of conditional ember production index for the broader region. Created by Pyrologix and based on existing fuels, average wind conditions, topography, and fuel type, this map represents model outputs of an effort to predict the relative volume of embers produced by potential fires in the area. Relative to all of California, the area immediately around Windsor faces low and moderate ember production risks on a percentile ranking basis. However, embers produced in distant areas can be carried significant distances, and given the extreme risks faced elsewhere, "low" ember production risk within the state is no justification for low levels of caution. Forests upwind of the town to the west have significant ember production potential. (Source: Tukman, et al. 2021)

Typically, firestorm and ember cast behavior are not predictable using traditional models for quantifying wildfire risk. Where wildfire behavior is generally predictable and the expansion of wildfire events outside the wildland intermix and interface regions is hindered by changes in geography and vegetation, firestorms defy expectation. Firestorms exhibit much higher burn temperatures, with the ability to melt steel and PVC in the process. In addition, they consume so much oxygen that they can create their own weather systems. They also travel great distances with incredible speed; it is increasingly common for firestorms to advance at speeds exceeding 20-25 miles in a single day, consuming hundreds of square miles in a short period of time. Compared to traditional wildfires, firestorms are unpredictable, erratic, and much more difficult to suppress because of the convective forces that enable them to move against strong prevailing winds.[82] The windstorms that feed them (and those they create) can carry burning embers miles

[82] Siegler (2018)

from the fire itself, at times with such intensity as to be nicknamed 'ember attacks.' These ember-driven phenomena can ignite structures far from the fire in places assessed as falling safely beyond any WUI risk zone.[83] Firestorms, also called 'megafires,' can even produce pyro-cumulonimbus clouds that spawn "fire tornadoes." A viable secondary hazard, fire tornadoes are disasters in and of themselves, traveling beyond the wildfire front and destroying everything in their path inclusive of fire-resistant structures, vehicles, homes, and infrastructure considered well outside traditional wildfire risk zones.[84] Unlike firewhirls, which look like tornadoes but are just spinning funnels of flames (typically about 8 feet in diameter), fire tornadoes are true tornadoes and deliver an equivalent impact. The F-3 fire tornado created in the Carr Fire in 2018 was the largest and most powerful tornado in California history, and it was spurned not by a natural weather pattern but by the weather created by the wildfire itself.[85] More recently, the 2020 Loyalton Fire produced five fire tornadoes.[86]

In terms of exposure, the capacity for an ember attack or a fire tornado to transfer the heat and ignition of a wildfire miles from its source means there is no location in Windsor that is safe from this type of hazard. Increases in the likelihood of firestorm events increases wildfire exposure far beyond the boundaries of the intermix and the wildland urban interface (WUI) zones, including into the flat and more lightly vegetated Russian River Valley where Windsor is situated. For example, the 2017 Tubbs Fire approached Windsor from the southeast, assuming characteristics of a firestorm in the process. County first responders who were present at the fire describe conditions not only consistent with a firestorm, but also with fire tornadoes. In this event, a column of embers and wind-driven fire and smoke rushed beyond the WUI-designated zones into Santa Rosa's residential Coffey Park neighborhood. Responding officers described conditions as being 'unstoppable,' reporting the presence of smoke so low and dense as to obscure operations and prevent their ability to offer additional wildfire protection in the area. By the time the event was brought under control, over 1,000 structures had burned, most of which had been previously characterized as falling outside even the most moderate wildfire risk zones, including in those maps that detail LRA wildfire risk. The following maps illustrate how CAL FIRE FRAP WHRZ maps cannot accurately portray the risk of wildfires given their erratic behavior and that these phenomena are not predictable using traditional drivers of wildfire hazards (*see Figure 31*). The absence of any designation of risk within the outlined Coffey Park neighborhood as shown on this map is presumed to be the result of: 1) its location in the LRA where FHSZs that falls below the 'Very High' designation are omitted; and/or 2) it falls outside the area considered to be Wildland Urban Interface or intermix. In the third map that follows, the extent of the Tubbs fire is detailed. This fire advanced across several streets including a major multi-lane highway (Highway 101) to reach Coffey Park (outlined in blue). Much of the neighborhood burned completely, as did other residential areas just to the east. The last map details the WUI, color coded to indicate housing density. None of the Coffey Park neighborhood that was destroyed in the Tubbs fire was actually classified as WUI.

[83] Berlin (2020)
[84] Finn (2020)
[85] Cappucci (2018)
[86] Chadosh (2020)

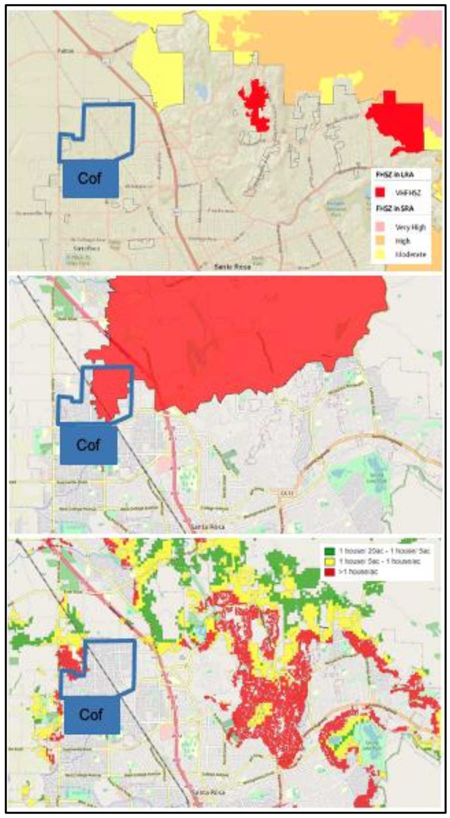


Figure 29. Map of Coffee Park burned area (outline highlighted in blue and labeled Cof). Top: Excerpt of the 2008 CAL FIRE FRAP WHRZ Map showing no wildfire risk; Middle: Excerpt of the Tubbs Fire Extent showing the actual burned area from Coffee Park, 2017; Bottom: Wildland Urban Interface zone illustrating non-traditional wildfire risk classifications for Coffee Park. (Source: CAL FIRE FRAP, 2007)

THE INDIRECT IMPACTS OF WILDFIRES

As evidenced by recent experience, wildfires produce an array of indirect impacts that affect Windsor residents. Most notably, smoke from local and regional fires present a significant threat to the health and wellbeing of Windsor residents. Wildfires create an acute and particularly severe form of air pollution through the smoke clouds they generate. New research shows that smoke is more harmful than pollution from other sources, including car exhaust.[87] These clouds contain a number of dangerous pollutants, some which cause immediate and direct impacts (especially for those with breathing difficulties like asthmatics or those with COPD), and others that are carcinogenic or otherwise damaging to public health and present long-term implications for the populations exposed. Smoke also creates social and economic problems. Because exposure to areas of high airborne pollutants as is present in wildfire smoke can cause mass public health emergencies, it is not uncommon for governments and organizations in impacted communities to cancel activities and close facilities. Schools may be forced to close or curtail activities, businesses may close or be required to protect employees' health, and certain economic or social drivers may be negatively impacted (such as occurred when wildfire smoke impacted tourism in California's wine growing regions and impacted the quality of the grapes themselves).

[87] Aguilera et al. (2021)

At the community level, it is impossible to prevent wildfire smoke given it can travel hundreds of miles. Fires burning in other states can cause prolonged periods of smoke in Windsor. As fires burn more often and for longer periods of time, smoke will become an increasing hazard even if wildfire hazard remains relatively constant in Windsor. Unlike wildfires, vulnerability to smoke has little to do with construction materials or distance from the WUI. Rather, it is a factor of an individual's health status inclusive of their age, weight, blood pressure, history of pulmonary problems, and other factors. Addressing the impacts of smoke relies on the capacity to provide clean air spaces, whether in homes, workplaces, schools, or public buildings. The community must have the capacity to monitor and predict air quality conditions as wildfires burn and communicate information to citizens that enable early action. Protocols to address the curtailment of school activities or school closures, and the direction of public and commercial activities throughout the town, will be critical. Public health facilities must be prepared to deal with a surge in associated medical conditions especially if prolonged periods of smoke occur. The greatest risk is from small particulates that are difficult to filter. These particles that are smaller than 2.5 micrometers, or less than one third the thickness of a human hair, can cause both immediate and long-term health impacts, affecting the eyes, throat, and lungs, and contributing to asthma and heart disease through prolonged exposure. Moreover, exposure suppresses the immune system which increases the prevalence of other diseases (especially during the presence of highly transmissible viruses and bacteria as is the case with the ongoing COVID-19 pandemic).

As wildfire seasons become longer, and more acreage burns as a result of increasing fire size and prevalence, the severity and scope of smoke inhalation hazards will continue to increase. Windsor is already experiencing increases in the number of days where smoke inhalation hazards exist. As exemplified in Figure 29, which reports the number of days that wildfire smoke was present in each part of the state in 2020, illustrates the scope of the problem.

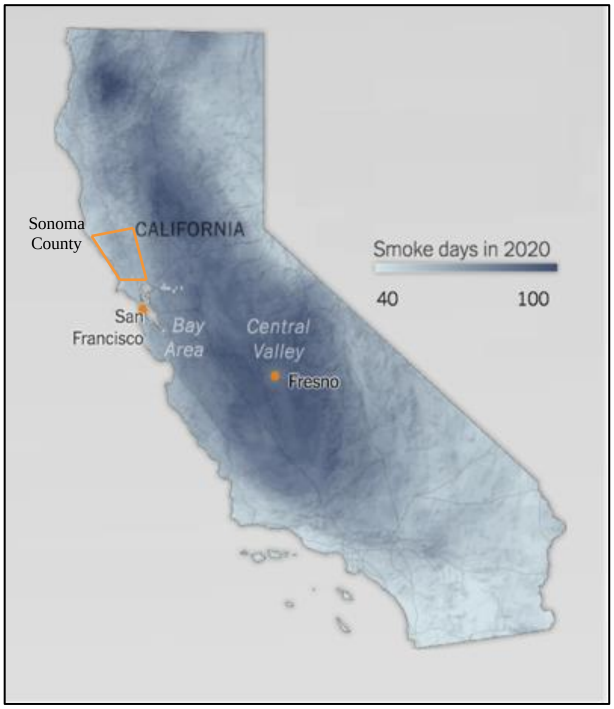
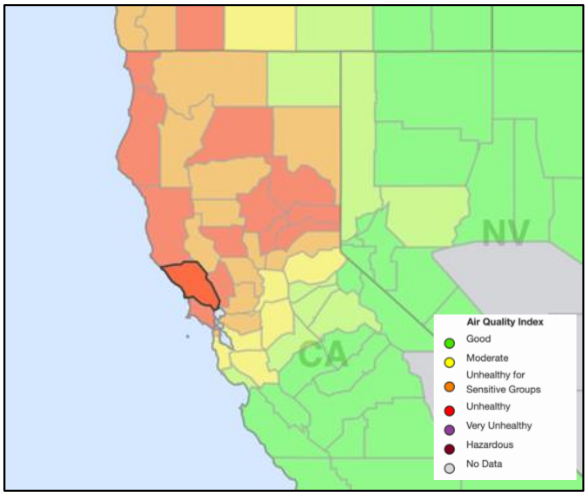


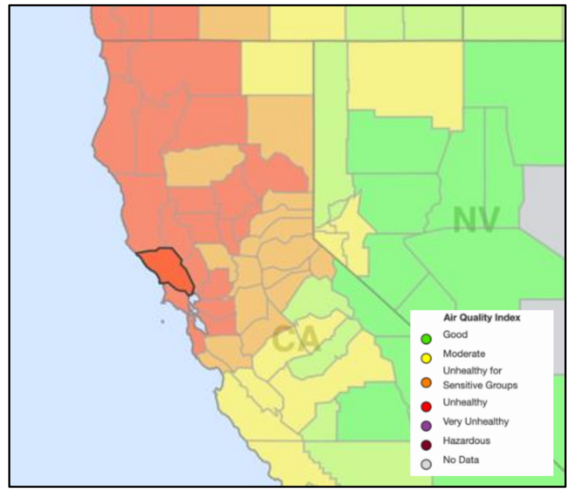
Figure 30. Map of California wildfire smoke days in 2020. (Source: Stanford University, based on NOAA data)

Looking forward, it is expected that smoke inhalation hazards will increase in conjunction with an increase in wildfire risk. A study[88] that considered wildfire smoke generation behavior in past events in relation to expected climate change impacts (from weather, changes in vegetation, and other drivers of air pollution) projected smoke inhalation hazards in the western states. According to this study, smoke inhalation risk in Sonoma County is already at a very high level and will increase in intensity over the next 30 years. The study also predicted the occurrence of 'Smoke Waves', which are periods of at least two consecutive days of elevated concentrations of PM 2.5 particulates. Risk is measured according to a Fire Smoke Risk Index (FSRI) which combines wildfire frequency, intensity, and length for each county. The following maps (*see Figure 31)* portray the high and increasing risk that exists in Sonoma County, and by extension, in Windsor. The greatest change that will occur with respect to this hazard in Windsor over the next 30 years, as portrayed in these diagrams, is that smoke intensity will increase considerably.

[88] Liu et al. (2017)



Sonoma County Wildfire Smoke Risk Index – Present



Sonoma County Wildfire Smoke Risk Index - 2050

Figure 31. Maps of current and projected wildfire smoke risk air quality index for Sonoma County. These maps show an increase in wildfire smoke days. Wildfire smoke is particularly problematic for older individuals or those with pre-existing health conditions.

APPLYING LESSONS LEARNED FROM PAST WILDFIRES

In the past five years, the Town of Windsor has experienced several significant wildfire events and evacuations. In 2017, the Tubbs fire burned nearly 37,000 acres, destroyed more than 5,500 structures, and killed 22 people. While the Tubbs fire ultimately spared the Town of Windsor, it significantly impacted nearby Santa Rosa and resulted in severe smoke for weeks. In 2019, the Kincade fire - which burned more than 77,750 acres and over 350 structures - presented a more immediate and direct threat for the Town. Nearly 190,000 people were evacuated across all of Sonoma County including the entire Town of Windsor. And in 2020, multiple fires approached the Town from both the east and west directions.

For Windsor, the Tubbs and Kincade Fires represented a wake-up call by signaling that 'curb and gutter' communities in the suburbs and town center are less safe than previously believed.

Thus far, every major wildfire to have impacted the region in the past 80 years has spared the Town, and only in one instance have structures burned within the Town's jurisdictional limits. That being said, the 2019 Kincade Fire brought the reality of changing wildfire risk to Windsor's doorstep. As the wildfire advanced towards the Town, state and county modelers assessed the possibility that the entire town could be destroyed, thereby prompting a total evacuation of Windsor's residents. Windsor Police conducted a street-by-street clearing of the town over the course of four hours, aided by County fire officials, mutual aid partners, and State responders. Ultimately, the advance of the Kincade fire was stopped just as it entered the Town from the northeast at Foothills Regional Park. Not all homes were spared, but the destruction sustained was nonetheless a fraction of what has undoubtedly become possible in a similar future event. Moreover, the event created a new risk for debris flows where none had previously existed; the result of damaged stabilization elements. By 2020, these fire scars resulted in actual threats to the parts of town located in their paths.

For Windsor, the Tubbs and Kincade Fires also represented a wake-up call by signaling that 'curb and gutter' communities in the suburbs and town center are less safe than previously believed. These events, and others that have since followed, reveal an elevated potential for loss anywhere in the Town of Windsor, and the possibility that the entire town could experience significant loss under specific conditions. A wider lens capable of accounting for alternate drivers of risk is required to better capture wildfire risk in light of firestorms, fire-generated smoke, and debris flow.

EVACUATIONS AND "TRAFFICSHEDS"

Wildfire exposure has a direct influence on local emergency response mechanisms such as wildfire evacuation. Planning for evacuation, including establishment of coordination mechanisms and methods of communicating between responders and with the public, is guided by the manner in which the wildfire hazard threatens Windsor, its resources, and its residents. Emergency evacuation procedures and principles can differ markedly between hazards in terms of warning availability, speed of approach and onset, geographic distribution, the manner in which the hazard affects human and animal life, and other factors. As wildfires become increasingly unpredictable, with ember cast and wildfire tornadoes having the capacity to travel great distances in short amounts of time, evacuation capabilities become all the more important. Multiple recent evacuations, in both 2019 and 2020, highlight both the increasing nature of wildfire risk in Windsor and the importance of having effective evacuation protocols in place. Sonoma County law decentralizes the authority to issue an evacuation order to the local level, unless arrangements (formal or informal) exist according to which the County government assumes such responsibility. The Sonoma County Sheriff's office will inform Windsor officials of the need to conduct an evacuation, yet the law does state that the declaration can be made at the Town level.[89] Therefore, the Town has the authority to issue a local evacuation order if deemed necessary. Once this notification is issued, the County Sheriff's office coordinates the evacuation effort from a local Emergency Operations Center with input from the Sonoma County Fire Department, Town staff, and other local stakeholders. Evacuation notifications are made using several channels, including app-based messages which are received by residents who have downloaded the software, local radio coverage, and through the use of 'high-low' sirens installed on Town police vehicles that are driven through priority (event specific determination) neighborhoods. The County also is the primary alert activator for SoCoAlert, WEA, EAS, and Nixle alert messages.

In May 2021, the Town of Windsor published updated evacuation sub-zone maps (see Figure 31). These maps were originally developed by representatives of the Town Emergency Operations Center during the Kincade Fire and were crosschecked with the police and fire departments. Since that time, the maps have been maintained and updated, and informed the evacuation coordination for the Wallbridge and Glass Fires in 2020. County deputies and Town officers coordinated in their efforts to go door to door to ensure that residents were evacuating.

[89] Sonoma County (2021b)

Since that time, the Town has identified a need for continued public education and awareness with these maps to ensure that all residents are aware of their own evacuation zones if needed.[90]

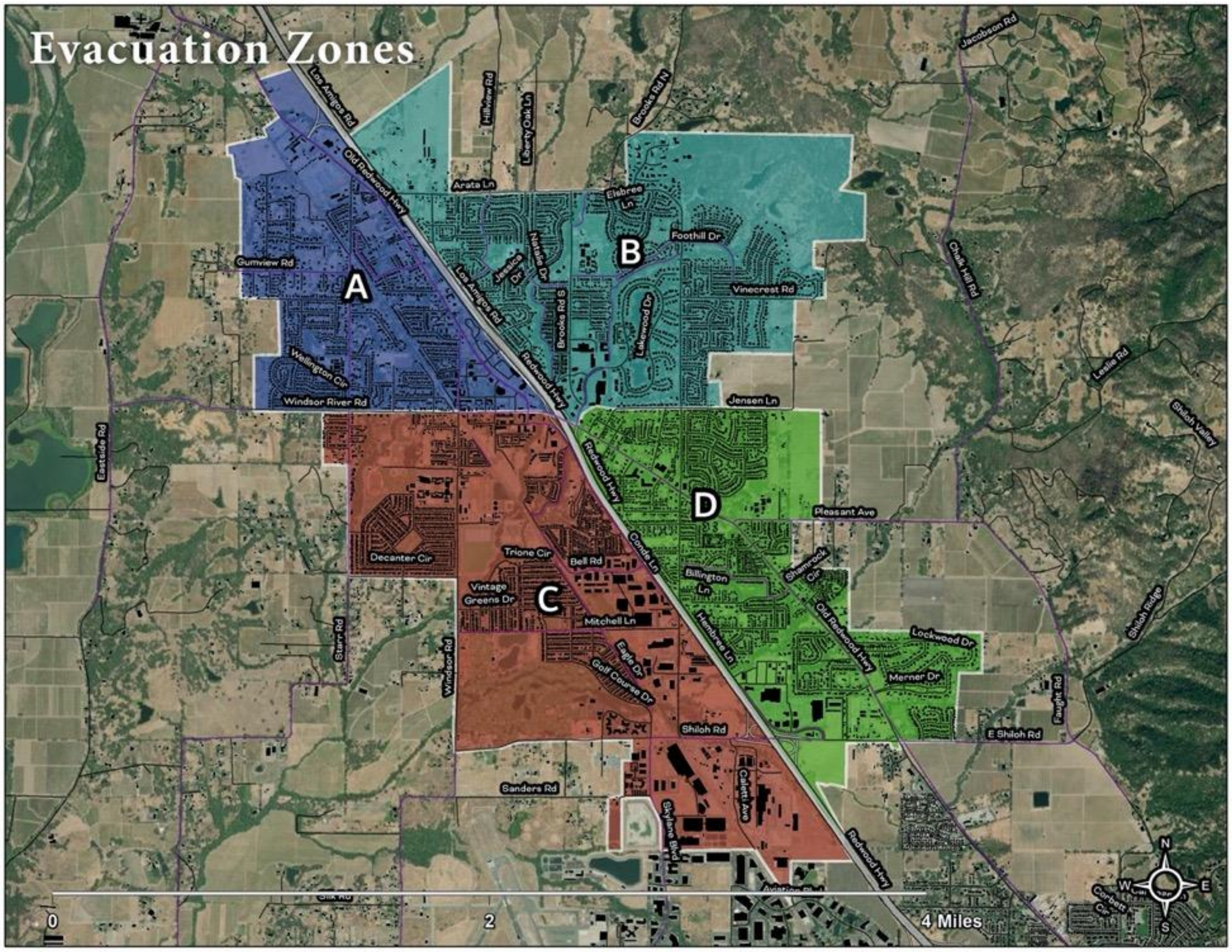


Figure 32. Map of evacuation zones for the Town of Windsor published May 2021. (Source: Town of Windsor)

A recent study highlighted the significance of wildfire ignition points and wildfire detection times when planning for extreme wildfires,[91] demonstrating the unique challenges that emergency planners are faced with when planning for evacuations during catastrophic wildfires exacerbated by climate change. In this current planning reality, there are a number of factors that determine whether or not an evacuation is carried out successfully including: fire spread rates, wildfire ignition points, the time it takes to detect a wildfire, warning technologies, evacuation decision-making and communication, and random adverse events.

In 2019, California State bills SB 99 and AB 747 were signed into law and added new requirements for including evacuation routes in the Safety Element of a community's General Plan. According to Cal OES, SB 99 specifically required that the safety element "must be updated to include information identifying residential developments in hazard areas that do not

[90] Town of Windsor (2021b)
[91] Cova et al. (2021)

have at least two emergency evacuation routes."[92] AB 747 specifically required that evacuation routes must be identified including "their capacity, safety, and viability under a range of emergency scenarios," in an emergency operations plan, LHMP, or other community planning document. Generally speaking, this information should be included in a community's Emergency Operations Plan (EOPs) and/or Emergency Action Plan (EAPs) as both documents are updated annually and are used to guide a community's emergency response during a disaster. Neither bill requires a standard nor provides recommendations for how many homes are "allowed" a single evacuation route in any particular community.

"TRAFFICSHEDS", CHOKEPOINTS, AND CRITICAL INTERSECTIONS

Any evacuation event will put stress on the existing transportation network as most, or all, of Windsor residents, as well as people residing in rural areas to the east and west of the town, will require access to just a few critical road segments that allow travel away from the threat. The curvilinear nature of some of the Town's neighborhood street networks, especially east of the 101, increase the criticality of certain intersections as many evacuees will feed into these exchanges that provide access to the regionally connected network. This has the potential to create evacuation chokepoints particularly at major arterials that will likely require additional attention from the Town either in the form of personnel deployment during an evacuation event, redesign of street geometries, or evacuation signal timing -- all methods of increasing adaptive capacity.

In an effort to identify which specific neighborhoods and intersections might face the biggest risks of bottleneck formation, the project team developed a "trafficsheds" approach. This approach looks at networks of residential and commercial streets, lanes, courts, other smaller roads that are linked to one another - and the various points at which these self-contained networks are connected to the major roadways and arteries throughout the Town. These points of connection between neighborhoods and the main road network are "exit nodes," also referred to in other state planning documents as "ingress/egress points" and, if unable to handle the traffic loads during evacuation events, have the potential to become severe bottlenecks. In normal times, they also represent critical infrastructure for the specific neighborhoods that rely on these intersections to go about their daily activities. Identifying these nodes and the areas served by them, can highlight where potential congestion might be the highest. The areas defined by a shared set of ingress/egress points to the main road network are "trafficsheds" (derived from the term watersheds, which comprises the total area into which precipitation drains to a particular stream).

A trafficshed includes the total area and structures that "drain" to an internally linked set of major road network access points (*see Figure 34*). To develop this dataset, the project team used 2019 USDA NAIP imagery, ESRI and Google satellite composite imagery services, Microsoft Bing Building Footprint layers, Sonoma County parcel data, USGS road network, and manual identification of 153 distinct trafficsheds within, and immediately surrounding, the town.

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[92] State of California (2021)

This work highlights:

- Residential or commercial road networks with limited connections to the larger road system, especially those with only one way in or out (i.e., one ingress/egress point);
- The number of structures and their zoning designation served by each particular sub-network of roadways; and
- The ratio of structures (primarily residential homes) to the ingress/egress points available to them, highlighting both areas with few ingress/egress points and those with multiple but high numbers of structures dependent upon them.

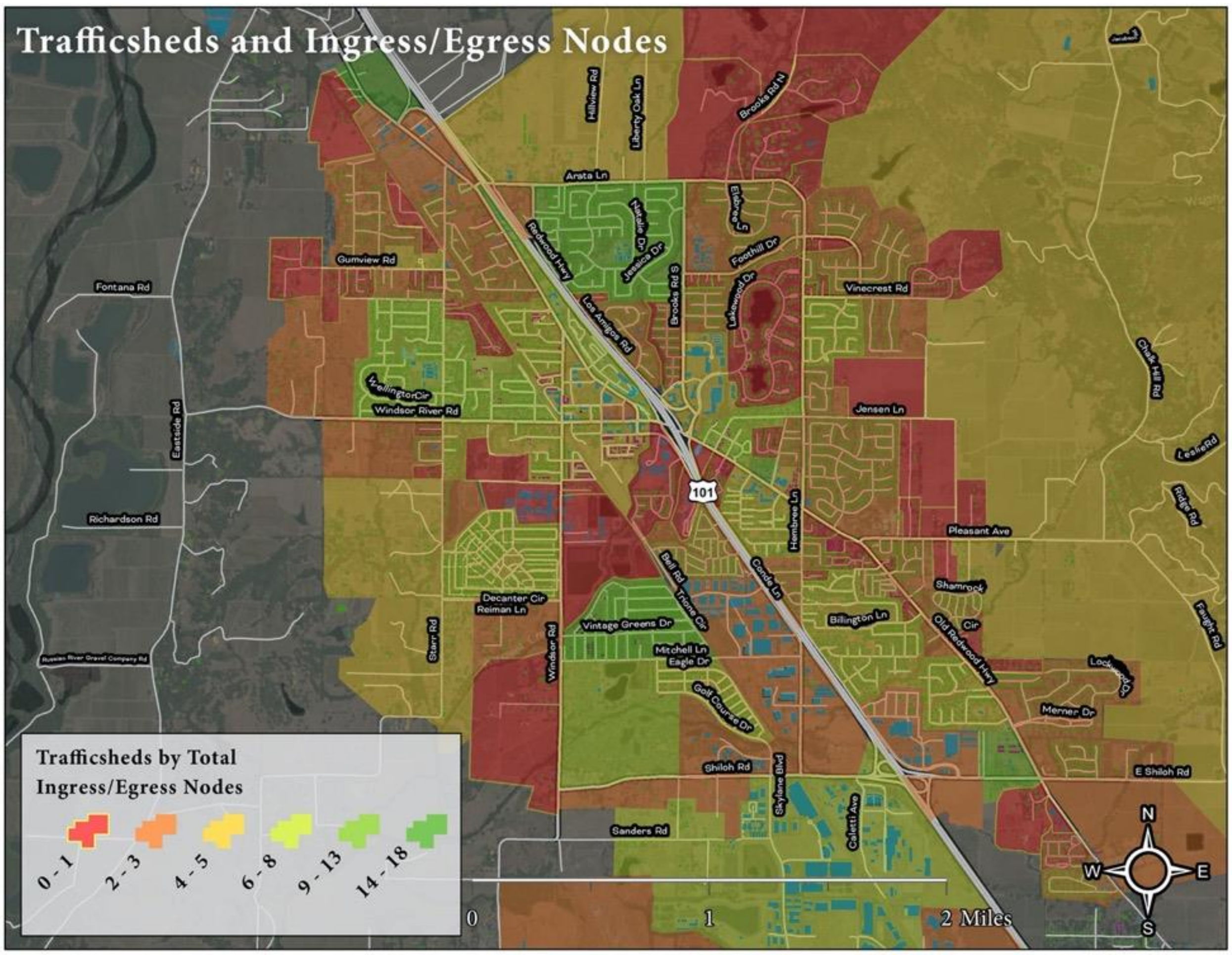

Figure 33. Map of trafficsheds for the Town of Windsor and surrounding areas. Trafficsheds are areas defined by a shared set of ingress/egress points to major roadways. Areas shown in reds and oranges have fewer ingress/egress points. Those shown in light green and dark green have more access points. The number of access points per residential structure or business can affect or limit the flow of traffic and people during emergencies, especially those that require large numbers of people to evacuate.

CONSEQUENCES/IMPACTS

PEOPLE

Wildfire poses a direct threat to the safety and wellbeing of all Windsor residents. Due to the small size of the Town and to the changing dynamics of wildfires, wildfires pose a significant and direct threat to the health and safety of the residents of the Town of Windsor. As exemplified by past examples (e.g., Coffey Park), changing fuel, weather, and climate conditions increase the exposure of Windsor residents to wildfire. This is particularly true due to limited evacuation routes in the Town and the proximity of the Town to the wildlands, especially for residents with limited access to vehicles, disabilities, older adults, children and families with children, and those that experience mobility issues. The proportion of Windsor residents below 17 and above 65 make up a significant percentage of Town demographics (in some areas of the Town, as high as 42.4%), which presents unique evacuation challenges during a wildfire.

Limited regional transportation network connectivity and limited egress/ingress for some Windsor neighborhoods pose significant safety and health concerns during an evacuation due to wildfire. Due to a combination of reliance on personal vehicles and chokepoints in the roadway network, Windsor residents and emergency responders may face congestion while traveling in and out of the Town during a wildfire. In addition, access to/from homes and critical services, such as hospitals, social services, water, energy and food supplies, is essential during and after a wildfire.

There are a significant number of sections located in the Windsor network that service a considerable number of people and have limited roadway connectivity. As evidenced in Table 3, there are several trafficsheds (as defined in this analysis) with limited ingress/egress points, which could significantly limit the ability of residents to evacuate the Town safely in the case of an emergency. Although not in Windsor, technically, the area to the east of Town is also of some concern, as it includes over 800 residential and agricultural structures and is confined to 4 feasible evacuation points for accessing Highway 101, 2 of which are Pleasant Ave and East Shiloh Rd. These roads both intersect Old Redwood Highway (Sonoma County evacuation zones 2L7, 2M1, 2N1), complicating potential evacuation considerations with Windsor Evacuation Zone D (208+ structures per exit). Other neighborhoods clearly in the WUI zone with limited exit points include: Vinecrest Road and Foothill Drive (253 structures, 2 exit points); Glen Miller Way (124 structures, 1 exit point); Winemaker, Reiman/Oak (491 structures to 4 exits); and Broadleaf Circle (333 structures, 3 exit points); that all have more than 100 structures to each exit point. There are 58 trafficsheds that have only 2 or 3 exits, containing 3083 single-family residential structures, 11 multifamily structures, 490 commercial structures, and 47 agricultural structures. Among these, the Shadetree/Leafhaven neighborhood (500 structures, 3 exits), Foothill Dr. neighborhoods (253 structures, 2 exits), and Merner/Savannah neighborhoods (197 structures, 2 exits) are the most prominent in terms of likely residents dependent on a small number of outlets during an emergency. Although not directly located in the WUI (and therefore not included in Table 3), another couple of areas of concern are the Herb/Kidd/Gumview intersection which contains 295 structures and only one exit node at Gumview and Starr. In addition, Lakewood Drive at the Lakewood Hills subdivision has 185 structures and only one 1 exit node.

Table 3. Select critical intersections that serve trafficsheds located in the WUI. While the WUI is no longer the sole determinant of wildfire risk for the community, these intersections provide ingress/egress routes for a large number of structures (and therefore people) and provide critical connections to the broader transportation network for these residents, both to allow residents to leave in the event of an emergency evacuation and to allow first responders and firefighters into these neighborhoods during a wildfire event. All intersections in this table serve a minimum of 50 structures.

Critical Intersections That Serve Trafficsheds Located in the WUI				
Key Intersections for Trafficshed	**# of Structures**	**# of Residential Zoned Structures**	**# of Exit Nodes**	**Structure : Exit Ratio**
Herb/Kidd/Gumview Rd	295	291	1	295
Mountainous Area (Access to Windsor via Pleasant or Shiloh)	833	479	4	208.25
Vinecrest Rd and Foothill Dr	253	253	2	126.5
Glen Miller Way and Brooks Rd	124	124	1	124
Winemaker/Windsor, Reiman/Oak, H/Starr	491	491	4	122.75
Broadleaf/Circle/Basswood/Conde	333	333	3	111
Savannah/Merner/Old Redwood	197	197	2	98.5
Elabree/Arata	195	191	2	97.5
Old Oak/Armondo Renzulo/Conde Ln (Windsor Creek Elementary)	90	77	1	90
Lazy Creek/Foxwood/Los Amigos	153	149	2	76.5
Jessica/Brooks; Arata/Camelot; Amigos/Cordelia	755	742	10	75.5
Old Redwood/Shamrock Cir (Shamrock MHP)	141	132	2	70.5
8th, 9th, 10th Hole and Mitchell Ln	274	274	4	68.5
Ventana/RioCamino/Macero and Foothill Dr	132	132	2	66
Pulteney Pl/Bond Pl and Brooks Rd S	128	128	2	64
Billington/Northampton and Hembree Ln	315	315	5	63
Starrview/Bingelli/Orion, Buckingham/Starr	414	400	7	59
Jones Rd and Windsor Rd	53	44	1	53
Vinecrest Cir	50	50	1	50

Regional transportation considerations may impact the ability of Windsor residents to evacuate in an emergency. The town has four main evacuation zones (shown in detail in Figure 35). Each evacuation zone contains potential chokepoints in the case of an evacuation. If heavy traffic from Santa Rosa emerged due a wildfire coming from the Southeast, the ability of Windsor residents to evacuate will also be affected. Another example are the houses and facilities off of Brooks Rd to the north of Town and Evacuation Zone B, where 91 mostly residential structures empty through a single ingress/egress node onto Arata Lane. These areas are both directly exposed to wildland vegetation in difficult to manage areas and have shown substantial regrowth in areas where the Kincaid Fire burned. Furthermore, many homes outside the Town boundary in the nearby WUI are only accessible through narrow, one-way, and/or heavily vegetated roads.

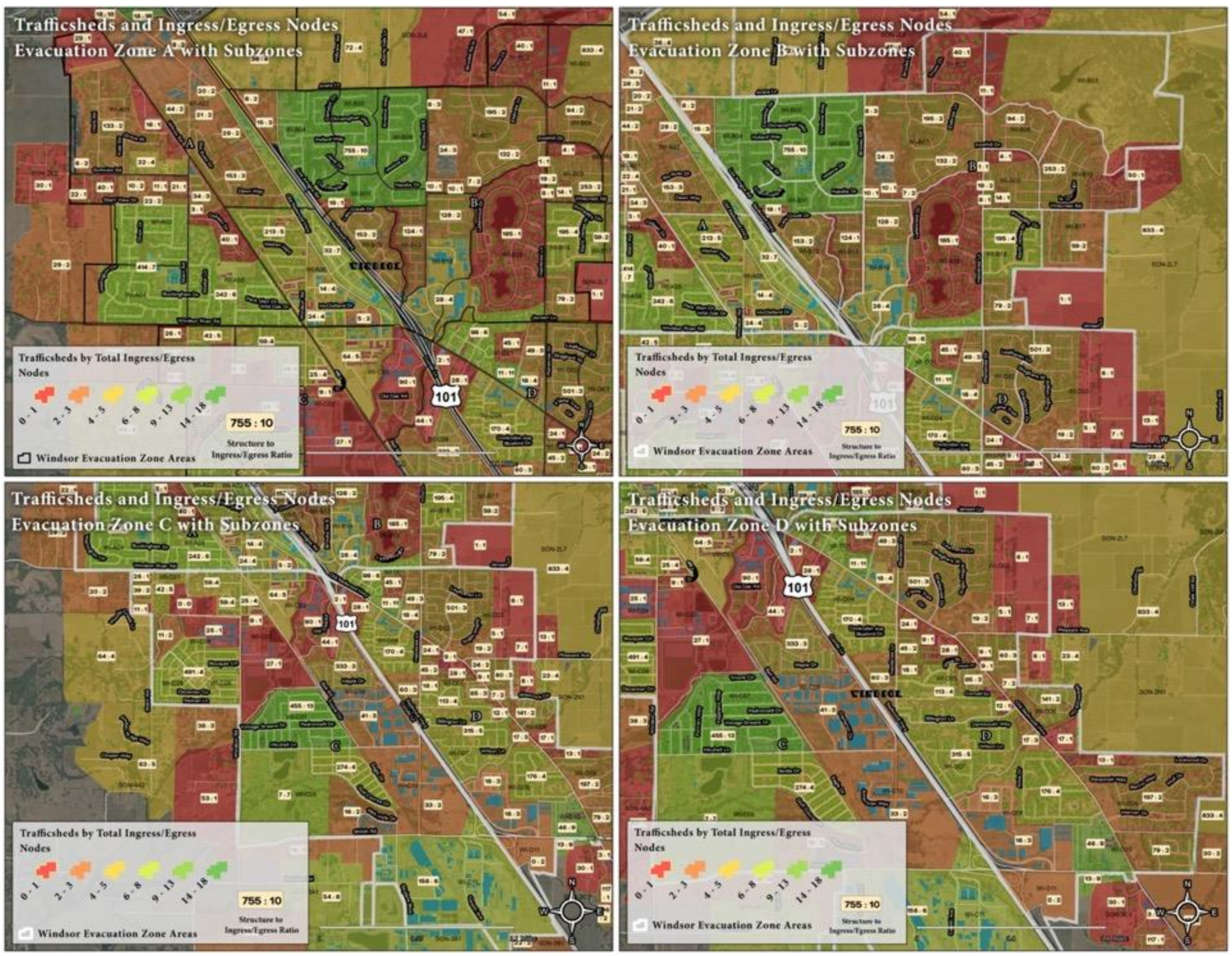

Figure 34. Map of trafficsheds and evacuation zones for the Town of Windsor. Trafficsheds (areas defined by a shared set of ingress/egress points to major roadways) for the Town of Windsor and Windsor's Evacuation Zone A (Top Left), Zone B (Top Right), Zone C (Bottom Left), Zone D (Bottom Right). Areas shown in reds and oranges have fewer ingress/egress points. Those shown in light green and dark green have more access points. The number of access points per residential structure or business can affect or limit the flow of traffic and people during emergencies, especially those that require large numbers of people to evacuate. To reference larger versions of these graphics, see Appendix A.

Smoke from near and distant wildfires pose a significant health concern for the residents of Windsor, particularly community members that have pre-existing health conditions like asthma, heart disease, and more. In some instances, residents recall smoke from distant fires having more of an impact on the region than smoke from fires in much closer proximity. New research shows that smoke is more harmful than pollution from other sources, including car exhaust.[93]

Specific indicators (including race, socioeconomic status, mental health, and ethnicity, among others) influence the ways in which residents will be impacted during and after a wildfire. A 2018 study highlights that more than 29 million people in the U.S. are at risk of wildfire, but 12 million people would be devastated by the event because they lack the financial means or insurance to rebuild.[94] A variety of factors exacerbate the risk of wildfire that certain Windsor residents face. This is especially true for parts of Town that experience poverty, extreme housing cost burdens (in some areas as high as 22.6%), and renters with severe housing burden. In some parts of the Town, over 49% of the population are of minority status and may face unique barriers to evacuating (e.g., linguistic isolation) and recovering post-wildfire. In addition, many people exposed to extreme events or natural disasters, such as wildfires and prolonged smoke exposure, experience stress reactions or serious mental health consequences. These can include symptoms of post-traumatic stress syndrome (PTSD), depression, and general anxiety as well as mental health effects such as grief/bereavement, increased substance abuse or misuse, and suicidal thoughts. All of these reactions can exacerbate existing mental health conditions or lead to the onset of new ones that can significantly impact the lives of residents and be especially problematic for sensitive populations.[95]

BUILDINGS

Due to ember cast, firestorms, and other changing wildfire dynamics, all structures within the Town of Windsor are vulnerable to loss and/or damage from wildfires. Very few of the Town's buildings and homes are located in the WUI - a traditional indicator of sensitivity to wildfire. Yet, increasing wildfire exposure due to climate change (among other factors) is exacerbating wildfire risk and the potential impact on Windsor homes continues to increase. Under an extreme wildfire scenario, all Windsor homes and businesses are sensitive to the impacts of wildfire - particularly those in closer proximity to the wildlands, as evidenced by past regional wildfires (e.g., Coffey Park). Wildfire embers can travel up to ~5 miles in extreme weather conditions, therefore due to the proximity of Windsor to the wildlands on the East and West sides of the Town, and the fact that Windsor is only ~3 miles wide at its greatest width, the general exposure of all Windsor homes and businesses to wildfire is high. Most of Windsor's commercial buildings and critical facilities (e.g., police and fire department buildings) are located in the central part of the Town, which may be easier to protect in the case of a wildfire. Across the county, over 30 fire stations are located in "high wildfire risk areas," potentially limiting the emergency responders to protect local assets in the Town.[96] Several Windsor schools and retirement homes are located near the periphery of the wildlands, resulting in increased exposure to wildfire.

[93] Monroe (2021)
[94] Davies et al. (2018)
[95] USGCRP (2016)
[96] FireSAFE Sonoma (2016)

Most homes within Town boundaries do not use fire-resistant materials or construction methods. Most of the homes built within the town boundaries (where wildfire risk has historically been considered as limited) were not built with fire-resistant materials or construction methods because they were built prior to the Town's incorporation. As a part of the 2019 Building Code updates, the Town adopted additional 7A building standards to create additional requirements for existing and new construction to meet more rigorous fire-resilient building standards. New homes are required to meet those standards, and there are trigger mechanisms in place for older homes to become wildfire code compliant, yet new builds and homes that have already undergone this process represent a small proportion of homes located within Town boundaries. This means that the sensitivity of homes and businesses within Town boundaries to wildfire is classified as high. Adaptive capacity of homes to be retrofitted with fire-resistant building materials and construction methods is relatively medium/high, but additional municipal codes, policies, or programs that require or support these changes would improve this.

INFRASTRUCTURE

Infrastructure damaged and destroyed by wildfire can have significant impacts on the safety, health, and well-being of Windsor residents, particularly during an evacuation. Most telecommunications and electric utilities infrastructure in Windsor were built prior to codes requiring utilities to be undergrounded, therefore are at risk from being damaged or destroyed due to wildfire. If damaged or destroyed, telecommunications infrastructure - which is essential during an evacuation or emergency response - can pose significant safety and health concerns for residents. This is particularly true for residents who live in hard-to-reach areas, who experience technological barriers, or those who face linguistic isolation. Overall, the sensitivity of telecommunications infrastructure that supports the Town is considered high.[97] Regionally, the county relies on a wireless communications network for its broader public safety and emergency response communication, and 6 out of 11 total tower sites are located in areas considered at high risk of wildfire.[98] Specifically, Windsor's infrastructure was not developed with emergent fire risk in mind, which has left both networks and nodes more vulnerable to the effects of wildfires, and the capacity to meet the demands that are likely to arise in a rapidly-escalating wildfire emergency as inadequate.

Regional wildfire risk impacts the functionality and use of electric, water, and telecommunications infrastructure that residents rely on. Some of the Town's water, telecommunications, and electric utility infrastructure that residents rely on is at risk of being damaged or destroyed due to wildfire. For example, the Town's water distribution lines - while buried at depths ranging from 32 inches to over eight feet - are made of PVC, which can distort at fairly low temperatures (~180 °F). In the case of a large wildfire, damage to these lines could generate leaks in the water distribution system resulting in disruption to water supplies and expensive repairs (as seen in the Fountaingrove area of the City of Santa Rosa due to the Tubbs Fire).

Recent catastrophic wildfires across the State triggered by damaged or downed power lines have also led utility companies like PG&E to take short-term measures to reduce the risk of power

[97] FireSAFE Sonoma (2016)
[98] FireSAFE Sonoma (2016)

line-induced wildfire ignitions.[99] This includes implementing Public Safety Power Shutoffs (PSPS) - regional power shut offs for homes and businesses - during Red Flag Warning days (days with low humidity levels, sustained winds above 25 MPH, wind gusts above 45 MPH, and dry fuel conditions).

NATURAL SYSTEMS

Extreme wildfires can cause biodiversity loss and significantly impact the ability of ecosystems to regenerate post-wildfire. Wildfires and toxic smoke can cause significant biodiversity loss that is hard for some systems to recover from. For example, a recent study connected wildfires in 2020 to massive migratory bird die-offs in the west.[100] In addition, wildfires exacerbate the ability of invasive species to outcompete native grasses, forbs, shrubs, and trees and also are more susceptible to fueling additional wildfires.

Post-wildfire precipitation events can create additional hazards that impact natural systems, people, infrastructure, and buildings. Catastrophic wildfires can lead to increases in water runoff, erosion, and landslides due to the destruction of soils, shrubs, forbs, grasses, trees, and additional organic materials on the forest floor (aka detritus or litter layer). Extreme wildfires inhibit the ability of soil to absorb water and increase the rate of precipitation runoff and erosion, particularly on steep hillsides. In addition, it also limits the ability of seeds to germinate and survive, creating a negative feedback loop for forest regeneration.[101] These secondary impacts can be particularly damaging to sensitive aquatic ecosystems, especially those that support threatened and endangered species (e.g., California Coast Coho Salmon).

ECONOMY

Wildfires can have significant direct and indirect impacts on the regional economy. Regional wildfires and the subsequent smoke that they produce close businesses, disrupt operations, or limit businesses to operate at full capacity. An analysis by Moody's Analytics estimated that the Kincade Fire caused $235 million in lost economic output. In the broader region, wildfires limit the ability of tourists to travel to popular destinations (e.g., wineries) in the county which also impacts the local economy. Wildfires directly impact agriculture and viticulture economies by destroying essential and critical infrastructure, vines and vineyards, and wine stocks.[102] [103]In addition, wildfire smoke can impact vintners and wineries due to "smoke taint," a process in which grapes are exposed to wildfire smoke producing a charred, smoky, burnt, or medicinal flavor.[104] These systems can take significant time to recover.

[99] Pacific Gas and Electric (2021)
[100] Learn (2021)
[101] Chen et al. (2019)
[102] Tatko-Peterson, A., & Orlin, M. (2017)
[103] Canon (2020)
[104] Ramakrishnan (2020)

Flooding

VULNERABILITY SUMMARY

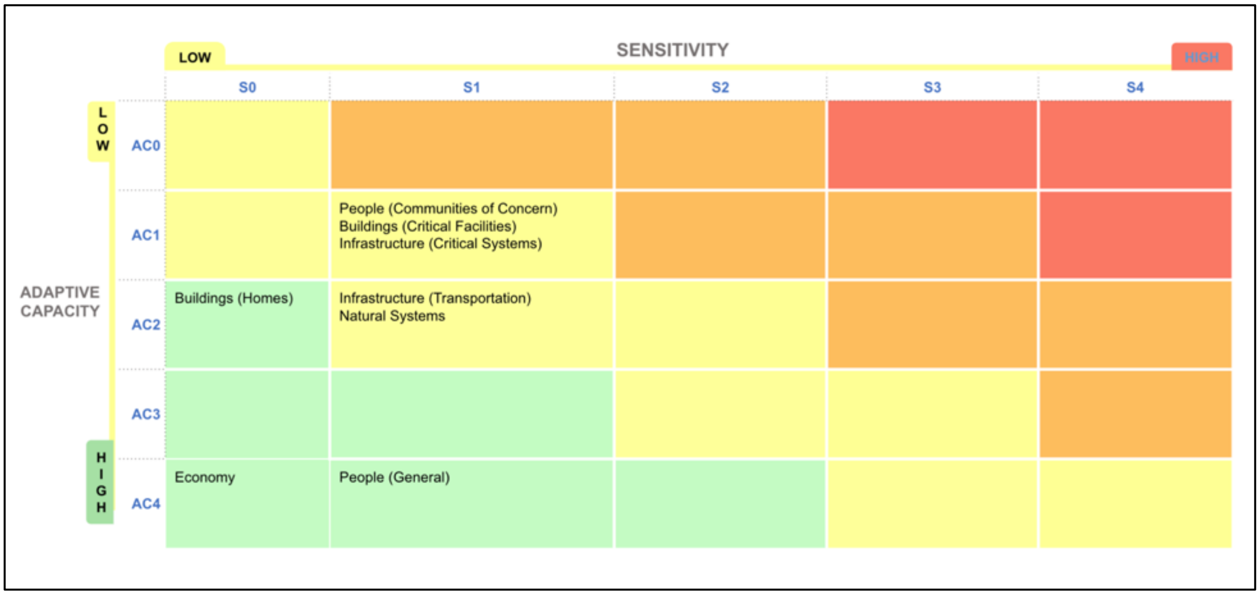

Figure 35. Relative vulnerability assessment of flooding for the Town of Windsor. Vulnerability is shown by the different colors of the matrix (Red = Extreme Vulnerability; Orange = High Vulnerability, Yellow = Medium Vulnerability; and Green = Low Vulnerability). Given the climate hazards, relative vulnerability is based on the assessment of sensitivity (x-axis ranging from S0 = not at all sensitive to the projected changes to S4 = extremely sensitive to the projected changes) and adaptive capacity (ability to respond to those changes ranging from AC0 = no ability to respond to AC4 = ability to respond to projected changes in a beneficial way).

PEOPLE: Windsor's residents have limited vulnerability to flooding; however, Communities of Concern are moderately vulnerable due to their sensitivity to secondary and tertiary flood impacts (e.g., transportation disruptions, water quality threats, or power outages). From a life safety standpoint, it is highly unlikely that any resident would be injured or killed as a result of fluvial (riverine) or pluvial (rainfall-induced) flood forces other than in attempting to drive through moving flood water that has accumulated at intersections and roadway segments with known flood risk. This results in a low sensitivity rating (S1) and a high adaptive capacity (AC4) of the general Windsor population. If flood waters were to result in contamination of Town water supplies, a boil water order may have a more severe impact on people who may not receive or understand boil water warnings, or whose health status puts them at greater risk if they are to accidentally ingest contaminated water. And finally, those whose health or safety require continuous delivery of one or more utility services (water, electricity, communications) or services (e.g., daily medical support) that might be temporarily impacted by flooding are more vulnerable than the general population. While the overall sensitivity of Communities of Concern remains the same as the general population (S1), the ability of these populations to adapt to changing flood conditions is much lower (AC1) than the general population.

BUILDINGS: Homes and critical facilities are moderately vulnerable to flooding. Most homes and critical facilities have a low sensitivity to flooding (S1) because they are constructed outside of the 100- and 500-year floodplain or are elevated above areas exposed to pluvial flooding (e.g., ponding, runoff). The vast majority of at-risk properties (homes and critical facilities) that have been identified as being exposed to a flood event of 1% annual likelihood (a 100-year flood) are unlikely to sustain inundation of a depth exceeding 12 inches, and almost no properties would experience greater than 18 inches of inundation.[105] Climate change will increase the number of exposed buildings over the next thirty years, but only by a small number. The most widespread impact will be street flooding leading to and in front of exposed buildings. Buildings inherently have a lower adaptive capacity to flooding (AC1 for critical facilities and AC2 for homes) rating due to their fixed nature.

INFRASTRUCTURE: Windsor's infrastructure is moderately vulnerable to flooding. Flooding has the potential to impact several networked transportation systems, including water, transportation, power, and communications, yet the sensitivity of these networks is generally low (S1). There are a small number of key infrastructure nodes, including schools and assisted living facilities as well. Of greatest concern is that contaminated flood waters will negatively impact Windsor's fresh water supply. Past flood events have impacted power infrastructure, leading to widespread yet short lived power interruptions. Transportation infrastructure is the most regularly impacted infrastructure system, but the impacts are generally limited in duration to the time required for drainage to occur, and with little to no long-term damaging effects. The schools and assisted living facilities are unlikely to sustain flooding within the facilities themselves, but access to and from these facilities, and primary utility services, may be interrupted. The Town has jurisdiction over local road infrastructure but less over other utility networks, and the ability of these systems to adapt to changing flood conditions are inherently low due to the permanence of the infrastructure, leading to a low adaptive capacity rating for transportation networks (AC2) and other infrastructure systems (AC1).

NATURAL SYSTEMS: Windsor's natural systems have limited vulnerability to flooding. Exposure to fluvial flooding within Windsor itself has remained largely consistent with the natural 100- and 500-year floodplains, while pluvial flooding has not increased in an appreciable way as to impact natural systems. The natural adaptive capacity of flood prone areas has typically limited the loss of grasses, plants, shrubs, and other protective vegetation, nor has there been a high incidence of erosion. The potential for contamination exists if a flood triggers the release of hazardous materials, but to date this has not been found to be a significant threat within Windsor.

ECONOMY: Windsor's economy has limited vulnerability to flooding. Direct financial costs associated with the flooding of public and private property and infrastructure in Windsor remains low on account of the availability of risk transfer mechanisms, and the low likelihood that transportation infrastructure is heavily damaged. Disruptions caused by flooding are relatively limited in duration, and do not tend to disrupt business operations or government services. Temporary roadway disruptions represent inconveniences, but the existence of viable alternatives (detours) mitigates larger economic costs associated with such disruptions.

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[105] Flood Factor (2021)

WINDSOR FLOOD EXPOSURE OVERVIEW

Flooding occurs when there is an overabundance of water on land (or which engulfs property) that is normally dry. A flood can result from very different conditions and causes, which include sustained or heavy rainfall, melting snow, obstruction of natural waterways (e.g., by beavers, ice, debris, or landslides), reduced absorptive capacity of land, rapid release of stored water, and others.

Major floods affecting large geographic areas are typically associated with large-scale weather systems that generate prolonged rainfall. However, flood events with significant impact can develop over very short periods of time as occurs following an intense thunderstorm or the failure of a dam, for example. There is much less opportunity for warning with flash floods, dam breaks, and other rapid onset flooding events that reach peak velocity within minutes, making these types of events much more likely to require rescue efforts or result in the loss of human or animal life. The complexity and multifaceted nature of impacts associated with flooding often make this hazard the most highly prioritized in at-risk communities. First and foremost, floodwaters can be highly destructive to anything they contact, whether that is the built environment, natural resources, or people.

Flooding remains the most frequent and economically damaging[106] natural hazard worldwide. This statistic is also true at the national level in the United States, where flood-related damages amount to a staggering $17 billion[107] per year on average. Flood exposure in the United States is primarily the result of an extensive stock of housing and other community infrastructure that has been constructed within the designated floodplain (the technical distinction for land that subject to a 1% annual chance of flooding, often referred to as the '100-year flood' even though several 100-year flood events can and often do occur in quick succession). The First Street Foundation, a nonprofit organization that uses a combination of Federal, academic, and other sources of flood risk assessment data, estimated in 2020 that at least 14.6 million US properties, including the homes of 41 million people,[108] are exposed to this threshold 1% annual risk from flooding.
A risk assessment conducted during the development of Sonoma County's Hazard Mitigation Plan found that flooding is the County's leading natural hazard threat (mirroring the national experience). However, as it applies more specifically to Windsor , flood risk has a *comparatively lower* associated risk on account of the town's climate, topography, and hydrology. This is largely due to the fact that the Town's flood exposure is relatively small in size, and a low number of buildings - including almost no components of critical infrastructure - lie within this area.

Windsor's flood risk is almost exclusively fluvial (relating to or produced by a river or stream), though a small risk posed by pluvial (relating to excess rain) flooding exists and is growing on account of climate change and development practices. Multiple areas in Windsor that are not indicated in the FEMA Flood Insurance Rate Map as being at risk from riverine flooding (typically annotated as zone AE) or sheet flooding / ponding (typically annotated as a zone AO or AH) do nonetheless experience shallow flooding, sheet flooding, and/or roadway flooding. The current Windsor Flood Damage, Flood Control, and Drainage Ordinance (Title IX, amended

[106] Meyers (2016)
[107] Duguid (2021)
[108] Varanasi (2021)

by Ordinance 2008-249) contains provisions that limit exacerbating construction practices within the Special Flood Hazard Area, but does not address the full extent of pluvial roadway flooding and ponding that has been reported in TWG meetings, through consultant interviews, and which is supported by external independent technical analysis (e.g., First Street Foundation's Flood Factor). Moreover, with plans to increase housing and commercial development in multiple locations outside the SFHA, regrading, paving, hardscaping, and other practices that increase the imperviousness of land, coupled with an increase in the prevalence of heavy precipitation events associated with climate change that are expected to occur during the next 30 years, pluvial flooding should be expected to increase without more comprehensive floodplain restrictions that apply to the whole community. A single interconnected system of creeks and tributaries drains all of the Town's floodwaters (*see Figure 36*), which merge at a point southwest of Windsor and just west of the Sonoma County Airport (*see Figure 37*).

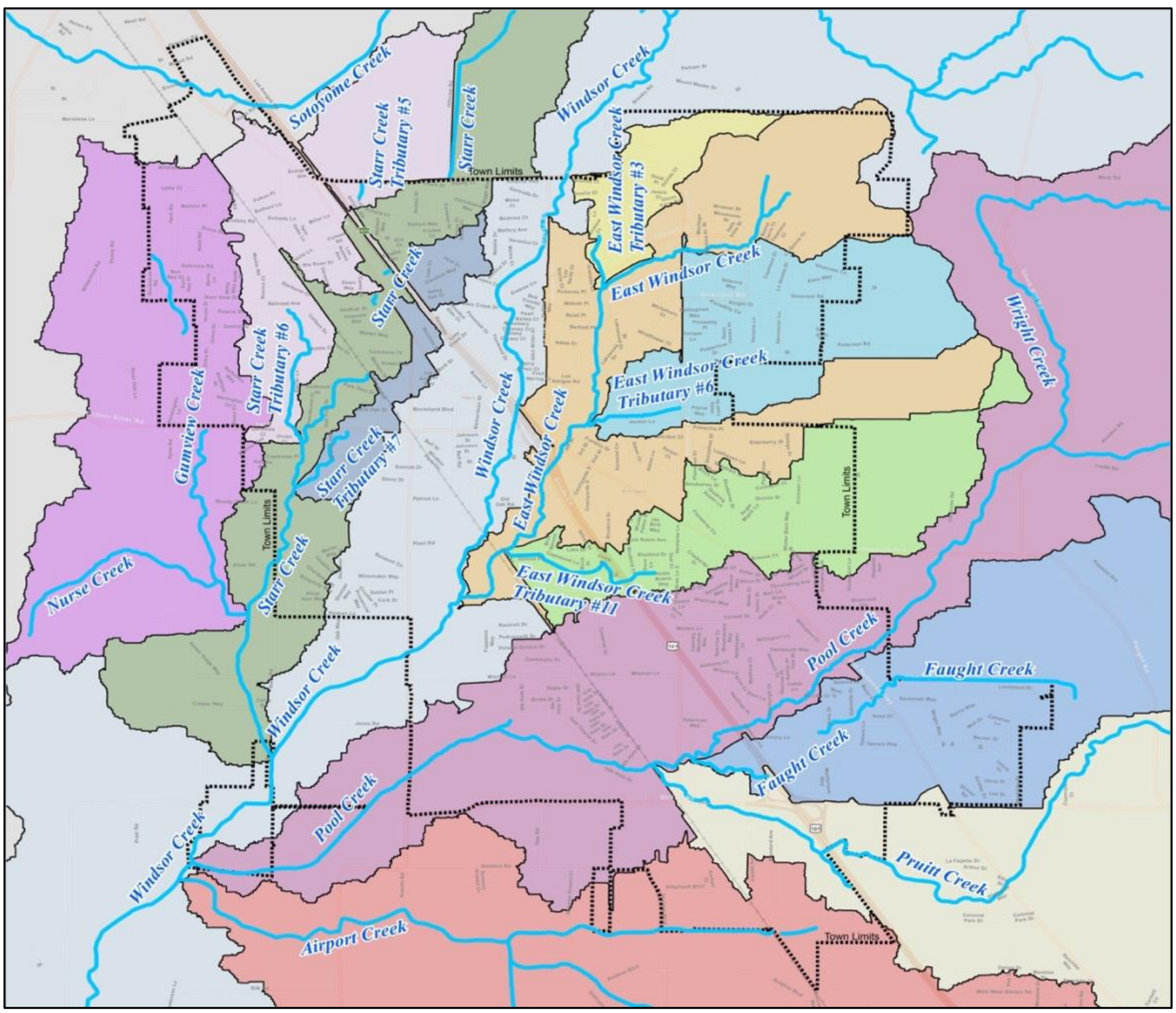

Figure 36. Map of watersheds across the region. (Source: Town of Windsor Storm Water Program, 2018)

The FEMA digital flood insurance rate maps (DFIRMS), which provide the official designation of flood risk in participating National Flood Insurance Program (NFIP) communities,[109] indicate that flood exposure in Windsor is largely confined to the land that is located within close proximity to five interconnected stream systems that transect the town. These include Windsor Creek, East Windsor Creek, Pool Creek, Pruitt Creek, and Starr Creek.

FEMA DFIRMs depict two levels of risk: 1) those that have a 1% (100-year) annual chance of flooding, for which the purchase of flood insurance is a requirement under Federal mortgage program provisions; and 2) those that have a 0.2% (500-year) risk of flooding, which would only be expected to occur in the most severe flood events. Figure 37 shows flood hazard zones, buildings, roads, and critical facilities both within those zones and throughout the Town.

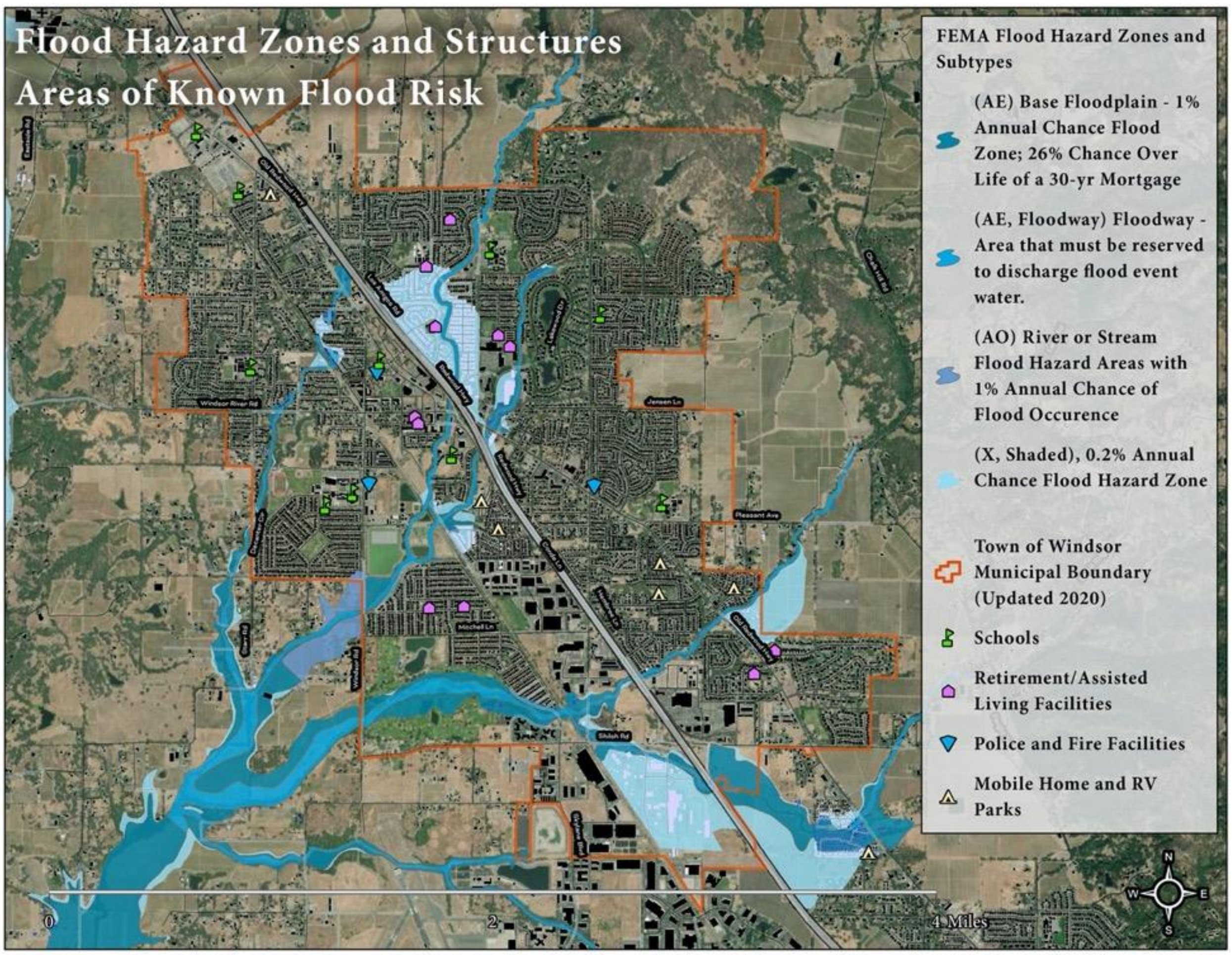

Figure 37. Map of flood exposure for the Town of Windsor. The main flooding exposure in Windsor as identified by FEMA. Generally confined to areas within and around existing creek beds, along with areas of low to moderate flood risk in the 0.2% annual chance floodplains in the vicinity of Old Redwood Hwy and Hwy 101 as well as south of Shiloh Rd near Hwy 101.

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109 Windsor is an NFIP Participating Community (https://www.fema.gov/cis/CA.pdf)

HISTORICAL EXPERIENCE WITH FLOOD HAZARDS

Flooding typically occurs in the region over a few particular months (December through February). That said, flooding can occur in Windsor at any time of year. Flooding has been observed most often during and after periods of heavy and/or sustained precipitation, especially when the Russian River is at or above flood stage and/or saturation excess overland flow is expected to exist.

Inundation experienced in Windsor has almost always presented as shallow in depth and has been confined to known risk areas as mapped on FEMA Digital Flood Insurance Rate Maps (DFIRMs). Inundation has also impacted the Windsor Golf Club, which is partially located within the floodway and flood zone of Pool Creek.

Past periods of widespread flooding in Sonoma County have resulted in significant physical damage to homes, businesses, and the environment. In Windsor, however, this has not been the case on account of the Town's geography and because of actions taken to limit or otherwise address development in the floodplain.

Dates of notable past flood events in Windsor include the following:

- December 17, 2005 to January 12, 2006 (multiple events, including one single precipitation event that resulted in almost 7 inches of rain and caused flooding in several areas in the south part of Windsor)[110]
- January 2010 (Power failure for over 4,500 Windsor residents; Windsor Golf Club flooded)[111]
- Fall/Winter 2012 (Starr and Mark West Station Roads)[112]
- December 15, 2016 (Starr and Mark West Station Roads)[113]
- January 6, 2016 (Starr and Mark West Station Roads)[114]
- January 9, 2017 (Russian River)[115]
- February 13, 2019 (Skylane Blvd., Windsor Road)[116]

REGIONAL/WATERSHED PERSPECTIVE (RUSSIAN RIVER, DAMS, ETC.)

The physical risk associated with flood hazards in Windsor is relatively low relative to other hazards. However, flooding has much greater significance at the regional level, and flood events that occur close to the town can and have had severe, and potentially unexpected secondary consequences for Windsor. On account of geography, flooding is more impactful to and generally more frequent in the towns to the north and south of Windsor as well as in the unincorporated areas that surround the town. For instance, nearby Guerneville, situated less than 20 miles downstream from where Windsor creek flows into the Russian River, has experienced 38 devastating flood events since 1940[117], or an average of one event every other year. A recent flood in that town, which occurred in February of 2019, inundated almost all of the town's land area. This resulted in the evacuation of nearly half of Guerneville's 4500 residents, and the damage to or destruction of over 2500 homes and businesses. To the north of Windsor,

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[110] Town of Windsor (2018a)
[111] Town of Windsor (2018a)
[112] Porter (2012)
[113] Johnson, J., & Mason, C. (2016)
[114] ThePressDemocrat (2016)
[115] Moore et al. (2017)
[116] Rossmann (2019)
[117] Rogers (2019)

Healdsburg is also situated on the Russian river, and as a result has a flood experience similar to Guerneville in its frequency (although much less of Healdsburg's land area is exposed to flooding than in Guerneville).

PLUVIAL FLOODING

Fluvial flooding is the dominant source of flood exposure and risk in Windsor, the result of expansion and contraction of drainage in the watershed's associated floodways. Pluvial flooding - which occurs away from these streams and is the result of excess rainfall or from patterns in precipitation runoff - poses increased risk for the Town. Ponding, as it is often called, is most often the result of rainwater draining from normally dry land at a rate that is lower than it accumulates. Ponding is increasing in Windsor on account of two factors: 1) increased development, namely that which results in the sealing of previously porous landscape (e.g., the paving of roads, parking lots, and driveways, construction of sidewalks, pouring of foundation slabs) which decreases the absorptive capacity of that land; and 2) a trend towards increased frequency and severity of heavy rainfall events. Ponding is further exacerbated after severe wildfires,[118] when extended drought hardens topsoil,[119] and when groundwater levels are very high on account of extended precipitation. Ponding is indicated in newer FEMA flood risk maps where it is affiliated with stream systems, but it still can occur away from such systems where large areas of runoff collect in low-lying land (and thereby affecting homes and other structures whose owners may not have known to take action to mitigate potential impacts).

The following maps display emergent flood risk and zones (dark blue circles with orange borders) where ponding occurs in or adjacent to floodways, as indicated on the most recent FEMA flood maps. They also indicate areas where ponding occurs outside of these floodways, as identified by the Technical Working Group members.

118 Nyman et al. (2014)
119 Jenkins et al. (2020)

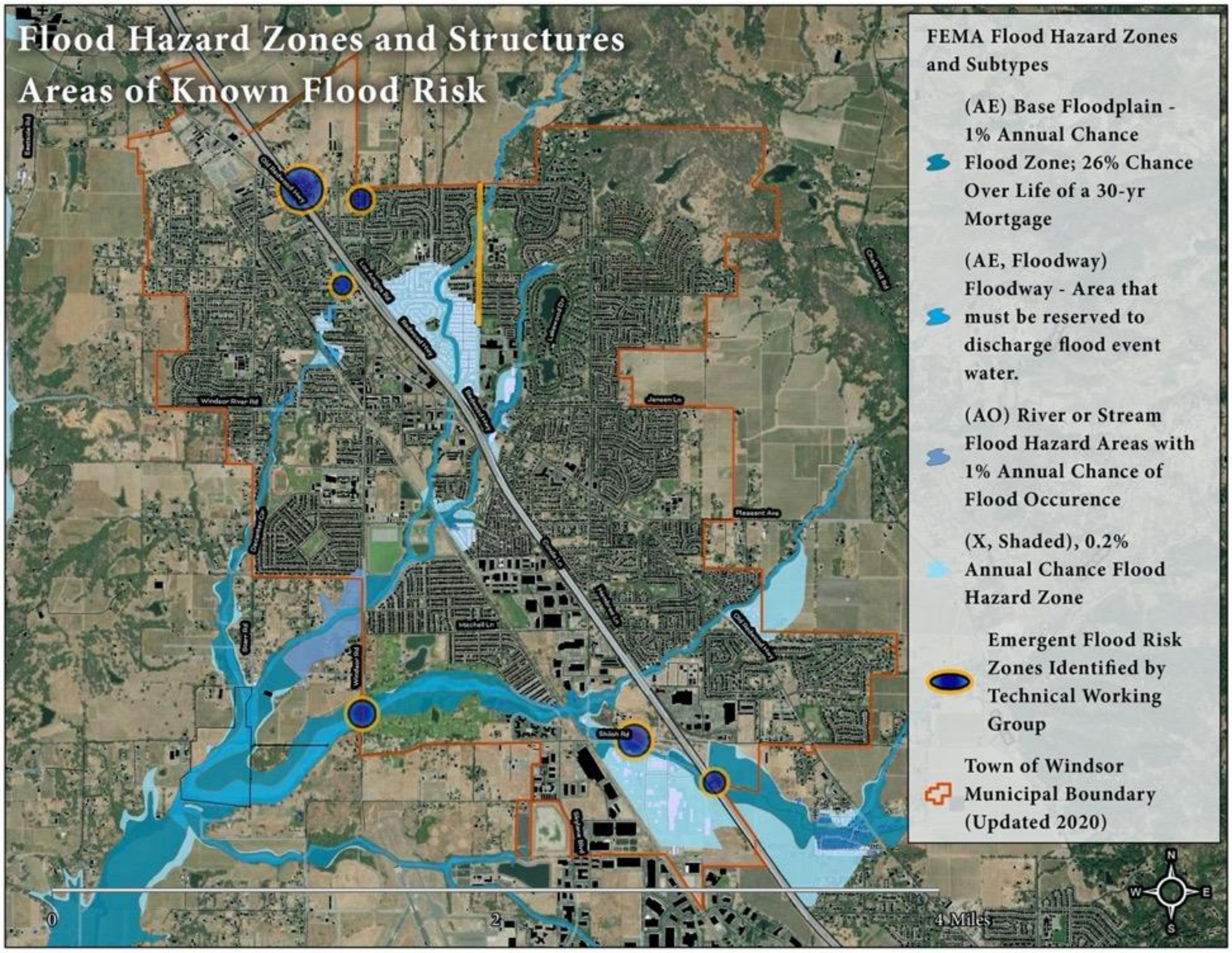

Figure 38. Map of flood hazard zones for the Town of Windsor. FEMA flood zones are show in light and dark blue. The Dark blue circles with orange borders show emergent flood risk areas (some in flood zones and some outside those zones where flooding is observed. (Source: Discussions with Technical Working Group members and FEMA, 2021)

Without interventions to address both the increase in prevalence of heavy rain events and development practices that reduce the absorptive capacity (infiltration) of land in and around Windsor, it is likely that the number of intersections and roadway segments impacted by ponding and flash flooding will increase over time. It is important to note that emergent problem areas may not necessarily occur in designated flood zones. The most likely locations are those areas where roadways are at natural depressions within watershed areas.

FLOOD EXPOSURE AND VULNERABILITY OUTLOOK

Stormwater management plans exist in Windsor and are helping to address the identified areas of concern, but flood exposure is nonetheless expected to increase in terms of both the geographic area affected and the frequency of events due to climate change. The greatest future threat exists for homes in the 1% and 0.2% areas of flood risk, and in areas of emergent flood risk outside of these areas, that lack adequate freeboard (elevation above the base flood elevation) to account for increases in predicted inundation depths. Ultimately, all neighborhoods will be exposed to flood risk as the intensity of rainfall events increase, as determined by stormwater management capabilities. And while this represents a very real source of secondary impacts from transportation and other infrastructure disruptions, whether or not structures are inundated will almost exclusively be dictated by the existence of sufficient freeboard.

From a frequency standpoint, little can be done to address global trends that point to more highly variable swings in precipitation (with some years marked by drought while others have much higher-than-normal total sustained rainfall) and more frequent heavy rainfall events (large volumes of rainfall experienced in single events), several options exist to limit how much runoff (non-absorbed water) exists and how that runoff is managed. As such, the best available option is one of minimizing physical vulnerability.

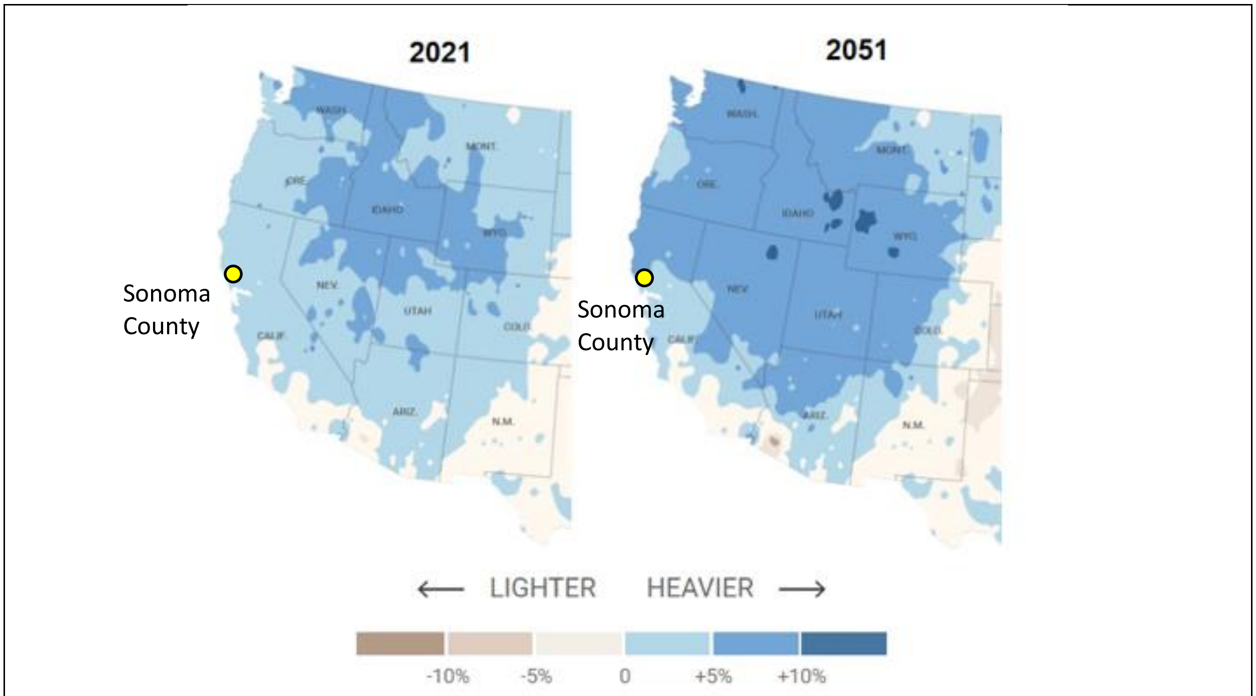

Figure 39. Map of precipitation projections for the Western United States through 2051. (Source: Floodfactor, 2021)

Given the comparatively small geographic area in Windsor that is classified as having a 1% or greater annual likelihood of flooding (as compared to Sonoma County as a whole), and the relatively small amount that inundation depths increase between the 100-year and 500-year flood zones (in most cases this is less than one foot of depth - see Sonoma County Flood Insurance Study 06097CV003E), the increase in exposure over time is nominal. In fact, the First Street Foundation study found that the number of structures exposed to flooding in a 1% likelihood flood event will increase by only 38 structures between 2021 and 2051, and the number of structures exposed to flooding in a 0.2% likelihood flood event will increase by only 40 structures (without intervention).

DAM-RELATED FLOOD EXPOSURE AND RISK

Flooding related to dam failure poses a risk to Windsor that is very different from that of pluvial or fluvial flooding that is more directly linked to climate change. There are a number of different reasons that a dam might fail. The most common cause of dam failure, overtopping (exceeding its holding capacity or being subject to wave action), is rare but increasing in likelihood on account of climate change and the potential for extreme precipitation events. Though less likely, a dam may also fail because of defects in construction or because of some other natural or technological hazard (such as an earthquake), including excessively high or low water levels.[120] Exposure to dam-related flooding poses an especially dangerous threat to Windsor residents and property because there may be little or no notice prior to occurrence of a dam failure, and because both the depth and the velocity of flood water may be very high. The implications of flooding due to dam failure are covered in more detail in the Windsor Local Hazard Mitigation Plan and are not addressed further in this analysis due to the unlikely event of a dam failure occurring due to climate changes. It is important, however, to mention that extreme precipitation events could exacerbate the risk of a dam failing in the event of a tectonic event or catastrophic structural failure.

FLOODING IMPACTS ON WATER QUALITY

Floodwater, regardless of the source or type, has the potential to pick up hazardous materials as it moves across land and makes contact with objects and features its path. Chemicals and contaminants are found on lawns, on farms, in storage tanks, in vehicles, in buildings, and elsewhere. Once in the flood water, these hazardous materials move with the water until deposited or carried into rivers, streams, lakes, ponds, or groundwater stores. Windsor's drinking water supply is almost exclusively locally sourced. It is also subject to limited treatment because it is considered groundwater (and therefore not subject to more stringent surface water treatment regulations). Disinfection is provided to address bio contaminants, but introduction of heavy metals to drinking water supplies,[121] as can occur in a large-scale release of hazardous materials into the Russian River or other sources of groundwater supply, would present a unique and major hazard to Windsor's drinking water supplies. The potential for contamination exists if a flood triggers the release of hazardous materials, but to date this has not been found to be a significant threat within Windsor.

CONSEQUENCES/IMPACTS

PEOPLE

The flood impacts to people in Windsor are presumed to be relatively low. There is the possibility that people may be injured or killed if they attempt to cross fast moving water in their automobiles either at inundated intersections or on road segments that are alongside or crossing the floodway. Only six inches of moving water is enough to knock a person over, while only two feet of water can carry away most automobiles.[122] Where dam-related flooding is concerned, impacts to the immediate health and safety of people is much higher. Just a few inches of moving floodwater crossing a roadway can carry away vehicles, their drivers, and any passengers, if an attempt is made to cross them.

It is unlikely that evacuations of Windsor residents would be necessary in the event of a flood event caused by fluvial or pluvial flooding. Emergency shelter may be required if a high number

[120] United States Bureau of Reclamation (2019)
[121] Town of Windsor (2011)
[122] NOAA (2021b)

of homes are damaged in a single incident, but this is also unlikely given almost all homes that are at risk of being inundated face less than 1.5 feet of inundation risk).[123] At this time, fluvial and pluvial flooding are not considered likely reasons for a need to issue evacuation orders. However, there are few areas, such as the Windsor Mobile Home Park (evacuation subzone C-08), located off of Conde Ln, that has 333 structures tucked behind 3 feasible exit routes and exposed to both 1% and 0.2% annual change in floodplains. If this area were flooded, the residents could require emergency assistance, support evacuation, or an emergency shelter.

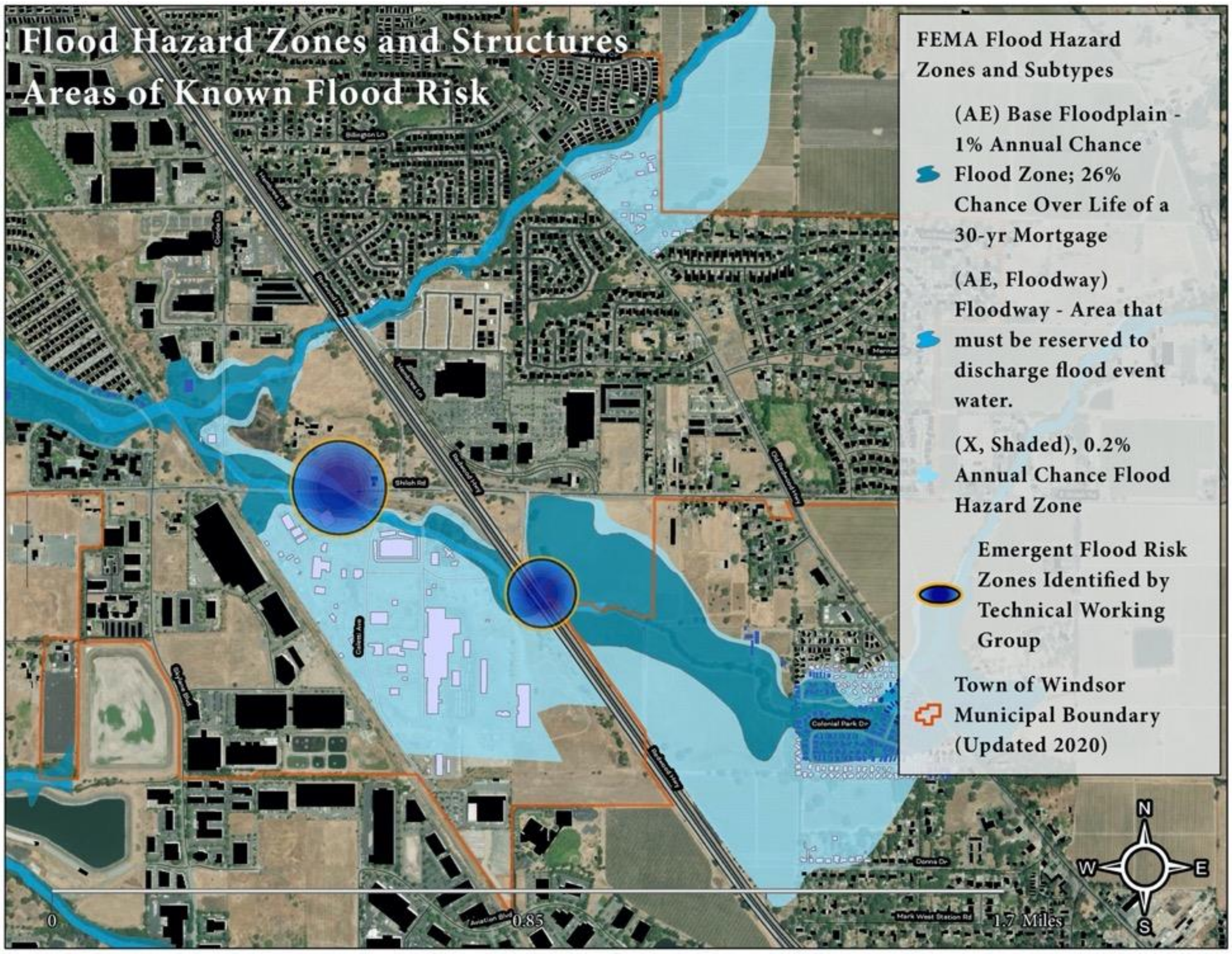

Figure 40. Map showing FEMA 1% and 0.2% annual chance of flood risk for the southeast part of the Town. The Windsor Mobile Home Park (bottom right corner) located off of Conde Ln, has 333 structures tucked behind 3 feasible entrance and exit locations and located almost entirely within the FEMA flood zones. Note emergent flood risk zones identified by the Technical Working Group (dark blue circles with orange borders).

The impact risk for people that is posed by a dam break, namely the Warm Springs Dam on Lake Sonoma, is significant even though the likelihood is small. While the probability of a dam failure is low, it is important to consider the magnitude of impacts to human safety if such an event does occur, and the fact that climate change effects increase the probability of a future dam failure

[123] Flood Factor (2021)

event. Sustained high rates of precipitation can lead to overtopping, which is associated with compromising the integrity of a dam in sudden and dramatic ways. In the unlikely event of a dam failure, especially of the Warm Springs Dam, an evacuation order would be likely.

Repetitive, chronic, or long-term flood exposure can have negative impacts to indoor air quality and mold exposure. People generally spend the majority of their time indoors, and poor indoor air quality can impact the health of Windsor residents, especially those with asthma, allergies, or other respiratory illnesses. Repetitive exposure or even a single exposure to flood waters can lead to increased humidity, mildew, and mold growth in building materials, all of which can have a negative impact on indoor air quality and overall health.

BUILDINGS

The Windsor LHMP identified no critical infrastructure that exists in the 1% likelihood flood zones, and only two (a utility facility and a community resource) together valued at just over $3 million in the 0.2% likelihood flood zone.. Risk to infrastructure from fluvial and pluvial flooding is very low. Even for the two critical facilities, both of which are assisted living facilities, known to be located in the 500 year exposure zones the expected flood depth for these facilities is nonetheless very low.

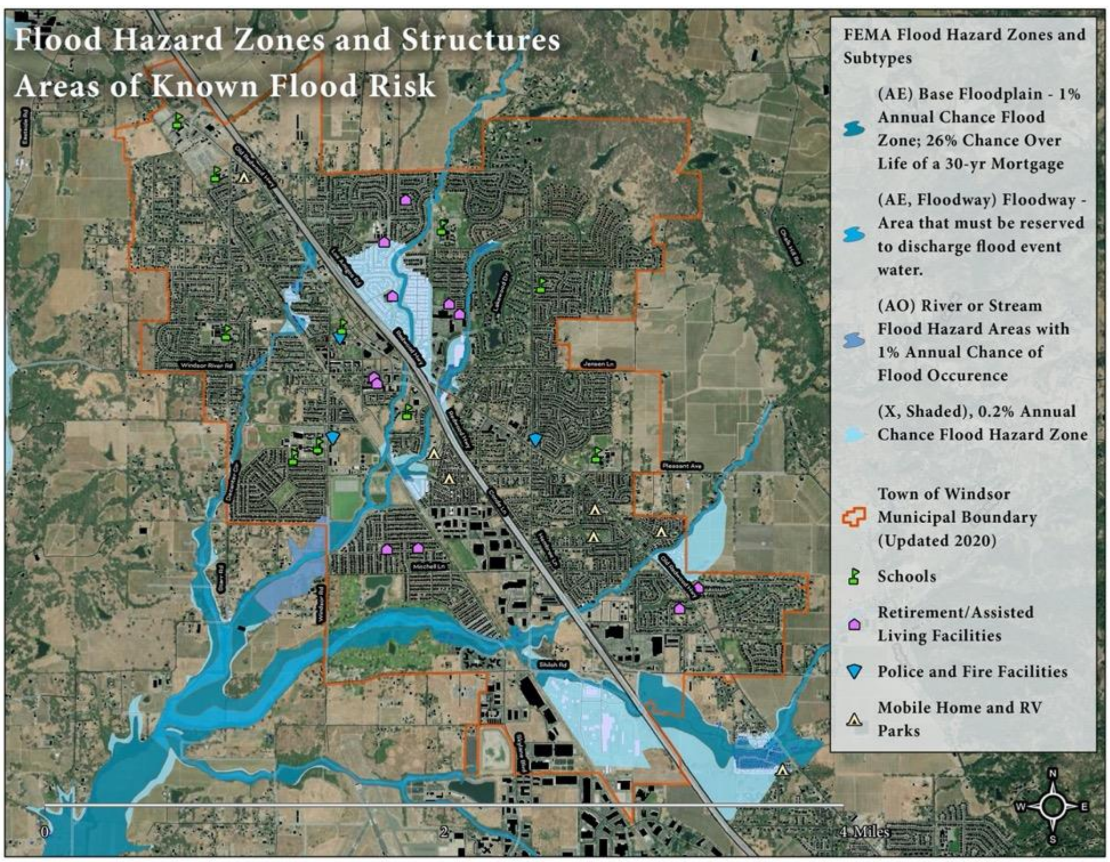

Figure 41. Map showing FEMA 1% and 0.2% annual chance of flood risk for the Town of Windsor. Note Buildings are show in black outlines throughout the Town. Critical facilities are show per the legend throughout Town. Only two critical facilities (both assisted living facilities) are located in the 0.2% annual flood risk zone.

Windsor's buildings have a generally low flood exposure. About 10% of Windsor properties (about 829) currently have some level of flood risk for a 500-year flood event (0.2% annual probability or greater).[124] This number is considerably lower than the United States average, which is approximately 25%. By levels of expected impact severity, the properties at risk in Windsor include:

- Minor: 47 (5.4%)
- Moderate: 207 (23.8%)
- Major: 357 (41%)
- Severe: 204 (23.4%)
- Extreme: 55 (6.3%)

Of these, 600 properties have at least a 1% annual risk of flooding, though only 93 would be expected to experience over 1.5 feet of inundation in a 1% (100-year) likelihood flood event.

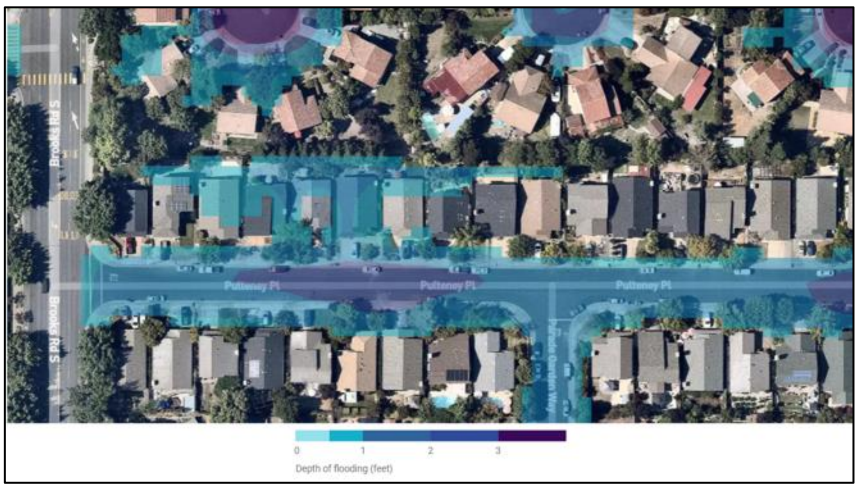

Figure 42. Example neighborhood level flood impacts in Windsor. Note that while properties may be shown in the flood areas, the exact finished floor elevations of the structures is not shown, so these individual homes and buildings may not be at direct risk of flooding. (Source: Floodfactor, 2021)

The financial impact of flooding on properties is high despite the relatively low flood exposure of properties in Windsor. Annualized flood costs associated with Windsor properties have been assessed to be approximately $267,200. This figure accounts for the fact that some years will be characterized by almost no flood-related impacts while in others there will be costs that far exceed this average. Floods are the most expensive hazard in the United States because of the great amount of damage that can be caused by even a small amount of flood water. In fact, one inch of standing water in a home can result in tens of thousands of dollars in damage (while a few feet will likely result in a total loss).[125] Interestingly, in Windsor almost all (95.4%) of the anticipated costs are likely to be incurred by 55 properties identified as having an 'extreme' level of risk.[126]

[124] First Street Foundation (2021)
[125] Jones (2021)
[126] Flood Factor (2021)

INFRASTRUCTURE

The most common impact of flooding in Windsor is disruption of roadways that transect the six major streams. The main flooding risks related to roadways and infrastructure are road blockages from debris, road erosion, bridge overtopping, and excess flooding from stormwater infrastructure along roads. The likelihood of direct impact from fluvial flooding, ponding, and flash flood events is almost completely limited to transportation infrastructure within the Town. Each of these impacts can potentially limit emergency services access to homes and services, such as hospitals. Furthermore, roads themselves can contribute to intensified flooding and run-off since they do not absorb water. The rescue of trapped motorists has been required in several past events as a result of attempts to cross deep and/or flowing water on roadways.

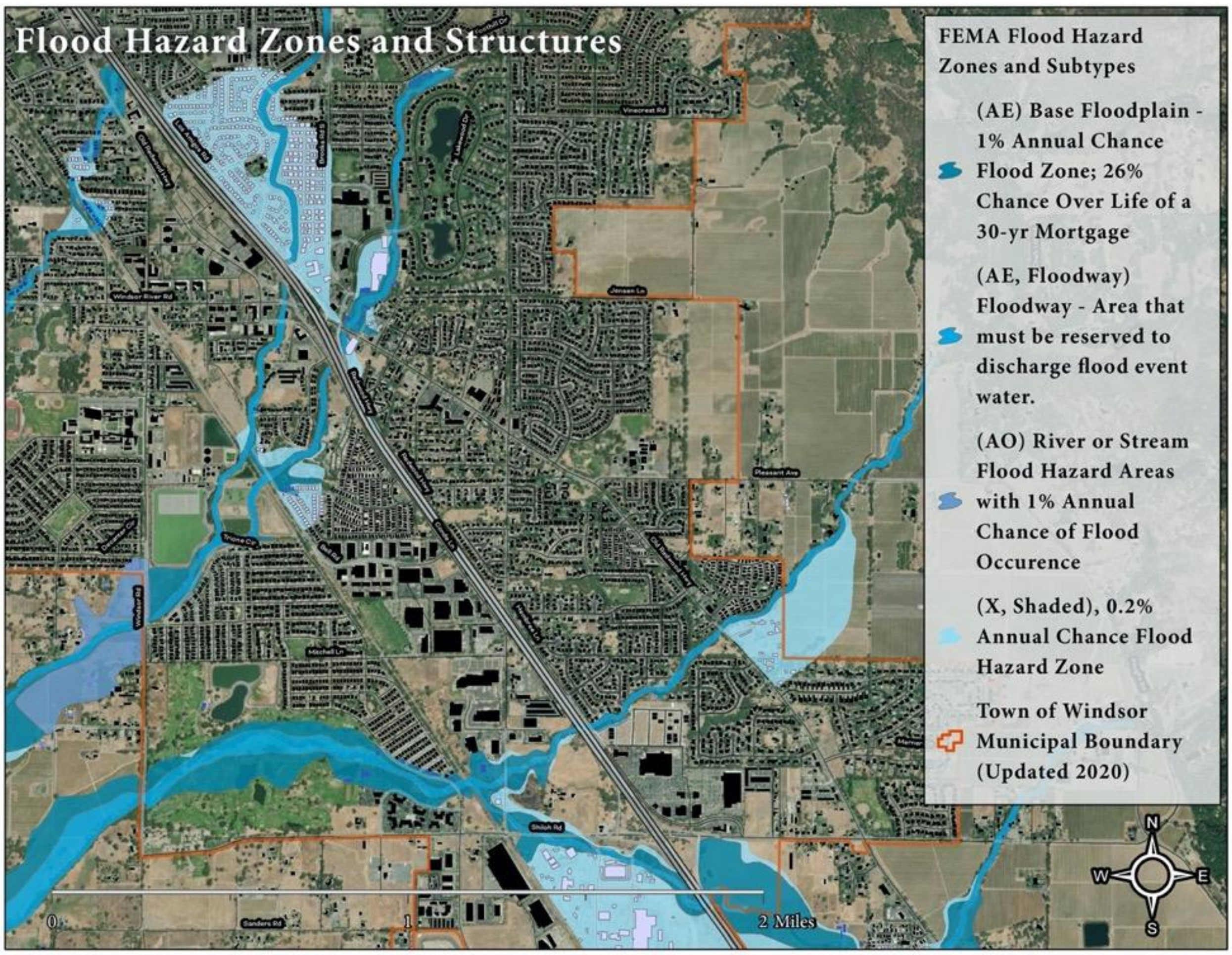

Figure 43. Map showing 1% and 0.2% annual chance of flood risk for the northern part of the Town. Impacts to infrastructure (primarily transportation) can be seen on key roadways and select intersections that are within those flood zones.

Flooding to the north and south of Windsor has, on a fairly frequent basis, resulted in disruption in transportation routes when key intersections that cross nearby floodways become overtopped, as often occurs along heavily trafficked Mark West Station Road. Similar frequent flooding occurs on Old Redwood Highway to the north of town between Windsor and Healdsburg. Even

Highway 101, the main thoroughfare to and from town, has experienced intermittent flooding[127] that has closed all lanes in at least one direction, as occurred in 2014 when all northbound lanes were closed near the Arata Lane off ramp. Windsor's electrical infrastructure is similarly vulnerable to regional impacts. In a January 2010 regional flood event, over 4500 Windsor residents lost electricity.

Table 4. Select critical intersections located in the FEMA's 1% annual chance of occurrence flood layer. These intersections provide ingress/egress routes for a large number of structures (and therefore people) and provide critical connections to the broader transportation network for these residents, both to allow residents to leave in the event of an emergency evacuation and to allow first responders and firefighters into these neighborhoods during an extreme weather event. All intersections in this table serve a minimum of 50 structures. Simply because the intersection is flooded does not necessarily imply the structures (homes and buildings) within the associated trafficsheds will be flooded.

Key Intersections for Trafficshed	# of Structures	# of Residential Zoned Structures	# of Exit Nodes	Structure : Exit Ratio
Lakewood Dr	185	185	1	185
Glen Miller Way and Brooks Rd	124	124	1	124
Winemaker/Windsor, Reiman/Oak, H/Starr	491	491	4	122.75
Broadleaf/Circle/Basswood/Conde (Windsor MHP)	333	333	3	111
Elabree/Arata	195	191	2	97.5
Old Oak/Armondo Renzulo/Conde Ln (Windsor Creek Elementary)	90	77	1	90
Lazy Creek/Foxwood/Los Amigos	153	149	2	76.5
Jessica/Brooks; Arata/Camelot; Amigos/Cordelia	755	742	10	75.5
Old Redwood/Shamrock Cir (Shamrock MHP)	141	132	2	70.5
8th, 9th, 10th Hole and Mitchell Ln	274	274	4	68.5
Ventana/RioCamino/Macero and Foothill Dr	132	132	2	66
Pulteney Pl/Bond Pl and Brooks Rd S	128	128	2	64
Billington/Northampton and Hembree Ln	315	315	5	63
Jones Rd and Windsor Rd	53	44	1	53
Rio Ruso/Dawn and Old Redwood	153	153	3	51

Contamination of flood waters could pose a risk in the areas contained within the flood exposure zone of the floodway(s) affected. For instance, the potential release of hazardous materials into Russian River as a result of heavy upstream inundation poses a significant threat to five of the town's potable water system's six active wells[128] that are situated along the river's banks to the west of town. Beyond Windsor itself, there is the indirect risk of drinking water contamination if the Russian River is affected by the release of hazardous materials, especially to the west of Windsor where municipal wells are located.

[127] Schena (2014)
[128] Town of Windsor, Department of Public Works website: https://www.townofwindsor.com/225/Water

Increased precipitation or heavy precipitation events can decrease the response timing and effectiveness of emergency response throughout the Town and surrounding areas. While most of the Town's critical facilities are not in current or projected flood risk areas, heavy precipitation events and even temporary road closures or inundation of certain intersections can impact the amount of time needed before emergency responders are able to arrive on site to attend to residents' needs (even if the emergency is not directly related to flood hazards, such as a medical emergency). Every minute counts when emergency services are requested, and extended service time can increase the risk of mortality and harm in health and safety situations.

Moving flood water can cause significant erosion to land, undermining buildings and bridges, eroding riverbanks, and tearing out trees. Although floods do not currently have erosive effects on land and property, changes to stormwater quantities and patterns of drainage can affect the manner in which they cause damages in future flood events. In addition to posing an increased life-safety risk to those who find their way into the path of such water, floods are highly disruptive to the functioning of society by destroying roads and bridges, knocking out power, water, and gas transmission systems, and leading to the closure of buildings, housing, businesses, and organizations, among other impacts.

Increased ponding will affect Windsor's infrastructure and housing stock in several ways. Water that ponds regularly creates-increasingly deeper depression of the land, in turn further increasing the severity of ponding in future events. On roads, ponding results in uneven surfaces and cracking that increase the frequency of repairs. On private property, ponding often requires remediation that is not covered by insurance policies, and if next to a home can cause dampness and mold. Windsor residents have reported ponding in several neighborhoods and subdivisions, in some cases reaching levels that resulted in water entering garages or the first floor of the home. Ponding ultimately results in both public and individual burdens in terms of the associated remediation costs. The Town's Storm Drain Master Plan includes proposed storm drain capital improvement projects to help address existing flooding problems.

NATURAL SYSTEMS

Contamination of public and private land can occur when hazardous materials are released into flood water. Just as contaminants picked up by or deposited into flood waters threaten freshwater resources, they also pose a contamination risk to any land that such waters flow over or are absorbed into. Raw sewage, heavy metals, pesticides, and other chemicals and biological contaminants can impact the capacity of impacted land to support plant or animal life and can decrease the value of private property. Remediation costs associated with the removal of contaminants from land can be very expensive and may not be covered by standard insurance policies.

ECONOMY

During flood events, temporary disruption may occur for local businesses and commercial areas. Although widespread economic impacts are unlikely, individual businesses or organizations may be severely impacted if their location is heavily affected. The more likely flood events in Windsor have impacts that will cause temporary interruption to business activity, depending on where the flooding occurs and the extent to which individual businesses and structures are affected. More significant flooding can have longer-lasting impacts to local businesses and commercial areas.

Floods can lead to the loss of agricultural and farmlands as well as crops and livestock. While the majority of agricultural lands and farms are located outside of the Town of Windsor, impacts to these economic assets can have indirect impacts on the residents and lead to a temporary (or more permanent in severe situations) decline in tourism and visitor activity in the Town and surrounding area.

VULNERABILITY SUMMARY

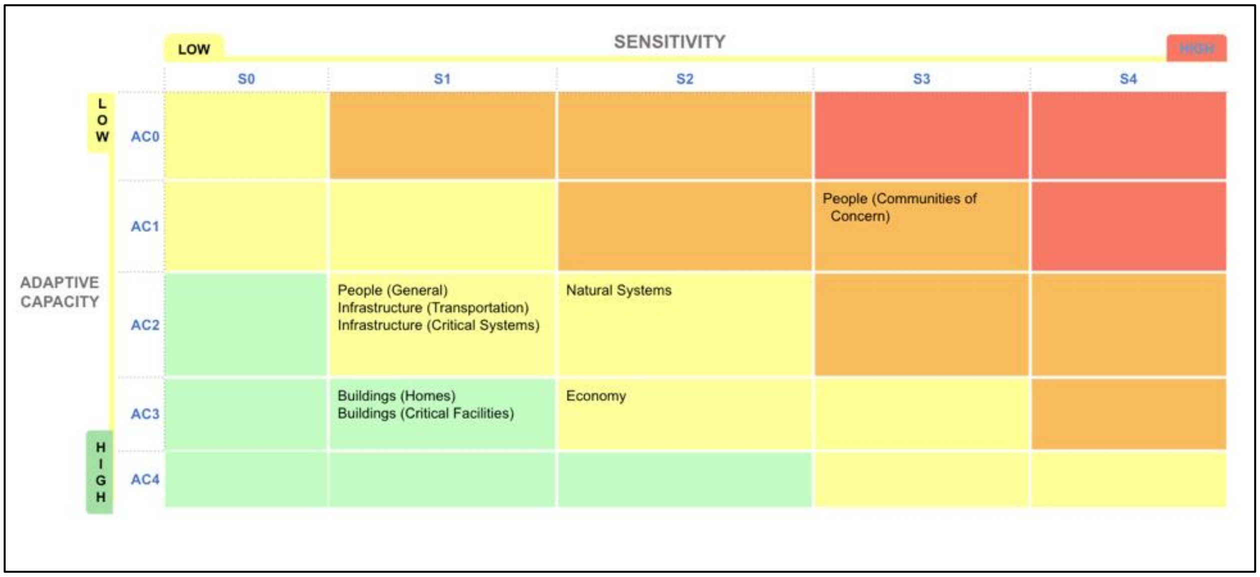

Figure 44. Relative vulnerability assessment of extreme heat for the Town of Windsor. Vulnerability is shown by the different colors of the matrix (Red = Extreme Vulnerability; Orange = High Vulnerability, Yellow = Medium Vulnerability; and Green = Low Vulnerability). Given the climate hazards, relative vulnerability is based on the assessment of sensitivity (x-axis ranging from S0 = not at all sensitive to the projected changes to S4 = extremely sensitive to the projected changes) and adaptive capacity (ability to respond to those changes ranging from AC0 = no ability to respond to AC4 = ability to respond to projected changes in a beneficial way).

PEOPLE: Communities of Concern within Windsor are highly vulnerable to extreme heat, and the general population is moderately vulnerable. Of all the categories assessed, people are the most vulnerable of Windsor's assets to extreme heat events. While the general exposure of all Windsor residents to extreme heat will be similar, different populations - particularly the elderly, children, those with pre-existing health conditions, and outdoor workers - are more sensitive (S3) to the increased number, intensity, and duration of extreme heat events as well as the decreased air quality due to the increase in ground-level ozone. Windsor is located in a relatively cool climate within California, so residents have less experience with extended periods of extreme heat; therefore, residents may not be as knowledgeable about the impacts of extreme heat or ways to adjust their daily activities to avoid heat-related health impacts (Communities of Concern AC1 - general residents AC2).

BUILDINGS: Homes and critical facilities have limited vulnerability to extreme heat. Extended exposure of the built infrastructure to extreme heat can lead to potential warping of certain materials, but generally, buildings are not very sensitive (S1) to increased heat exposure and can handle the projected increase in temperature for the region well (AC3) with only minor issues.

INFRASTRUCTURE: Infrastructure is moderately vulnerable to extreme heat, mainly due to the increased demand on utility systems during heat waves. Most infrastructure systems for the Town have limited sensitivities (S1) to extreme heat events. There are some vulnerabilities - for example during extreme heat events, there is an associated increased energy demand to cool homes and buildings. The heat itself can decrease the efficiency of the power distribution systems, and when paired with increased demand, extreme heat events can lead to more frequent brown or blackouts in the electric grid if proper measures are not in place. Generally, infrastructure systems have a moderate amount of adaptive capacity (AC2). Similar to certain building materials, rail and road infrastructure may warp under certain high heat exposure conditions, which can result in major or minor impacts to the multi-modal transportation network.

NATURAL SYSTEMS: Natural systems are moderately vulnerable to extreme heat. Increased temperatures and frequency of extreme heat days and events leads to increased rates of evaporation and loss of moisture in soils and vegetation. In an area that does not have the historical exposure to such heat, the natural systems are somewhat sensitive (S2) and less able to adapt (AC2) to changes in conditions, especially towards the end of the century as extreme heat events become longer and more pervasive.

ECONOMY: The economy is moderately vulnerable to extreme heat, mainly due to the importance of outdoor recreation and winery tourism for the Town of Windsor. Agricultural crops, such as grapes, are well adapted to the climate of this area of Sonoma County and are sensitive to temperature extremes. While the temperatures may not influence the desire to travel to Windsor for certain retail or economic purposes, the impacts to the water recreation and wineries make the economy somewhat sensitive (S2) to extreme heat but more able to adapt (AC3).

EXTREME HEAT EXPOSURE FOR THE TOWN

Excessively warm temperatures and extreme heat rank as one of the deadliest natural hazards nationwide, yet heat-related illnesses and deaths can be largely prevented.[129] The effects that extreme heat events have on people are determined and characterized by a “heat index”, which is a combination of temperature and humidity, and the threshold for these events can be different based on the location. The threshold for an extreme heat event for a particular location is generally defined as falling within the top 2% of historical temperatures for the location or region of interest.

In the State of California, the National Weather Service generally issues an Excessive Heat Warning/Advisory for any area of the state when a heat wave is expected to exceed a heat index of 105 degrees Fahrenheit or greater for two or more consecutive days (the temperature threshold is different for the various regions throughout California). These criteria and thresholds are not standardized, and different local forecasting offices can use different criteria for these heat warnings. It is generally recommended that particular areas use the relative temperature extremes for the area of concern to drive these advisory recommendations.[130] This is because people living in areas that are generally cooler are at risk of heat-related illness at cooler temperatures than

[129] California Climate Action Team (2013)
[130] California Climate Action Team (2013)

people who are more acclimatized to heat and who are likely to have more access to air conditioning and cooling systems. For example, what feels like an extreme heat event for people in the central valley or the Inland Empire in southern California would be at a higher temperature than something that feels like an extreme heat event for people living in San Francisco.

For the purpose of this assessment, historically observed and projected extreme heat days for Windsor are defined by Cal-Adapt and are based on an average estimate for Sonoma County. An extreme heat day is above the 98th percentile of the maximum temperature for Sonoma County using data from 1961-1990 for the May-October warm season.[131] The threshold temperature for an extreme heat day is 93.9 degrees Fahrenheit, which has been surpassed on average 4 days per year over the 30-year period. By mid-century, Windsor could experience up to 12 extreme heat days/year and 23 days/year by the late century under a high emissions scenario (RCP 8.5). For areas that are not accustomed to prolonged exposure to extreme heat, this nearly five-fold (475%) increase in extreme heat days can pose potentially serious issues for the community, especially more sensitive populations, and other systems in the Town and surrounding areas. Not only is the average annual total number of extreme heat days projected to increase for the Town, but the frequency of heat waves, defined by Cal-Adapt as at least 4 consecutive days of extreme heat, and the maximum duration, or the potential maximum number of days in a heat wave, are both projected to increase. Sonoma County has not observed a heat wave lasting at least 4 days between 1961-1990 (the average heat wave lasting about 2.3 days) but is projected to incur up to four of these events per year by the end of the century under RCP 8.5. In addition, the duration of a heat wave could increase to up to 7.7 consecutive days of extreme heat by the end of the century.

The number of extreme heat days (over 93.9°F) a year are projected to triple by the middle of the century.

Windsor is no stranger to hot days or heat waves. On the 14th of August 2020, high temperatures in Windsor were 108 degrees Fahrenheit as part of a regional heat wave. Soaring demand for electricity led to rolling outages as PG&E worked to maintain the integrity of the electrical grid.[132] Temperatures stayed high for weeks with high temperatures in Windsor hitting 114 degrees Fahrenheit on September 6th. Continued strain on the electrical system along with high winds caused a "red flag warning" with high risk of wildfires due to the high temperatures, high winds, and low humidity.[133] PG&E ended up conducting a Public Safety Power Shutoff event from September 7-9, 2020, that affected approximately 40,000 people in Sonoma County, primarily to the East of Windsor, but ultimately did not affect the Town directly. Power shut off events typically come with watches and warnings but can be detrimental to those who rely on power supplies for durable medical equipment, have limited mobility, and lose access to air conditioning during those events.

Like many other communities across California and the rest of the country, Windsor has a designated cooling center in the community where residents, particularly senior citizens and

[131] Cal-Adapt (2018)
[132] Kovner, G., & Chavez, N. (2020)
[133] The Press Democrat (2020)

those without adequate air conditioning in their homes, can go during extreme heat events. The senior center is currently designated as a cooling center, and the community center, while not officially designated a cooling center, is considered a “charging center” in the event of extreme weather, PSPS events, or blackouts. A charging center is designed to support residents in meeting basic needs like charging cell phones and/or laptops, accessing fans for cooling, and obtaining additional critical information. The Town of Windsor has been more conservative than neighboring Santa Rosa on the number of times per year that the cooling centers have been opened, opening them in the past only a few days per year. The decision to open the cooling center and the environmental criteria and thresholds around when these decisions will occur is ultimately at the discretion of the Town Manager. There is not currently a temperature threshold or heat index that, when met, would necessitate the opening of a community cooling center.

CONSEQUENCES/IMPACTS

PEOPLE

While all residents are sensitive to prolonged heat exposure, Communities of Concern (older adults, children, outdoor workers, socially isolated, economically disadvantaged) have a higher risk of health complications, becoming seriously ill, or dying due to extreme heat. Impacts of extreme heat are some of the most understood and preventable impacts of climate change on human health. Rising temperatures will lead to more frequent and more extreme heat waves in the region. These events, in turn, can affect the health and wellness of Windsor residents, visitors, and workers. A heat index of only 80 degrees Fahrenheit can cause fatigue with prolonged exposure or physical exertion, and even higher temperatures can lead to more serious conditions such as heat cramps, heat exhaustion, and heatstroke. If left untreated, heatstroke can lead to damage or failure of internal organs or even death.[134] While everyone is vulnerable to extreme heat, certain populations are more vulnerable to extreme heat, such as the elderly, the very young, low- to no-income residents, those that work outdoors, and individuals with pre-existing health conditions.[135] High temperatures can worsen chronic conditions such as cardiovascular disease or diabetes related conditions and lead to increases in hospital admissions for cardiovascular, kidney, and respiratory disorders.[136]

Another way to look at consequences of extreme heat events to people in the Town is to look at what the State of California calls Heat Health Events. These are determined to be heat events that lead to adverse health impacts.[137] Generally, Windsor has not been subject to many of these events; historical averages range from 0.1 events a year on average for the general population in the Highway 101 corridor to 0.7 events a year in the south side of Town.[138] The number of these heat health events is projected to increase (particularly under the higher change, RCP 8.5 scenario) to between 2.9 and 3.9 events a year for the Highway 101 corridor and southern portions of the Town (respectively) by the middle of the century and between about 7 and 5 events a year for the 101 corridor and southern portions of the town (respectively) by the end of the century.

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[134] Sarofim et al. (2016)
[135] Kinney et al. (2008)
[136] Kinney et al. (2008)
[137] California Heat Assessment Tool (2021)
[138] California Heat Assessment Tool (2021)

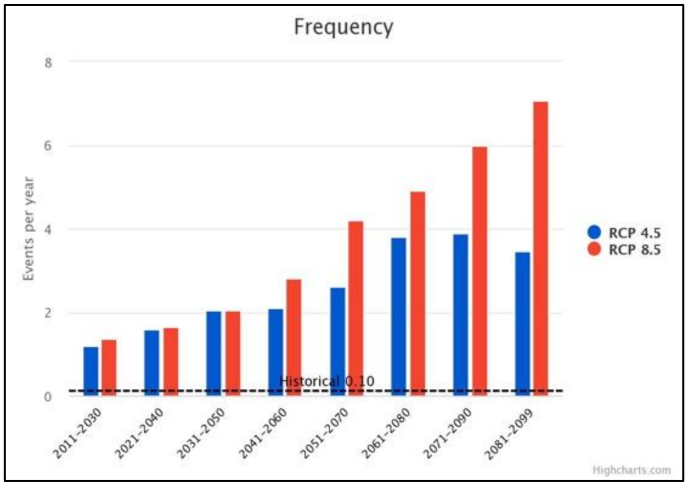

Figure 45. Heat health events for central Windsor around Highway 101. Projected number of heat health events for the 101 corridor tract (Census Tract: 6097153808) in Windsor according to the California Heat Assessment Tool (www.cal-heat.org) averaged by climate period. Historical average for the general population, RCP 8.5, and the 95% heat threshold event is shown on the dotted line. Other projections are shown for the different climate scenarios.

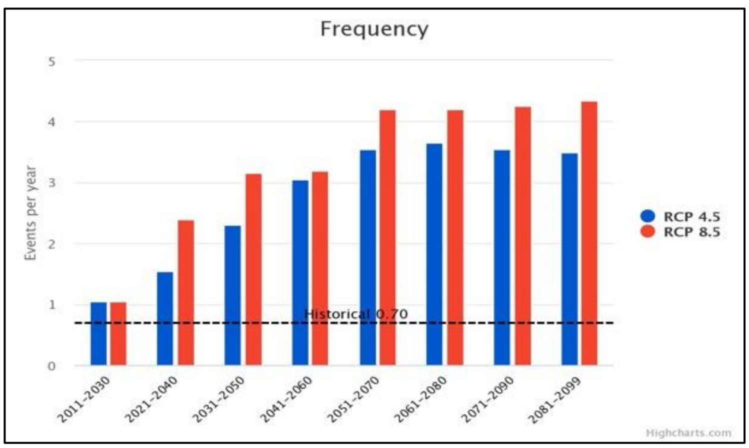

Figure 46. Heat health events for the southern part of Windsor. Projected number of heat health events for Southern Windsor (Census Tract: 6097152702) according to the California Heat Assessment Tool (www.cal-heat.org) averaged by climate period. Historical average for the general population, RCP 8.5, and the 95% heat threshold event is shown on the dotted line. Other projections are shown for the different climate scenarios.

How extreme heat events, or heat waves, affect the Town and its residents will depend significantly on the characteristics of individual neighborhoods as there will be local variations in the urban heat island effect and on the individuals themselves and their differential sensitivity to these higher temperatures. Populations more vulnerable to these impacts are the elderly, the very young, outdoor workers, and those with chronic diseases.[139] Older adults, particularly those who have preexisting diseases or are taking medications that affect thermoregulation are at

[139] USGCRP (2016)

greater risk of mortality or morbidity associated with these events. Children can spend more time outdoors, have higher metabolic rates and can see complications related to dehydration or heat stress.

Race, ethnicity, and socioeconomic status can also affect vulnerability to extreme heat events. Those community members with lower socioeconomic status and minority populations can be more sensitive to extreme heat events. This is not necessarily due to genetic differences, but to other multi-dimensional factors such as historical discrimination, access to air conditioning, access to health care, lack of tree cover or shade and more intense urban heat island effects in the neighborhoods where these residents live.[140] Poverty is a key risk factor that can exacerbate the effects of extreme heat on low-income individuals. With future financial resources, these community members will be less able to prepare for, respond to, and recover from extreme heat and other extreme weather events.[141]

The impact of extreme heat on mental health becomes evident with increased incidence of disease and death, aggressive behavior, violence, and suicide. There is also evidence of increased hospital and emergency room admissions for those with preexisting mental health and psychiatric conditions. Individuals with mental illness are more sensitive to increases in extreme heat and higher risk for poor physical and mental health due to these events. Extreme heat events are linked to impaired cognitive function, increased rates of insomnia (which can both impair cognitive function and lead to more depressed moods), and increased rates of violence and suicide.[142] Overall, the increased stress of extreme weather events can more dramatically impact sensitive populations.

Communities in cooler areas of California may be at greater risk of heat-related illness. This is due to multiple factors: 1) individuals are less acclimatized to heat; 2) people are not as familiar with behaviors or changes in their daily activities and routines that can reduce their exposure or physiologic stress; and 3) the built environment is not properly equipped to handle warmer conditions or the prolonged exposure to such high temperatures (e.g., homes, businesses, public places may not have adequate air conditioning). In addition, communities that do not have the historical exposure to such high temperatures may not be aware of the risks associated with increased temperatures and prolonged exposure and may not have plans or the existing capacity to handle an increase in emergency room visits, demand for power for indoor air conditioning, or need for cooling centers.

Air quality is negatively impacted by rising average temperatures, especially during extreme heat events. Higher temperatures lead to the degradation of air quality by favoring the formation of ground-level ozone and other air pollutants that form from chemical reactions with pollutants emitted from motor vehicles, power plants, and other emissions sources.[143] Reduced or poor air quality can greatly affect the health of many sensitive populations, with a disproportionate burden on elderly, children, and those with chronic underlying disease. As temperatures increase and extreme heat events become more frequent and pervasive, the demand on power generation will also increase, perpetuating the decline in air quality during these times.

[140] USGCRP (2016)
[141] USGCRP (2016); Ackerly et al. (2018)
[142] USGCRP (2016)
[143] California Climate Action Team (2013)

This can further contribute to the degradation of air quality and adversely affect the health of individuals during extreme heat events.

An increase in extreme heat days and increased frequency and duration of heat waves causes an increased demand for energy for cooling homes and buildings, which can have differential cost burdens to residents. As temperatures warm, there will be an increased demand for air conditioning in homes. This means that individuals living in homes already equipped with air conditioning units will likely incur additional costs to cool their homes for longer periods of time and more frequently than before. There are also likely homes that are not equipped with proper air conditioning that will likely need to be retrofitted to accommodate the increasing temperatures. These additional energy costs can disproportionately affect financially burdened populations within Windsor, putting them at a greater physical risk (if they are financially unable to pay for adequate cooling methods) or mental health risk (due to additional stress of the increased financial burden).

BUILDINGS

Extreme heat can physically damage buildings, homes, and other critical facilities. Extreme heat generally does not cause extensive damage to buildings; however, extended exposure to high temperatures can cause certain materials to warp. Attics in homes not built to withstand high temperatures, especially higher humidity, may trap the heat and humidity causing a more rapid deterioration of roof shingles and materials. These same high temperatures can also heat up shingles and cause them to expand and warp, ultimately leading to cracks that can cause roof leaks. Soil around building foundations can become so dry under extreme temperatures that it could cause cracking. The temperature ratings for different building materials should be known and can be determined for different residential and commercial structures.

INFRASTRUCTURE

Road and railroad materials can expand under high temperatures, causing roads to buckle and railroad tracks to warp. Thermal expansion can occur in asphalt and concrete roads under high heat conditions. Road buckling can be hard to predict and difficult to prepare for. Some tracks, bridges, and ramps are built with expansion joints that are designed to accommodate a certain amount of heat-induced change. In addition, it may be difficult for road maintenance and repair to occur if temperatures are hot enough to reduce the amount of time road maintenance and construction crews can work outdoors.

High temperatures can lead to power shortages and increases in the frequency of brownouts and blackouts. The effectiveness of electrical infrastructure is reduced under high temperature conditions. Additionally, demand on electrical systems drastically increases during these same periods due to increased air-conditioning needs for homes and buildings; this combination of factors can put strain on the electric grid and lead to blackouts if improperly managed.[144] These potential failures in the energy infrastructure, even if they are temporary, can put the health and safety of residents, visitors, and workers, at risk.

[144] Sonoma County RCPA (2014); Town of Windsor (2018a)

Power failure and the failure of critical transportation infrastructure during extreme heat events such as traffic signals and traffic operation failures can impact the transportation network. The threat of extreme heat events is also compounded by greater risk of wildfire during the event, wherein the loss of traffic signal operations would negatively impact evacuation efforts. Town residents and roadway users without access to vehicles are also highly at risk during extreme heat events. Many Windsor residents must use forms of active transportation to commute to work, an activity that may be a health risk in extreme heat events.

NATURAL SYSTEMS

An increase in prolonged extreme heat events contributes to drought conditions and impacts soil moisture as well as surface and groundwater storage and supply affecting plants and animals in the region. Increased temperatures lead to increased rates of evapotranspiration in vegetation and reduce the overall soil moisture and permeability in the soils. Extreme heat events contribute to and can exacerbate drought conditions, which are described in more detail in the context of drought. High heat events can damage trees, other plants, and animals in the region

ECONOMY

Extreme heat can damage or destroy agricultural crops. Extended periods of high temperatures can severely damage agricultural crops, especially when these periods of high temperatures are accompanied by reduced precipitation and drought conditions.

Extreme heat events can negatively impact tourism and businesses serving those visitors. As extreme heat events become more common, businesses may be impacted due to a decrease in tourism and visitors to Windsor and the surrounding area as people choose to remain in their homes.

Drought

VULNERABILITY SUMMARY

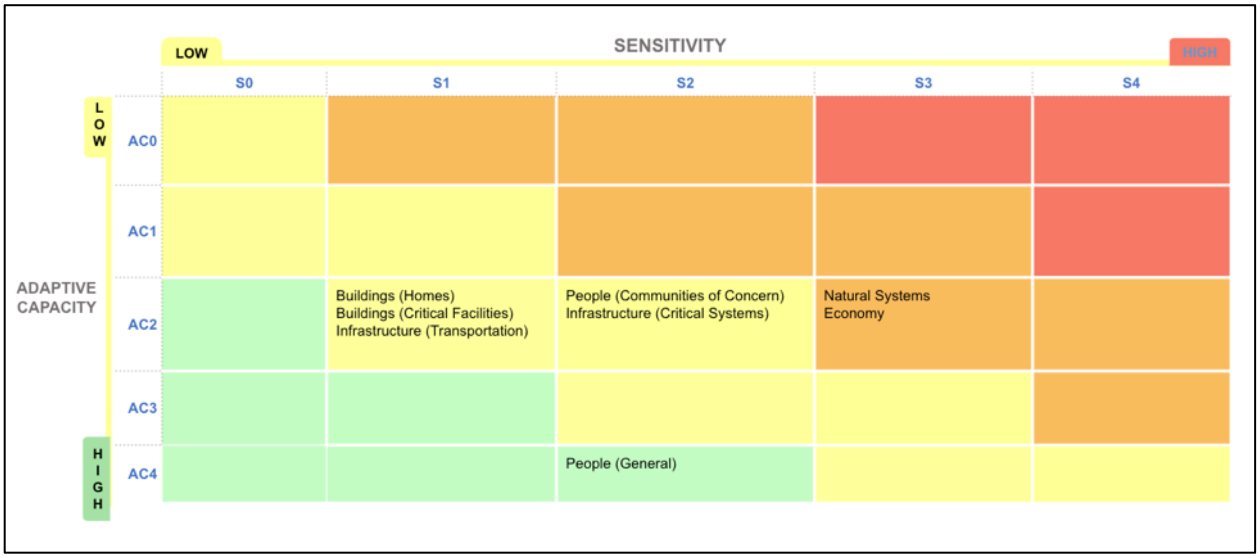

Figure 47. Relative vulnerability assessment of drought for the Town of Windsor. Vulnerability is shown by the different colors of the matrix (Red = Extreme Vulnerability; Orange = High Vulnerability, Yellow = Medium Vulnerability; and Green = Low Vulnerability). Given the climate hazards, relative vulnerability is based on the assessment of sensitivity (x-axis ranging from S0 = not at all sensitive to the projected changes to S4 = extremely sensitive to the projected changes) and adaptive capacity (ability to respond to those changes ranging from AC0 = no ability to respond to AC4 = ability to respond to projected changes in a beneficial way).

PEOPLE: Communities of Concern are moderately vulnerable to drought, and the general population has limited vulnerability to drought. The general exposure of drought for the Town is uniform, but the sensitivity of residents depends on a variety of factors. Overall, the sensitivity of Windsor residents to drought is medium (S2), particularly when water restrictions impact residents' ability to access water (for physical and property needs) and potentially the cost of water costs (e.g., increases in the price of water and food), or drought directly impacts the ability of residents to meet daily. While droughts rarely disrupt municipal water supplies and drinking water availability, they put additional burdens on low-income or housing burdened residents. Residents with preexisting conditions (e.g., respiratory illness) may be particularly sensitive to longer or more intense allergen seasons or dust due to drought conditions. Overall, the adaptive capacity of people to drought is medium (AC2) for Communities of Concern and high (AC4) for the general resident. Low-income residents and residents that experience poverty or housing insecurity are particularly sensitive if drought conditions damage housing and create additional expenses. Due to current and recent experience dealing with drought conditions, there are on-going planning efforts at the local and county level to limit the impacts of current and future drought events.

BUILDINGS: Homes and critical facilities are moderately vulnerable to drought. Across the Town, buildings generally experience the same exposure to drought conditions and drying soils. And generally, buildings themselves have limited sensitivity to drought (S1). Yet, under extreme conditions, drought can impact homes and buildings (e.g., foundations can crack due to shifting soils, surrounding vegetation can die and increase exposure to the building). Drought conditions can increase the risk of other climate hazards such as wildfires. The adaptive capacity of individual buildings is medium (AC2). The Town and the region have experience with drought and are working together to plan for and better accommodate drought conditions (e.g., Water Supply Strategy Action Plan, Groundwater Sustainability Plan, etc.), though it will take time for any changes to ripple through the infrastructure system and affect individual buildings.

INFRASTRUCTURE: Infrastructure is moderately vulnerable to drought. The sensitivity of the Town (and broader county's) water system to drought is medium (S1 or S2) due to the reliability of local water sources and the relative severity of drought needed to directly affect the transportation system or other infrastructure.[145] The adaptive capacity of infrastructure to drought conditions is also medium (AC2), due in part to the region's relative familiarity with drought existing planning efforts and technologies being used to accommodate drought conditions (e.g., Sonoma County Water Agency Climate Adaptation Plan).[146] It is unlikely that droughts would affect communication systems, though extreme droughts could affect the ability of the community to provide critical firefighting services which can be a challenge because the risk of wildfires is much higher during periods of drought. The Town's water supply system, especially the intake pump systems - require continued maintenance if not in use - may also be affected.

NATURAL SYSTEMS*: Natural systems are highly vulnerable to drought.* The sensitivity of natural systems in and surrounding the Town of Windsor is moderately high (S3) due to the impact that extended and extreme droughts can have. For example, drought can directly cause stress or mortality for a variety of both plant and animal species, which can increase mortality due to an inability to ward-off pests or disease (e.g., mountain pine beetle). Extreme and/or extended droughts can significantly impact aquatic ecosystems like creeks, streams, and rivers. And low water levels can increase water temperatures, concentrate pollution, and decrease water quality for natural systems. The adaptive capacity of natural systems is also moderately high (A3) due to the long-term evolution of natural systems in this region to drought. As drought conditions worsen due to climate change, the sensitivity of natural systems will likely increase and the adaptive capacity may decrease, especially when coupled with other hazards (e.g., wildfire, flooding, etc.). Research continues to emerge that aims to better understand the sensitivity and adaptive capacity of natural systems in the region.

ECONOMY: The economy is moderately vulnerable to drought. Reduced water availability and more water restrictions can present significant challenges for industries reliant on water (e.g., agriculture industry, wineries or breweries), making them more sensitive (S3) to drought conditions than other industries. Tourism can also be affected if the drought is severe enough that it limits outdoor recreation or affects the natural beauty of the region. The adaptive capacity of the economy to drought generally is considered high (AC3) though some businesses (primarily viticulture and agriculture) that rely heavily on water use may be less able to adapt to droughts.

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[145] Sonoma County (2018)
[146] Sonoma County (2018)

DROUGHT EXPOSURE FOR THE TOWN

Droughts occur during extended periods of time with limited or no precipitation, sometimes over years and other times over a series of months. They can take time to develop and dissipate. Drought conditions have both direct and indirect impacts on people, buildings, infrastructure, natural systems, and the economy.

Drought is the result of a natural decline in precipitation over an extended period of time and occurs in virtually every climate on the planet, including areas of both high and low precipitation. The severity of drought can be aggravated not only by high temperatures and a lack of precipitation, but by other climatic factors such as prolonged high winds, low relative humidity, and extreme heat. The following four definitions are commonly used to describe different types of drought and demonstrate the complexity of the hazard:

1. Meteorological drought: Degree of dryness, expressed as a departure of the actual precipitation from the expected average or normal precipitation amount, based on monthly, seasonal, or annual time scales.
2. Hydrological drought: Effects of precipitation shortfalls on stream flows, and reservoir, lake, and groundwater levels.
3. Agricultural drought: Soil moisture deficiencies relative to water demands of crops.
4. Socioeconomic drought (or water management drought): Shortage of water due to the demand for water exceeding the supply. The severity of a drought depends on several factors: duration, intensity, geographic extent, water supply demands for both human use and vegetation.

Drought is difficult to define in exact terms, due in part to the ways it differs from other hazards:

- The onset and end of a drought are difficult to determine because of the slow buildup of effects and the lingering impacts after its apparent end;
- There is no exact and universally accepted definition, adding to the confusion of existence and severity; and
- The impact of drought is less obvious and may be spread over a larger geographic area.

These characteristics have hindered the preparation of drought contingency or mitigation plans and can make it difficult to perform an accurate risk analysis.
Droughts occur with general regularity across the State; therefore, the Town of Windsor (and Sonoma County) is no stranger to its direct and indirect impacts. In the 2017 survey to inform the development of the Windsor LHMP, 73% of respondents indicated that they have been impacted by, and are concerned about, severe drought. Drought was classified as a “High” threat hazard for the Town.[147]

Notable droughts across the region have impacted the Town, including in 1928, 1975, 1987, 2012, 2017, 2019, and 2021. From October 2019 - September 2020, the region experienced the third driest year on record over the last 127 years.[148] More recently, on April 21, 2021, Governor Gavin Newsom declared a drought emergency declaration in Sonoma and Merced Counties due

[147] Town of Windsor (2018a)
[148] Sonoma Water (2021)

to drought conditions in the Russian River Watershed.[149] And on May 6, 2021, Governor Newsom expanded that declaration to 41 of the 58 counties across the State.[150] As of June 22, 2021, the U.S. Drought Monitor - a weekly mapping service showcasing drought conditions across the US compiled in partnership with several federal agencies - indicates that Sonoma County is currently experiencing an “exceptional drought” as indicated in Figure 52.

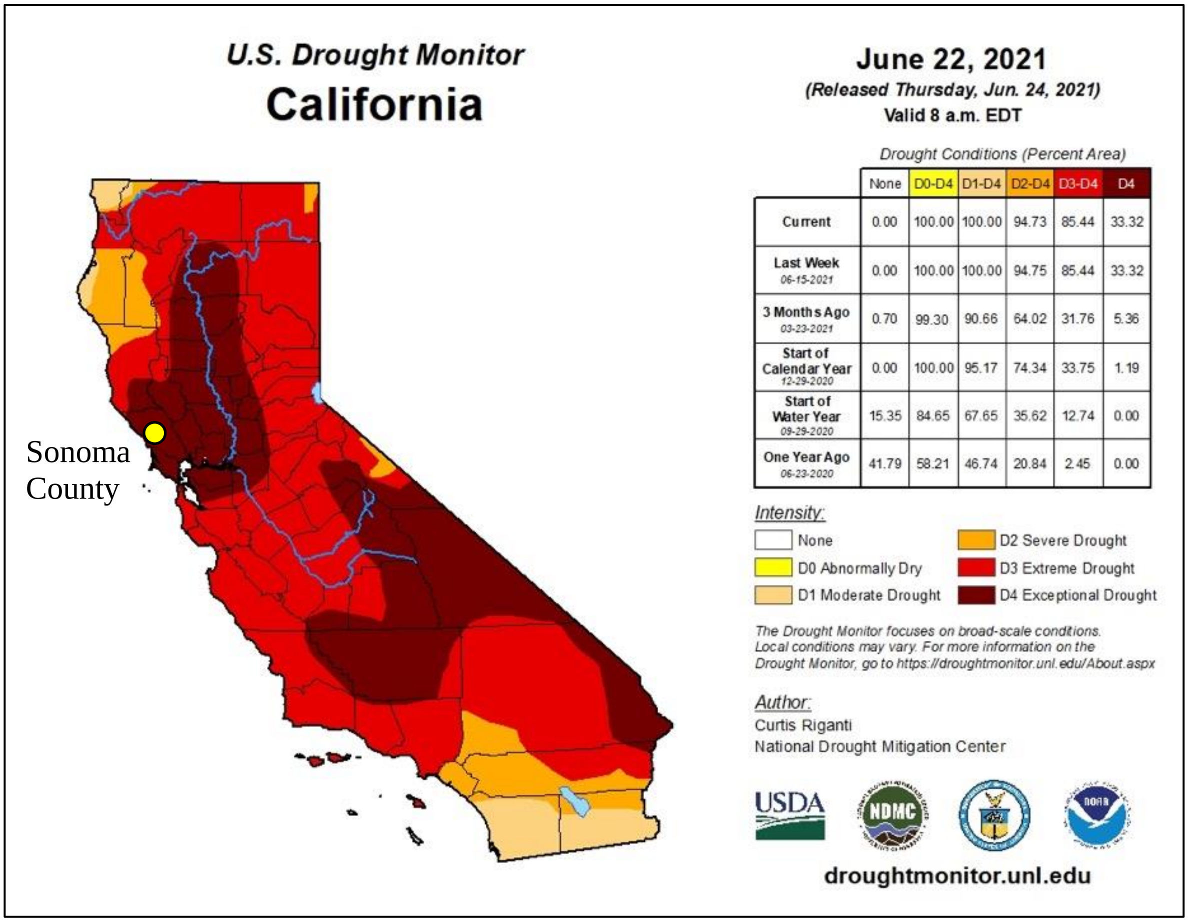

Figure 48. Map of drought conditions in California as defined by the U.S. Drought Monitor on June 22, 2021. Sonoma County was in the middle of an “exceptional drought” (D4 intensity) when this map was created. (Source: US Drought Monitor, June 22, 2021)

As a result of increasing average temperatures, changing precipitation patterns, and reduced snowpack, droughts are expected to increase in frequency, duration, and severity as the climate changes. In addition to dry spells within a given year (such as the summer dry season), changes to continental and global precipitation patterns may result in annual or multi-year rainfall deficits in the region. Projections show that in addition to a warming trend in the Russian River Valley and Santa Cruz mountains, early and late wet season runoff will likely decrease in frequency and quantity.[151] The intensity of a given drought episode is a function of the amount of precipitation received minus the amount of moisture lost due to plant evapotranspiration and direct

[149] Sonoma County (2021c)
[150] Pinho (2021)
[151] Flint, L.E., & Flint, A.L. (2012)

evaporation from soil and other land cover surfaces. Significant increases in regional temperatures - particularly during spring, summer, and fall months - will cause a deficit of available water, even in situations where precipitation remains generally within historical levels.[152]

Changing regional climate dynamics could lead to up to 10-20% drier conditions overall during the dry summer season[153], especially for areas like Windsor located in the southeastern portion of Sonoma County. Studies indicate that climate change will exacerbate the severity and duration of drought conditions over the coming decades.[154] [155] [156] In situations where rainfall deficits occur over longer periods of time, the intensity of droughts can be expected to go beyond even the significant drought episodes that have occurred in the last two decades. Evidence suggests that "megadroughts" - extreme drought events that can last extended periods of times - are more likely to occur due to climate change. These extended drought events, which could last decades, would likely lead to increases in wildfire risk as well as more complex impacts to the functionality of natural systems, such as intense drought episodes impact plant reproduction, groundwater infiltration, and other landscape-scale factors that contribute to the quality of life that Windsor residents currently enjoy.

CONSEQUENCES/IMPACTS

PEOPLE

Drought conditions may impact Windsor residents due to limited water supply and/or water restrictions. The Town sources the majority of its potable water locally and from surface water sources.[157] Most of its water comes from the Russian River and the remainder is purchased from Sonoma Water. Direct sources include the Russian River Well Field (aka "riverbank wells"), local (off-river) groundwater wells, Russian River surface withdrawals (via the Santa Rosa Aqueduct), and recycled water.[158] Surface water sources are often more susceptible to drought conditions than groundwater. This local dependence on surface water makes Windsor less vulnerable to drought than in other areas of the state but highly vulnerable to regional drought events. Extreme or extended droughts rarely pose a direct safety threat to Windsor residents, but may pose health risks to specific proportions of Windsor's residents. For example, water providers generally respond to drought conditions by increasing water rates or restrictions on water usage, which impacts low-income households, those experiencing poverty, etc. These changes in price and availability of water can cause undue hardships to low-income families as well as to residents who own or work for industries and businesses that are water dependent (e.g., wineries).[159]

Severe and/or extended periods of drought can reduce air quality and increase allergen seasons which impact human health and safety, particularly for those with pre-existing conditions. Drought can have direct health impacts on Windsor residents by exacerbating the frequency,

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[152] Sonoma County Water Agency (2015)
[153] RCPA (2016). See Chapter 6 - Sonoma County Climate Readiness
[154] Swain et al. (2016)
[155] Yoon et al. (2014)
[156] Dai et al. (2012)
[157] Town of Windsor (2018a)
[158] Town of Windsor (2011)
[159] Town of Windsor (2018a)

duration, and severity of allergen seasons. Residents with respiratory conditions (including asthma) may be particularly sensitive to these conditions.

Severe and/or extended periods of drought can exacerbate the size, intensity, and duration of wildfires. Despite the fact that native vegetation in California is adapted to drier conditions, drought conditions dry vegetation and fuels that feed wildfires which can directly and indirectly affect the health and safety of Windsor residents.

Drought conditions can lead to water contamination, impacting people through illness-causing bacteria, protozoa, and algal blooms. Water contamination can occur during extended and/or extreme drought conditions.[160] Not only can it impact resident health and safety, treating contaminated water can be extremely expensive.

BUILDINGS

Severe and/or extended periods of drought can result in direct impacts on Windsor homes, buildings, and critical facilities. Extreme changes to moistures in soils around homes, buildings, and critical facilities can result in cracked foundations, damaged siding and roofing materials, damaged pipes, broken sidewalks, and the misalignment of doors and windows. For low-income residents, those experiencing poverty (up to 29.4% of some sectors in Windsor), and those experiencing housing burden (up to 22.6% in some places in Windsor), these damages to their homes can be particularly acute.

Severe and/or extended periods of drought can result in significant secondary impacts (like wildfire or future flooding). Drought conditions can impact the ability of soils to absorb precipitation that can result in flooding due to runoff and ponding.[161] In turn, this can also exacerbate erosion and landslides, which can impact local buildings and infrastructure. Droughts can dry vegetation and make them more likely to burn during a wildfire.

INFRASTRUCTURE

Drought conditions may require extra maintenance for Windsor's infrastructure. Drought conditions are unlikely to directly impact or damage Windsor's critical systems, but water infrastructure that is not regularly used runs the risk of falling into disrepair without regular maintenance or system safeguards.[162] Drought requires an additional burden of maintenance for pipes and other water infrastructure when maintenance procedures require flush outs. Drought also affects the infrastructure of many of the newly-installed low impact development (LID) features that are currently required in new construction to capture and treat stormwater.

Drought conditions may also impact the susceptibility of Windsor's water infrastructure to wildfire. During periods of drought, stressed groundwater resources may necessitate greater reliance on surface water (Russian River), which can be more susceptible to impacts from wildfire impacting both water quality and quantity.[163] In addition, a water emergency may

[160] United States Department of Homeland Security (2015)
[161] Town of Windsor (2018a)
[162] Town of Windsor (2018a)
[163] Sonoma County Water Agency (2015)

develop when multiple climate and non-climate hazards intersect.[164] For example, if an earthquake occurs during a drought, a water emergency - often brought on by depleted water sources, insufficient pressure, or equipment failure - may impact a community's ability to respond to a wildfire due to the increased reliance on local wells.[165] In addition, drought and energy systems are closely tied due to the electric grid's reliance on water to operate.[166]

Drought conditions may directly and indirectly impact Windsor's transportation infrastructure. Extended and/or extreme drought conditions can impact local and regional transportation infrastructure including roads, bridges, railways, bike and pedestrian paths, by cracks or the weakening materials due to the dramatic reduction in moisture in the air and/or soils underneath the infrastructure.[167] The contraction of certain materials in these conditions can lead to minor cracks in asphalt or along sidewalks, but it can also have the potential for greater impacts to ramps and bridges that can weaken materials if they are not properly maintained or built to withstand these conditions. Following extended or extreme periods of drought, small amounts of precipitation can cause significant flooding; as soil is unable to absorb water, the velocity of flood waters increases and can move vegetation, cars, debris, and objects that may cause injury and/or block roadways.

NATURAL SYSTEMS

Drought conditions may significantly impact trees and other plants. Studies show that extended and severe drought conditions stress trees and plants due to a variety of factors including alterations to the carbon and nitrogen cycling process and limited ability to use evaporative cooling, impacting their reproductivity and susceptibility to pests and pathogens (e.g., pine beetle).[168] In addition, drought conditions can result in forest die-off, particularly in forests dependent on a reducing snowpack.[169] This can have cascading impacts on crop yield and ecosystem function. In addition, drought conditions will likely result in reduction to groundwater recharge.[170]

Drought conditions directly impact fish, aquatic species, and aquatic ecosystems. Extreme and/or extended droughts can significantly impact aquatic ecosystems like creeks, streams, and rivers. And low water levels can increase water temperatures, concentrate pollution, and decrease water quality for natural systems. Survival rates of fish decrease as streams, rivers, ponds, and lakes warm due to lower water levels and increasing water temperatures which impact water quantity and water quality. This is particularly critical for threatened or endangered species, like the California Coast Coho and Chinook Salmon and Central California Coast steelhead, all of which depend on the Russian River Watershed.[171]

Drought conditions directly impact wildlife. Drought conditions not only impact water availability for wildlife, but it also increases their susceptibility to pathogens and diseases. This is particularly true for species that rely on wetlands and riparian habitats.

[164] Sonoma County Civil Grand Jury (2020)
[165] Sonoma County Civil Grand Jury (2020)
[166] United States Department of Homeland Security (2015)
[167] https://nca2014.globalchange.gov/report/sectors/transportation
[168] Pedroncelli et al. (2019)
[169] Flint et al. (2017)
[170] Sonoma County Water Agency (2015)
[171] California Department of Fish and Wildlife (2021)

ECONOMY

Drought can directly impact the local economy through market impacts, disruptions to businesses, and increased unemployment. Severe and extended droughts significantly impact the agriculture and viticulture industries through crop loss and associated economic impacts. Sonoma County and the surrounding Windsor area rely on agriculture and viticulture industries not only for food, but for the tourism dollars it brings to the region. Extended and severe droughts may cause significant crop loss and unavoidable costs to local producers and businesses. It will also contribute to increased water needs from natural and human-controlled vegetation, including both agricultural crops and landscaping (e.g., urban trees), requiring increased maintenance, monitoring, and potential threats from diseases and insect pests that can capitalize upon diminished plant function during drought episodes.

Non-climate Shocks and Stressors

Earthquakes

Earthquakes are not directly linked to climate change and are therefore not discussed in detail in this assessment; however, it is essential to address this hazard as a main concern for the Town of Windsor and the potential for the consequences of a minor or major earthquake to exacerbate the vulnerability of the Town to the aforementioned climate hazards. Even impacts from a minor earthquake can have ripple effects across infrastructure systems, emergency response timing and availability, as well as an individual's capacity to respond to an emergency situation or particular hazard. This is particularly true when connected with a climate-related hazard, such as drought or wildfire.[172] While the Town's vulnerability to an earthquake is not linked to a changing climate, it is necessary to understand the interconnected nature of these natural events to the vulnerabilities highlighted in this assessment as well as the potential role that even a minor ground shaking event can have on the cause of a wildfire or dam failure, both of which are relevant to this assessment.

Man-made hazards

Man-made hazards are not directly related to climate change but may be indirectly influenced by climate change and extreme weather events. Man-made hazards include things such as the following: Illegal Drugs that are a perennial public health issue and a constant strain on public resources; hazardous materials release or pollution caused by the uncontrolled release of hazardous materials capable of posing a risk to life, health, safety, property, or the environment (generally from traffic accidents); or school/workplace violence involving edged weapons, firearms, explosives, or other weapons can inflict a high number of casualties in a very short timeframe, overwhelming immediate response capacity and leading to profound secondary effects that disrupt the community and adversely affect lives. These events are not the focus of this planning effort but may need to be considered in designing successful actions to reduce vulnerabilities.

Pandemics

As evidenced by the COVID-19 pandemic in 2020, pandemics impact all facets of our community. While the research continues to emerge on the interconnectedness of land use, biodiversity loss, wildlife trafficking, and climate change on the transmission of communicable diseases to humans, pandemics impact the vulnerabilities highlighted in this assessment in a variety of ways. It impacts successful planning and investment in emergency preparedness, evacuations, and social networks crucial to the resilience of a community. Research suggests that climate change is exacerbating the transmission of communicable diseases to humans and the implications of current and future pandemics on Windsor's social, physical, environmental, and political systems requires further attention.[173] This is particularly true when planning for and building resilience to the vulnerabilities of hazards mentioned in this assessment.

[172] Sonoma County Civil Grand Jury (2020)
[173] Lustgarten (2021)

Conclusion

Climate change is already impacting the Town of Windsor and those changes will continue to get worse. Drought, wildfire, extreme heat, and flooding present significant challenges to the Town's social, physical, economic, and natural systems. Not all aspects of the community, or the systems that it relies on, will be affected in the same ways or at the same time. This is true for both people and specific Communities of Concern as well as for assets, resources, and infrastructure.

This vulnerability assessment serves as the foundation for assessing the relative climate related risk to different sets of assets and will allow the Town and the community to prioritize where to take action. The next Phase of this project will be to develop localized, customized, and innovative resilience strategies to reduce these vulnerabilities and build a more resilient community.

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